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Multi-Stress And Human Performance: A Refutation Of Inverted-U Hypothesis

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***Abstract*—The purpose of this paper is to study the consequences of multi-stress (temperature, humidity, noise and whole-body vibration) with different intensities on cognitive and work performance as well as on the discomfort measured by using the Likert scale. Background: So far these effects have been investigated with fewer external stressors and of relatively low intensities. It was necessary a closer approach to the realities of working environments highly threatening to worker's health. Method: The experiment involved 20 people (10 women and 10 men) aged between 19-28 years, in good health. Each experiment was held for a certain temperature, humidity, noise level and vibration acceleration level transmitted to the subject. The temperature has been selected: 38, 42 and 48°C; the humidity: 60, 70 and 80%; the sound level: 75, 85 and 95dB; the acceleration of the vibrations transmitted to the subjects ($a_{r.m.s.}$): 2.38, 2.75 and 3.12m/s^2. Tests of human performances consisted in: Discomfort determination using Likert scale; Cognitive performance measurement (Attention measurement and Assessment of short-term memory) and Work performance measurement. Human performances were quantified using the results from the test presented above. Results: In the experimental set with 3 stressors the first dropouts appear: 4 in women and 1 in men. The increasingly values of the 3 stressors to which the subjects were exposed proved to be unbearable, especially for women. In the experimental set with 4 stressors were many dropouts, especially among women ending that after 7 experiments all the women gave up. The first man that dropout was the same one that gave up at the last set; the second was forced out of the experiment as he completely lost his balance and could not stand on the vibrating system. The women (sooner) and the men (later) presented dizziness, vomiting and had severe headaches (according to personal statements). Conclusion: in the experimental sets with 1, respectively 2 stressors, the performances curves could be read off using the upper part of „Curve A" from Yerkes–Dodson Law, meaning that the inverted-U hypothesis is correct for some areas.**

Keywords—multi-stress, temperature, humidity, noise, whole-body vibration, discomfort, Likert scale, cognitive performance, work performance

I. INTRODUCTION

It is well known that an environment that provides good working conditions leads to increased productivity as well as good health for the workers.

The stress factors which frequently intervene in a difficult working place, with a high risk to workers safety are: thermal environment stressors, acoustic environment stressors, vibration and other environment stressors [12]. These can lead to diminished attention, failure in achieving optimum work tasks, work accidents. The author created a model of how stress affects the physiological and psychological capabilities of workers [13].

Sutton and Rafaeli [45] studied how high density of people working in a confined environment affects the quality of work. The 109 workers who were studied stated that they are bothered more by the fact that they are forced to work in "hustle" conditions" than by the difficulty of the tasks they have to solve.

Another study, made by Leather et al. [19], refers to the direct and indirect effects of brightness at the workplace; the results showed the brightness has favorable effects on workplace satisfaction. Another good effect is brought by the presence of natural elements, for example: trees, vegetation, plants.

Similar results were also obtained by Baron et al. [3]: good lighting and proper spectral distribution generates positive effects on workers, influencing their conduct and the results of their work in a good way.

Another stress factor at the workplace is the temperature; in this regard Ramsey et al. [41] examined the workers behavior in two industrial plants, for 14 months. It was found that lower or higher temperatures than normal values for most people, had a negative impact on the behavior regarding the workers safety meaning that there were several unsafe behaviors at the workplace.

Enander and Hygge [9] proved that the thermal stress encountered in many work environments can adversely affect human behavior and workers performance. They established a relationship between measurable thermal parameters and behavioral effects of the subjects.

Pilcher et al. [40] results from 515 effect sizes calculated from 22 original studies and came to the following conclusion: "hot temperatures of 32.22°C Web Bulb Globe Temperature Index or above and cold temperatures of 10°C or less resulted in the greatest decrement in performance in comparison to neutral

temperature conditions (14.88% decrement and 13.91% decrement, respectively). Furthermore, the duration of exposure to the experimental temperature prior to the task onset, the type of task and the duration of the task had differential effects on performance." They also showed that the length of the working time in conditions of temperatures too high or too low, greatly influences human performance.

An extremely interesting analysis was made [15] on the military while in tropical environment missions: "While the adverse effects of thermal stress on soldiers' physiological capability are well established, this has not been confirmed for cognitive performance." In order to study this problem, functional brain electrical activity imaging was performed. Also, subjects underwent several psychological tests which have shown deficiencies in working memory as well as in storage and processing information. It was also found the emergence of significant differences in electrical responses of the brain when the subjects were exposed to high temperatures, suggesting an increased use of neural resources and an increased effort made by subjects to maintain the same level of performance as in neutral thermal conditions.

Other researchers studied in laboratory four neurobehavioral functions, including perception, learning and memory, thinking, and executive functions and these were measured with nine representative psychometric tests of workers, depending on different temperatures (19°C, 24°C, 27°C and 32°C). They found out that „Room temperature affected task performance differentially, depending on the type of tasks" and „Worker's productivity can be comprehensively evaluated by testing the neurobehavioral functions" [18].

Hancock et al. [14] made a meta-analysis of performance response under thermal stressors. The results showed that heat stress forces the individual to devote additional resources to cope with the requirements; this diminishes his ability to process relevant information.

A study on noise sensibility [Leq=55dB(A) and 75dB(A)] was made in a laboratory on 45 subjects [4] during which were analyzed the following psychological functions: Short-Term Memory, Search and Memory (vigilance), Hidden Figures (spatial reasoning) and Mental Arithmetic (parallel processing). The results showed that tests solving performances decreased under noise conditions; also there were some behavior deviations (some subjects presented states of frustration or even anger).

Persson Waye et al. [31] studied the effect of low frequency noise generated by two ventilation equipment on subjects undergoing cognitive tests. The results led to the conclusion that the subjects had a lower social orientation than when there was no noise; also the response time to the questionnaire was longer for low frequency noise exposure.

The noise is also a negative factor which influences the workers activity; it changes people's performance during complex tasks, modifies the social behavior and causes irritation [39]. Studies done on people exposed to noise in the workplace and environment also suggests an association with high blood pressure [44].

Noise, even if it overlaps other types of stress, has multiple specific effects on people who are in the occupational employment. Researchers [46] made specific tests to quantify these effects, and the results were consistent with maximum adaptability theory, namely additional mental resources are used to avoid this stress and thus performance dropped noticeably.

Several researchers have studied the combined effects of noise and heat on people's performance at work. For example, a total of 64 subjects were subjected for 2 hours to noises of 38 dB(A) and 53dB(A) and at temperatures of 19°C and 27°C [16]. The tests that they were intended to solve consisted of: working with mental arithmetic, a recognition task, hidden geometrical figures, proofreading, verbal fluency, and the five-choice serial reaction task. The results showed that human performances drop as the stressors values increase.

Other sets of experiments were done on 16 subjects who were subjected for 3 hours to noise of 35 dB(A) and 65dB(A) and at a temperature of 22°C; 26°C and 30°C [50]. It was found that with increasing temperature, people began to present nose and throat irritation, headaches, difficulty in thinking and poor performance. Noise induced fatigue and concentrating difficulties. At most subjects it was noticed that they tolerate heat easier than noise.

Another set of experiments were carried out with 18 subjects exposed to noises of 35 dB(A), 60 dB(A) and 75dB(A) and at temperatures of 18°C; 24°C and 30°C [30], for 30 min and 120 min. The combined effect of these two stressors came in the form of annoyance and loss of performance.

The negative effect of vibrations transmitted by moving equipment on operators have been studied by many researchers [5, 8, 11, 28, 32÷38, 47].

For example, Newell and Mansfield [27] found out on a group of 21 subjects exposed to vibrations of 1÷20Hz and placed in various positions (vertical, twisted, with and without armrests), that their work performances dropped significantly, the reaction times increased and the workload decreased. Including the armrest improved the working conditions, thus the performance.

The study of working conditions in double stress state (vibrations and noises) was a research area for some time. Seidel et al. [43] analyzed the feedback of 12 male subjects exposed to vertical vibrations with $a=2m/s^2$ while they heard in headphones sounds with frequencies of 1kHz; 1.1kHz and 2,01kHz and with sound levels of 60dB and 80dB. Each experiment lasted 11min with a 4min break. It was found that, under stressors presence the subject's ability to concentrate decreased significantly.

Also, cognitive performances of 18 operators were quantified in an off-road environment (vibration and noise) during a day, for each subject [42]. This experiment proved that double stress significantly affected subject's performances, compared with the results obtained by the same subjects on a normal road.

„Cognitive performance decrement measured as percent correct was found for the cognitive concepts time sharing, selective attention, inductive reasoning, spatial orientation, speed of closure, and memorization". In addition, were affected the "selective attention, the inductive reasoning, the spatial orientation, the response time and retention".

Another study examined the effects of noise and vibrations transmitted to the whole body, individually and combined, with different levels of intensity, on cognitive performance and subjective experience [20]. Experiments were made on 54 people exposed during a 20min period to 3 types of stress: low intensity [77dB(A) noise and 1.0m/s^2 vibration], medium intensity [81dB(A), 1.6m/s^2] or high intensity [86dB(A), 2.5m/s^2]. Changes were observed in memory and response time, and when the stress was of high intensity, all subjects complained of discomfort.

Ljungberg and Neely [21] analyzed 24 subjects exposed to combined stimuli: noise and vibration. The tests consisted of short-term logical reasoning and long-term memorizing. The study concluded that relatively brief exposures to noise and vibration in industrial vehicles do not significantly affect the performance in cognitive tasks, but long exposures lead to decreased cognitive performance.

The readability check in acoustic and vibration stress conditions was studied by Khan et al. [17]. The subjects were asked to read different texts on a laptop in various stress conditions. In addition to the expected conclusions, namely that human performance decreases with increasing the stimuli intensity, the results also showed that the subject's sex is an important factor in the perception of stressors.

A total of 16 subjects were exposed to noise and vibration for 44min [22]. After the external stimuli ceased, the subjects were asked to fill out a questionnaire to verify their attention. The results showed decreased attention after exposure to vibration, whether the vibrations were present alone or in combination with noise.

Drivers are a group of workers who are often exposed to multiple stresses, such as noise, WBV and mental tasks. Decreased performance due to environmental stress can lead to injuries or accidents [23÷25].

It is noted that the effects of multiple stressors which are acting on humans in real situations are very different from the results obtained in similar conditions but in the laboratory. This conclusion is based on the fact that reality is far more complex than what can be obtained in the laboratory.

Air quality in a work environment is particularly important. In addition to the ambient temperature, an important factor on the worker's performance is humidity. Several studies were made which show that with increasing humidity there is a sharp drop in attention, memory, response time and of the subject's comfort [10, 51 and 52].

In all aspects of life, but especially at work, people have to prove their performance. This depends on a large number of intrinsic and extrinsic factors. In this paper we will refer to some physical parameters which can lead to reduced work capacity, thus the occurrence of accidents.

It is well known that there are a number of rules that set the limit parameters of external factors inside which workers can perform well, but standards that govern health risk assessment do not take into consideration the complexities of these multiple exposure environments. In real life, besides personal problems that a worker may have (which have a great influence on their performance) there are a number of other stressors that overlap, leading to a state of profound discomfort. These two factors combined diminish attention, lower cognitive ability and memory and decrease alertness.

For example, Mackworth [26] performed a research on the problems he observed during World War II in radar operators who worked with a maximum level of attention over long periods of time and for whom vigilance should have had maximum values and operators who were exposed to high concentrations of irritant harassing factors or extremes of heat and humidity. Laboratory experiments done in multiple stress conditions have shown that for a large variety of such sensory tasks there is a regular and significant decrease in efficiency after 30 minutes of work. „The result seems to be due to a change in the central nervous or mental control of the whole sequence of the performance" [26].

It is necessary to review the principles, methods and models used in jobs ergonomics in which to be taken into consideration the aggregation of all effects of temperature, humidity, lighting, noise and vibration on health, comfort and performance of humans; also we need to take into account that people react differently to the same stressors and respond differently, depending their own characteristics and personality [29].

The purpose of this paper is to determine how a person reacts to an accumulation of high external stressors: temperature, humidity, noise and whole-body vibration.

II. MATERIALS AND METHODS

A. *Participants*

The experiment involved 20 people (10 women and 10 men) aged between 19-28 years, in good health. The women weight was between 56-72kg and the men's weight was 68-91kg. Each subject underwent a number of 5 experiments (1 - without stressors and 4 - multi-stress). Each experiment lasts 25 minutes and takes place in a laboratory of 5.8m x 3.5m x 4.4m in size.

B. *Experimental conditions*

Experiments were made during June and July, for a period of two years. During this time, outside temperature was 32÷43°C, and the humidity was 42÷61%. Inside the laboratory, the temperature and humidity can be set as desired.

The temperature was varied, using two electric heaters placed in two opposite corners of the laboratory, on chairs. The humidity was varied using 2

hot steam humidifiers placed in the other two opposite corners of the laboratory, on chairs. The noise level was varied using a CD-player with hard-rock music, placed in the middle of the laboratory, on a chair. The seats height is 45cm. The vibrations were transmitted to the human body using a vibrating system placed near the CD player.

The temperature and the humidity were measured with Kestrel 4000 Weather & Environmental Meter. The sound level was measured using a Blue Solo sound level meter. The vibrations were transmitted by Modal Exciter Brüel & Kjær type 4827 (The power supply of the exciter: power supply unit type 2830, command unit type 1056 & amplifier type 27210 B & K) and were analyzed with NetdB - Complex system to measure human vibration using PCB Piezotronics 356A16 - Triaxial Accelerometers. The equipment used for vibrations monitoring are part of the "Interdisciplinary Laboratory for Vibro-Acoustical Measurements in the Occupational Environment" of University "Dunarea de Jos", Galati.

Each experiment was held for a certain temperature, humidity, noise level and vibration acceleration level transmitted to the subject. The values of these parameters were chosen as close as possible to those in real conditions (the conditions were chosen from a forge room). The temperature (T) has been selected: 38°C, 42°C and 48°C; the humidity (u): 60%, 70% and 80%; the sound level (L): 75dB, 85dB and 95dB; the acceleration of the vibrations transmitted to the subjects ($a_{r.m.s}$): 2.38 m/s^2, 2.75 m/s^2 and 3.12m/s^2.

Each participant was asked to complete a health screening questionnaire (women should not have additional problems), to give written consent for tests and was instructed in writing concerning the experiment. Participants were informed that they may abandon the experiment at any time for any reason.

The subjects completed the test requirements in state 0, inside the laboratory, without any stress factor (T=22°C, u=55%, L=45dB, without vibration) in a day different from those when they completed the test under stress conditions. The conditions with present stressors are: A) the case in which the temperature rises; B) the case in which both the temperature and humidity increase; C) the case when the temperature, the humidity and sound level increase; D) the case when the temperature, humidity, sound level and the vibration acceleration transmitted to the subjects increase.

In order to determine how to quantify the action of these external factors on human performance, it will be considered that each of the stressors equally concurs to subject's disturbance:

$$S=\frac{1}{4}\cdot T+\frac{1}{4}\cdot u+\frac{1}{4}\cdot L+\frac{1}{4}\cdot a=\frac{T+u+L+a}{4} \qquad (1)$$

where S is the stress corresponding to the considered case (in Table I÷IV is written on the bottom line).

TABLE I. SET A: EFFECT OF TEMPERATURE ON HUMAN PERFORMANCE (T=38, 42, 46°C)

Case 1	Case 2	Case 3
T=38°C	T=42°C	T=46°C
u=55%	u=55%	u=55%
L=45dB	L=45dB	L=45dB
$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0
S=20.8875	**S=21.8875**	**S=22.8875**

C. *Tests of human performance*

Subjects answered 3 types of tests: the first one refers to a subjective appraisal of the discomfort caused by stressors on subjects; the second refers to people's changes in cognitive performance due to stressors to which they were subjected (this determination measures the subjects' attention and short-term memory); the third test measures the work performances of the subjects.

1) *Discomfort determination using Likert scale*

The first part of the experiment was to determine the subjects' discomfort exposed to stressors, using the Likert scale. Each subject was given a score for what he felt after the experiment ended.

The format of a typical five-level Likert item is:

Degree of discomfort	Scale
Very strongly	4÷5
Strongly	3÷4
Slightly	2÷3
A little	1÷2
Not at all	0÷1

Before starting the experiments, each subject was asked to determine – on the Likert scale – how he feels when all 4 stressors were applied simultaneously. This is necessary for the subject to appreciate the true value of being exposed to one single stressor, then 2 stressors and 3 stressors.

2) *Cognitive performance measurement*

a) *Attention measurement* This task was measured in this manner: the subjects completed the task in normal conditions (without stressors); the subjects were exposed for 25 minutes to stress; immediately the subjects took 3 sheets A4 on which were randomly written the numbers from 1 to 9. The font is TNR size 20, at a 1.5 row. Each sheet has 20 rows and 40 digits/row. Overall there are 800 digits on each sheet; on each sheet the digit 7 appeared 30 times; the subjects were asked to find the digit 7 in maximum 3 minutes; the accuracy was measured (percentage of omission errors); the speed was measured (the number of searched letters). The answers were scored on a scale of 1÷5. The test was repeated 3 times in 3 different days.

b) *Assessment of short-term memory* This task was measured in this manner: the subjects were exposed for 25 minutes to stress; immediately were read 3 lists with 20 words each, from different areas: literature, science and politics; on each list there are 5 words with a negative connotation, randomly placed; the subjects were asked to remember those words with negative connotation. The answers were scored on a scale of 1÷5. The test was repeated 3 times in 3 different days.

3) *Work performance measurement*

In the second part of the study the subjects solved the Purdue Pegboard test, under the same types of vibration exposure. The Purdue Pegboard test uses a board with two parallel rows, each with 25 holes into which the examinee places cylindrical metal nails.

There is a short briefing at the beginning of the test. The subsets for preferred, non-preferred, and both hands require the subject to place the pins in the holes as quickly as possible and the score is the number of pins placed in 30 seconds. The test was repeated 3 times in 3 different days.

D. Human performance

The performance (P) of a subject was determined as follows:

$$P=\frac{1}{2}\left(\frac{CP}{2}+WP\right)=\frac{1}{2}\left(\frac{AM+ASTM}{2}+WP\right) \quad (2)$$

where CP is cognitive performance measurement; WP is work performance measurement; AM is attention measurement and ASTM is assessment of short-term memory

The value of P will be compared with the subjective assessment on the Likert scale (I).

E. Stress changes the perceptions

Research on stress shows that a little bit of stress (arousal) can help a person to perform a task, because it heightens awareness. Too much stress, however, degrades performance [49]. Robert Yerkes and John Dodson first postulated this arousal/performance relationship, and hence it has been called the "Yerkes-Dodson law" [48].

TABLE II. SET B: EFFECT OF TEMPERATURE AND HUMIDITY ON HUMAN PERFORMANCE (T=38°C, 42°C, 46°C; u=60%, 70% AND 80%)

Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12
T=38°C	T=38°C	T=38°C	T=42°C	T=42°C	T=42°C	T=46°C	T=46°C	T=46°C
u=60%	u=70%	u=80%	u=60%	u=70%	u=80%	u=60%	u=70%	u=80%
L=45dB	L=45dB	L=45dB	L=45dB	L=45dB	L=45dB	L=45dB	L=45dB	L=45dB
$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0
S=20.9	**S=20.925**	**S=20.95**	**S=21.9**	**S=21.925**	**S=21.95**	**S=22.9**	**S=22.925**	**S=22.95**

TABLE III. SET C: EFFECT OF TEMPERATURE, HUMIDITY AND NOISE LEVEL ON HUMAN PERFORMANCE (T=38°C, 42°C, 46°C; u=60%, 70% AND 80%; L=75dB; 85dB AND 95dB)

Case 13	Case 14	Case 15	Case 16	Case 17	Case 18	Case 19	Case 20	Case 21
T=38°C	T=38°C	T=38°C	T=42°C	T=42°C	T=42°C	T=46°C	T=46°C	T=46°C
u=60%	u=70%	u=80%	u=60%	u=70%	u=80%	u=60%	u=70%	u=80%
L=75dB	L=85dB	L=95dB	L=75dB	L=85dB	L=95dB	L=75dB	L=85dB	L=95dB
$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0	$a_{r.m.s}$=0
S=28.4	**S=30.925**	**S=33.45**	**S=29.4**	**S=31.925**	**S=34.45**	**S=30.4**	**S=32.925**	**S=35.45**

TABLE IV. SET D: EFFECT OF TEMPERATURE, HUMIDITY, NOISE LEVEL AND WHOLE-BODY VIBRATIONS ON HUMAN PERFORMANCE (T=42°C, 46°C; u=60%, 70% AND 80%; L=75dB; 85dB AND 95dB; $a_{r.m.s}$ =2.38 m/s^2; 2,75 m/s^2 AND 3.12m/s^2)

Case 22	Case 23	Case 24	Case 25	Case 26	Case 27	Case 28	Case 29	Case 30
T=42°C	T=42°C	T=42°C	T=46°C	T=46°C	T=46°C	T=46°C	T=46°C	T=46°C
u=60%	u=70%	u=80%	u=60%	u=70%	u=80%	u=60%	u=70%	u=80%
L=75dB	L=85dB	L=95dB	L=75dB	L=85dB	L=95dB	L=75dB	L=85dB	L=95dB
$a_{r.m.s}$=2.38	$a_{r.m.s}$=2.38	$a_{r.m.s}$=2.38	$a_{r.m.s}$=2.75	$a_{r.m.s}$=2.75	$a_{r.m.s}$=2.75	$a_{r.m.s}$=3.12	$a_{r.m.s}$=3.12	$a_{r.m.s}$=3.12
S=29.995	**S=32.52**	**S=35.045**	**S=31.0875**	**S=33.6125**	**S=36.1375**	**S=31.18**	**S=33.705**	**S=36.23**

Yerkes–Dodson Law states that a relationship between arousal and behavioral task performance exists, such that there is an optimal level of arousal for an optimal performance. Over- or under-arousal reduces task performance (Fig. 1) [7].

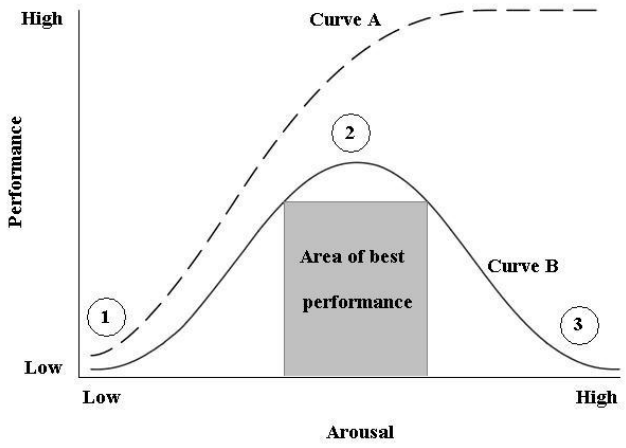

Figure 1. Original Yerkes–Dodson Law (1908) The inverted-U relationship between arousal and performance (Image from mindtools.com) Curve A: Simple task (focused attention, flashbulb, memory, fear conditioning); Curve B: Difficult task (impairment of divided attention, working memory, decision-making and multitasking)

From Fig. 1, it can be seen that according to Inverted-U model (also known as the Yerkes-Dodson Law [53]), people reach peak performance when the excitation has an average level. If the excitation is too low or too high, the performance decreases, sometimes very much. On the left side of the chart (zone 1) is shown the case in which the people do not pay enough attention and work sloppy; in the middle part of the chart (zone 2) - the people are motivated enough to work accurate; on the right side of the chart (zone 3) - the people are overwhelmed by the work volume and by the requirements thus the performance decreases drastically.

III. RESULTS AND DISCUSSIONS

In this study, the number and the intensity of the stressors applied to subjects increased gradually (from 1 stressor – temperature: cases 1÷3, to 4 stressors –

temperature, humidity, noise level and whole-body vibrations: cases 22÷30).

The performances obtained by the subjects during the 30 cases are presented in Fig. 2÷5. The stress was calculated using (1) and the performance P with (2).

Discomfort determinations using Likert scale by the subjects, in the 30 cases are presented in Table V÷VIII. The numbers from the tables show how many subjects considered that the degree of discomfort has a certain value on the Likert scale. For example, in the 1st case, 9 men considered that the degree of discomfort is 0.5, meaning „Not at all" and 1 man considered that the degree of discomfort is 1, meaning „Not at all" to „A little".

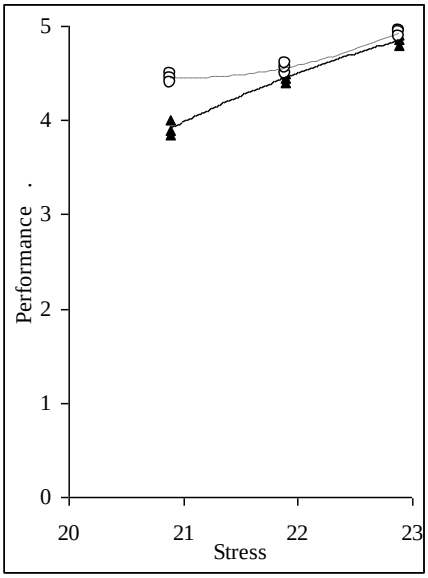

Figure 2. The average values of the human performances depending on the different values of the temperature (Cases 1÷3); (—▲—) = male; (--o--) = female

a) Effect of temperature on human performance (T=38°C, 42°C, 46°C) (Cases 1÷3)

For first set of experiments was obtained the following results (Fig. 2 and Table V). Fig. 2 shows that most subjects had great performances during the tests.

Performance		$\overline{P}_M$	$\overline{P}_F$
Cases 1÷3	Score	4.4055	4.6411

It was found that the average performance obtained by men ($\overline{P}_M$) is almost equal to the average performance obtained by women ($\overline{P}_F$). This is in perfect agreement with what the subjects declared on the degree of discomfort (Table V). For the female subjects were only 3 cases when „A little" was declared.

b) Effect of temperature and humidity on human performance (T=38°C, 42°C, 46°C; u=60%, 70 and 80%) (Cases 4÷12)

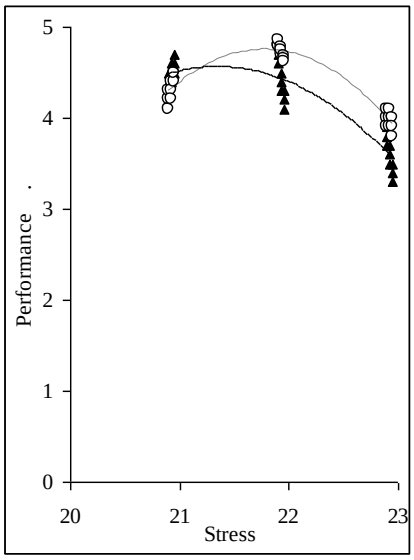

Figure 3. The average values of the human performances depending on the different values of the temperature and humidity (Cases 4÷12); (—▲—) - male; (- -o- -) – female

For the second set of experiments was obtained the following results (Fig. 3 and Table VI). Fig. 3 shows that during the first cases (4÷6), men had higher scores on tests than women but in the latter cases the situation was reversed. So women have been proven to be more attentive in the last 3 cases (the most difficult ones), basically maintaining a constant focus throughout the experiments.

Performance		$\overline{P}_M$	$\overline{P}_F$
Cases 4÷6	Score	4.500	4.3222
Cases 7÷12	Score	4.0166	4.3333

This is in perfect agreement with what the subjects declared on the degree of discomfort (Table VI). For all the cases, 83% of men declared that the degree of discomfort is „A little" to „Slightly". For all the cases, 87% of women declared that the degree of discomfort is „Slightly" to „Strongly".

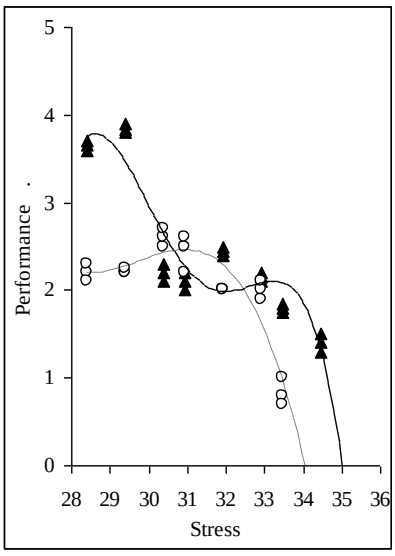

Figure 4. The average values of the human performances depending on the different values of the temperature, humidity and noise level, (Cases 13÷21); (—▲—) = male; (- -o- -) = female

TABLE V. THE AVERAGE VALUES OF DISCOMFORT DETERMINED BY USING THE LIKERT SCALE (CASES 1÷3)

Likert scale		0.5		1		1.5		2		2.5		3		3.5		4		4.5		5		Number of subjects	
Male	*Female*																						
Case 1		9	10	1																		10	10
Case 2		8	9	2			1															10	10
Case 3		7	7	3	1		2															10	10

TABLE VI. THE AVERAGE VALUES OF DISCOMFORT DETERMINED BY USING THE LIKERT SCALE (CASES 4÷12)

Likert scale		0.5		1		1.5		2		2.5		3		3.5		4		4.5		5		Number of subjects	
Male	*Female*																						
Case 4						8		2			2		7		1							10	10
Case 5				1		7		2			1		8		1							10	10
Case 6				3		6		1			1		7		2							10	10
Case 7				3		7					2		6		2							10	10
Case 8								4	1	6	5		4									10	10
Case 9						1		2	1	7	1		7		1							10	10
Case 10						2		4	1	4	1		6		2							10	10
Case 11						3		5		2	3		5		2							10	10
Case 12						5		4		1	2		7		1							10	10

c) Effect of temperature, humidity and noise level on human performance (T=38°C, 42°C, 46°C; u=60%, 70% and 80%; L=75dB; 85dB and 95dB) (Cases 13÷21)

For the third set of experiments was obtained the following results (Fig. 4 and Table VII).

In the penultimate case (20) were 2 dropouts in women. In the last case (21) were 4 dropouts in women and were 1 dropout in men.

Performance		$\overline{P}_M$	$\overline{P}_F$
Cases 13÷17	Score	2.8493	2.2900
Cases 18÷19	Score	1.9750	1.4166

In Fig. 4 can be seen that men concentrated better, obtaining higher scores in tests. However, in both sexes, for the first 5 cases (13÷17), higher scores were obtained then those in cases 18÷19. In the last 2 cases (20÷21) 2 women abandoned and in the last case (21), 1 man abandoned.

This is partially in accordance with what the subjects declared regarding the degree of discomfort (Table VII). Only for the cases 13, 17 and 18, men declared that the degree of discomfort is „Strongly"; for the rest they declared „Strongly" to „Very strongly", which is not consistent with the fact that they obtained extremely poor results at tests, in these situations, they have achieved extremely weak results at the tests from the beginning. For the cases 13÷15, most women declared that the degree of discomfort is „Strongly", and for the cases 16÷19, women declared that the discomfort is „Strongly" and „Very strongly".

d) Effect of temperature, humidity, noise level and whole-body vibrations on human performance (T=38°C, 42°C, 46°C; u=60%, 70% and 80%; L=75dB; 85dB and 95dB) (Cases 22÷30)

For the fourth set of experiments was obtained the following results (Fig. 5 and Table VIII).

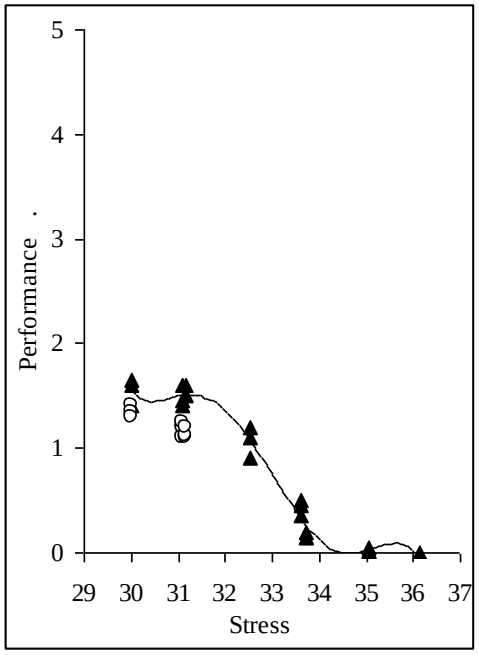

Figure 5. The average values of the human performances depending on the different values of the temperature, humidity, noise level and whole-body vibrations (Cases 22÷30); (—▲—) = male; (- -o- -) = female

In the last case (30) were 2 dropouts in men. Starting with case 25 women started to abandon: first 2 women, then another 2 and from test 29 no woman participated.

Performance		$\overline{P}_M$	$\overline{P}_F$
Cases 22÷24	Score	1.6322	1.4744
Cases 25÷29	Score	0.3373	abandon

TABLE VII. THE AVERAGE VALUES OF DISCOMFORT DETERMINED BY USING THE LIKERT SCALE (CASES 13÷21)

Likert scale	0.5		1		1.5		2		2.5		3		3.5		4		4.5		5		Number of subjects	
Male / *Female*																						
Case 13											8	6	1	2	1	2					10	10
Case 14										2	7	5	3	2		1	1				10	10
Case 15											1	2	5	6	1	1	3	1			10	10
Case 16											3	1	1	2	2	5	2	1	2	1	10	10
Case 17											3	1	3	1	5	3		4		1	10	10
Case 18											1	2	5	3	4	2		2		1	10	10
Case 19													8	4	2	3		2		1	10	10
Case 20													7		1	6	2	1		1	10	**8**
Case 21																	7	5	2	1	**9**	**6**

TABLE VIII. THE AVERAGE VALUES OF DISCOMFORT DETERMINED BY USING THE LIKERT SCALE (CASES 22÷30)

Likert scale	0.5		1		1.5		2		2.5		3		3.5		4		4.5		5		Number of subjects	
Male / *Female*																						
Case 22											7		2	5	1	2		1		2	10	10
Case 23											6		2	4	2	3		1		2	10	10
Case 24													6	3	2	3	2	1		3	10	10
Case 25													6		3	2	1	3		3	10	**8**
Case 26															5	2	3	2	3	4	10	**8**
Case 27															4		4	2	2	4	10	**6**
Case 28															4		5		1	3	10	**3**
Case 29																	2		8		10	**0**
Case 30																			8		**8**	**0**

Fig. 5 shows that men managed to reach near the end of the set of experiments (with 2 exceptions in the last case and one of whom was the same person from the previous case), and their performances were almost equal with those of women from the first 3 cases.

The very low scores obtained in tests (1.4÷1.6) are not according to the degree of discomfort evaluated by the subjects (Table VIII) because they gave values from 3 to 4, which means „Strongly"; in reality the subjects felt extremely uncomfortable – this was reflected in the answers they gave to. The state in which they were should have been reflected on the Likert scale with values of 4÷5, and mostly 5 („Very strongly").

IV. CONCLUSIONS

After analyzing the results obtained in tests it is found that as the temperature increased (Fig. 2) the performances also increased tests therefore better results were obtained. This may seem unnatural, but there is an explanation, namely, subjects have become increasingly attentive with the increasing of stress level, becoming more focused.

During the cases (1÷3), when there was only one stressor, the curves obtained for human performance depending on different temperature values are:

Males (—▲—):
$P=-0.0229\cdot S^2+2.0417\cdot S-40.575$ $(R^2=0.9864)$ (3)

Females (--○--):
$P=-0.0102\cdot S^2+0.9167\cdot S-15.643$ $(R^2=0.9704)$ (4)

where S represents the addition of all stressors corresponding to the case in question case, according to (1).

The curve given by (1) could be read with the ascending part of "Curve A" of the Yerkes-Dodson Law because there was only one stressor, meaning that the inverted-U hypothesis is correct for a certain area. For women it was not possible to find a resemblance to "Curve A".

From Fig. 2 it appears that there is a resemblance to the decreasing part of "Curve B" from the inverted-U hypothesis for male subjects in all cases 4÷12. For female subjects, it can be said that there is a similarity with the superior part, for all cases 4÷12.

For cases (4÷12), when there were 2 stressors, the curves obtained for human performance depending on different values of temperature and humidity are:

Males (—▲—):
$P=-0.3963\cdot S^5+16.927\cdot S-176.16$ $(R^2=0.8609)$ (5)

Females (--○--):
$P=-0.5984\cdot S^2+26.062\cdot S-279.02$ $(R^2=0.9224)$ (6)

By fitting the test results, (5) and (6) of the subjects performances are 2nd order polynomials with a higher error in men than in women.

In the third set of experiments the first dropouts appear: 4 in women and 1 in men. The increasingly values of the 3 stressors to which the subjects were exposed proved to be unbearable, especially for women. If in the beginning, the noise – which was introduced as additional stressor – did not raise up too many problems, after the first half of the experiments set the first critical situations emerged: 16 women complained of migraines and vomiting and 9 women have experienced dizziness and balance losses. In such circumstances, performance had dropped a lot and 4 of them abandoned. The man who dropout in last case (21) had headaches and dizziness since the 19th case; for these reasons, the evaluations which he made on the Likert scale cannot certainly give a fair assessment of the situation.

For cases (13÷21), when there were 3 stressors, the curves obtained for human performances depending on the different values of temperature, humidity and noise level are:

Males (—▲—):

$$P=-0.0096\cdot S^4+0.6191\cdot S^3-14.78\cdot S^2+154.76\cdot S-595.69 \quad (R^2=0.8491) \quad (7)$$

Females (--○--):

$$P=-0.0153\cdot S^3+0.6337\cdot S-8.6224\cdot S+40.74 \quad (R^2=0.8905) \quad (8)$$

In these cases also, by fitting the test results, (7) and (8) the subject's performances are 4th, respectively 3rd order polynomials with quite big errors.

If a parallel is made between the test results obtained for this set of experiments and the degree of discomfort assessment, it appears that there is a fairly large discrepancy: for test results that show the performance of order (1.4÷2.8), it should have been expected that Likert degree of discomfort be, mostly, "Very strongly" for both sexes.

In the last set of experiments T=38°C was excluded in order to further increase the stress to which the subjects were exposed. For these experiments – when the multi stressors increased very much – the physical parameters were chosen as closer as possible to the reality inside a forge room.

Because of this, there were many dropouts, especially among women. After only 3 experiments, 2 of them gave up, ending that after 7 experiments all the women gave up. The first man that dropout was the same one that gave up at the last set; the second was forced out of the experiment as he completely lost his balance and could not stand on the vibrating system.

The women (sooner) and the men (later) presented dizziness, vomiting and had severe headaches (according to personal statements).

For cases (22÷30), when there were 4 stressors, the curves obtained for human performances depending on the different values of temperature, humidity, noise level and whole-body vibrations are:

Males (—▲—):

$$P=-0.0034\cdot S^5+0.4294\cdot S^4-21.79\cdot S^3+550.99\cdot S^2-6942.9\cdot S+34881 \quad (R^2=0.9843) \quad (9)$$

Females (--○--): —

For the case in which the subjects were women we could not draw a curve because they abandoned quickly. For the case in which the subjects were men, by fitting the results obtained in tests, (9) of the subjects performances is 5th order polynomial, with a sufficiently small error.

In the last two sets of experiments, the performance curves do not resemble at all with Yerkes-Dodson's "Curve B". The multi-stress to which the subjects were exposed was so intense that all of them massively erred the tests and women have abandoned in unexpectedly high numbers.

All previous discussions have been made on the analysis of each set of experiments in part, but from (1) it can be seen that the multi-stress values for the last 2 sets of experiments are no longer in ascending order. For this reason, starting from the rearrangement of these values and by fitting them to each subject, Fig. 6 is obtained.

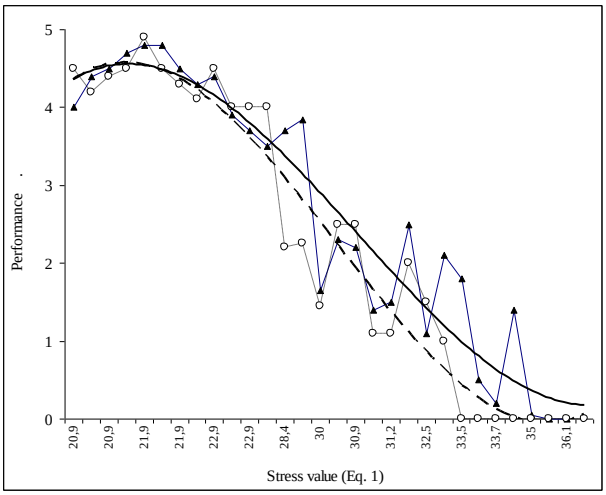

Figure 6. Human performance variation depending on the multi-stress, for all sets of experiments, (—▲—) – male; (– –o– –) = female; (———) fitting for men; (– – –) fitting for women

Males (———):

$$P=0.0005\cdot S^3-0.0253\cdot S^2+0.1828\cdot S+4.1978 \quad (R^2=0.9088) \quad (10)$$

Females (— —):

$$P=0.0007\cdot S^3-0.0322\cdot S^2+0.2219\cdot S+4.1639 \quad (R^2=0.9421) \quad (11)$$

In Fig. 6 we have shown how performance varies in men (10) and in women (11) for the 4 sets of experiments, in which we sorted in ascending order the values of all multi-stressors. It seems that such a representation could be considered as the decreasing part of Yerkes-Dodson's "Curve B".

It is seen that for men there is an apparent deviation of the curve for the cases in which the multi-stress values are: S = 29.4; 31.925; 32.925; 33.45 and 34.45. There is a similar situation for women also: S = 29.4; 31.925 and 32.925 (after which the women abandoned). This is due to the fact that certain values of multi-stress (S) in a set of experiments intersect the values of another set.

When the variation was analyzed for each set separately, the performances decrease was obvious, as the value of the multi-stress increased constantly.

Following the measurements it was found that subjects who already had work experience (2 women and 5 men), which implies a certain discipline and rigor in carrying out the demanded duties, have achieved better results in tests while subjected to multi-stress tests compared with subjects who did not have a job so far. It was found that subjects who work scored higher in tests; they are used to solve the tasks they have to perform, so external stressors do not have an importance as great as to younger people who are not working.

Age was also an important factor: subjects aged 26-28 years can better withstand difficult conditions compared to those aged 19 to 26 years.

The results show that the noise was not a stressor as influential as humidity, for example; explanation could be that all subjects are young and they are used to high sound levels from music and also, none of those who work, do not carry out their daily tasks in an environment pollutant from this point of view. However, the results obtained in the tests are not satisfactory.

It is important how the emergence of the 4th stressor influenced the test results: if for the first 3 sets of experiments one could express the obtained curves as an approximate inverted-U curve, the supplementation of the multi-stress with the whole body vibrations pushed the adaptability of the subjects to hard working conditions to zero.

Regarding the differences occurred in subject's performances by gender, it was found that women fared better than men to lower stress, but with stress increasing, they abandoned. Clearly, the personality of a person affects his performance; it was observed that extroverted people work better under multi-stress, than the introverted ones.

Other important factors that appears when carrying out tasks are the personal problems that each subject has (in private life or at work), as well as the level of fatigue of each person [1, 2, 6, 53].

Due to all these reasons it is particularly important to be able to find, for each person, the average activation range to achieve optimum results.

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