MENTAL FATIGUE ASSESSMENT IN DIFFERENT THERMAL ENVIRONMENTS – PROTOCOL

Emília Quelhas Costa[1]
J. Santos Baptista[2]
Jorge Carvalho[3]

ABSTRACT

Environmental and personal characteristics influence the behavior of individuals through the limitation of effort levels by a more or less rapid induction of fatigue. In particular, mental fatigue is recognized as a major cause of errors leading to accidents. As a consequence, thermal environment study has gained increasing importance in recent years. In order to contribute to enlarge the knowledge in this field, this work aims to present an essay protocol to evaluate the influence of the thermal environment on mental fatigue, based on electroencephalographic (EEG) analysis. With this purpose an exploratory study was held with 36 volunteers to validate the protocol. Volunteers simulated an administrative task for one hour. Fatigue assessment was carried out by analyzing *Alpha* and *Beta* waves amplitude over time. Assays were performed in a climatic chamber with controlled temperature and humidity: 22°C (40 and 80% RH) and 32°C (40 and 80% RH). Results suggest that both temperature and humidity influence the amplitude of the EEG signal (*Alpha* and *Beta* waves) in both hemispheres. The greatest amplitudes were found whenever environmental temperature and/or relative humidity values were higher. At the end of the article the advantages and limitations of mental fatigue assessment are discussed.

Keywords: EEG; Mental Fatigue; Thermal Environnement; Fatigue Indexes.

JEL Classification: C91

1. INTRODUCTION

Cultural intelligence and multicultural personality emerge as new constructs that enhance adaptation and effective adjustment to environments characterized by cultural diversity, namely within enterprises context (Sousa *et al.* 2015). According to Pinto (2013) for a better economic development, it is fundamental to have a very close cooperation between companies and universities. Information and knowledge have taken a central role in the economy (Sequeira *et al.*, 2011).

In studies about the influence of the thermal environment, one of the factors that needs to be controlled is the acclimation state. Acclimation plays a key role in human health risks prevention. It occurs in Human body, as a physiologic adjustment process to a continuous exposure to a thermal environment different from the usual. This physiological response has transient characteristics during the adaptation time of the body between the initial state and the one to which it is intended to acclimate. Several authors as Olesen & Fanger (1973)

[1] Faculty of Engineering, University of Porto, Portugal (eqc@fe.up.pt)
[2] Faculty of Engineering, University of Porto, Portugal (jsbap@fe.up.pt)
[3] Faculty of Engineering, University of Porto, Portugal (jorcarv@fe.up.pt)

and Parsons (2003) investigated acclimation and its consequences and one of the easiest parameters to measure is the skin temperature.

Dry heat acclimation is different from humid heat acclimation, because the physiological adaptation is different between these two conditions. Although the literature about this matter is rather scarce, there is evidence to support this expectation (Sawka, 2001). Acclimatization to heat, in dry or hot conditions, is likely to confer an important advantage by causing a decrease in core body temperature between 0.3 and 0.5 °C (Buono *et al.*, 1989). Radakovic (2007) also studied the effects of acclimation on cognitive and physiological performance under heat stress in soldiers, when carrying out stress tests.

The development of mental fatigue is a complex process. It is determined by an interaction between psychological and physiological factors. Mental fatigue may manifest itself through the reduction of alertness levels as a consequence of reduced cognitive performance, leading to a decrease in safety levels. The nature of mental fatigue can be subjective, objective and physiological. Subjective fatigue corresponds to the feeling of tiredness, objective fatigue is usually related to a decrease in performance and physiological fatigue can be defined as a reduction in the neuromuscular capacity of the system to carry out its functions as a result of physiological overload and strain (Haworth *et al.*, 1988).

Fatigue contributes to a significant number of accidents. In driving, the values of 20-30% are indicated (Punsawad *et al.*, 2011). For this reason, in recent years, there has been a growing interest in studying mental fatigue, being electroencephalography (EEG) technology widely used. EEG is indicated as the most reliable and predictive indicator of mental fatigue even when it has physiological origin (Shen *et al.*, 2007).

Mental fatigue is related to the effects that people may experience during or after prolonged periods of cognitive activity (Zang *et al.*, 2010). Therefore, sleepiness and a lack of concentration may arise in people performing long and/or stressing period tasks (Fallahi *et al.*, 2016; Jolly *et al.*, 2016). EEG is also used to study problems as different as visual fatigue (Zou *et al.*, 2015), dissociation between mental fatigue and low motivational state (Gergelyfi *et al.*, 2015) or even the effects of computer games on changes in cognitive functions (Aliyari *et al.*, 2015).

There have been several indexes associated with the EEG, presented as possibly being correlated to mental fatigue. Among them are the four EEG wave types (delta, 0-4 Hz, theta, 4-7 Hz, alpha, 8-13 Hz and beta, 13-20 Hz) (Shen *et al.*, 2007; Cheng *et al.*, 2007). The relationship between the power of α / β waves is also used as an early warning indicator (Nybo *et al.,* 2001; Ftaiti *et al.*, 2010). Cheng (2007) classified the EEG indices into two groups: the basic indices (delta, theta, alpha and beta features) already mentioned and the ratios derived from these basic indices (Cheng *et al.*, 2007).

To measure fatigue, usually, are used 17 electrodes placed on specific points of the scalp labelled as: front (F), central (C), parietal (P), occipital (O), the temporal lobe (T): FP1; FP2; F7; F8; F3; F4; T3; T4; C3; C4; T5; T6; P3; P4; O1; O2 e Fz; Cz; Pz (Shem *et al.*, 2007). Among these key points, it was found that the electrodes placed in the frontal and occipital regions of the scalp are the most important for the classification of mental fatigue at various levels. These findings are consistent with knowledge about the functions of the anatomical regions that manage mental fatigue. Based on this previous knowledge, this study aims to present an essay protocol to evaluate the influence of the thermal environment on mental activity.

2. MATERIALS AND METHOD

2.1. Stages of Protocol Development – Global Overview

The development of the protocol went through two stages:

1. The first stage, involving: literature review, test of the necessary equipment to perform the experimental trials, submission of the project to CEUP (Ethics Committee of the University of Porto) and selection of the sample according to the defined strategy.
2. The second stage, definition of the study design, involved two steps:
   - the first step: a pilot test to analyze the repeatability of the study, testing five volunteers in different conditions of temperature and relative humidity (RH) (22ºC-40%RH; 22ºC-80%RH; 32ºC-40%RH; 32ºC-80%RH).
   - the second step: design of the final protocol, was made with all the experience, decisions and corrections from the essays carried out in the pilot tests.

2.2. Materials

The materials used to test and implement the protocol are identified in the Table 1.

Table 1. Equipment and its function

EQUIPMENT	FUNCTION
Climatic Chamber (Fito-Clima 2500EC20)	Simulation of thermal environments
Brain-sensors (Emotiv Epoc – EEG*)	Monitorization of brain activity
Skin Thermal Sensors (BioPlux)	Monitorization of skin temperature
Computer	Real time control of all parameters
Precision weighing scale (039-SA700.102)	weighting each volunteer before and after each test to determine body weight loss.
Questionnaires	Comfort/discomfort evaluation according to the standard ISO10552:1995
Individual Data Sheet	Registration of individual and environmental parameters of each test
Cognitive tests	GoNoGo - Continuous classic performance task

Source: Own Elaboration

*Electoencephalogram

2.2.1. The importance of maintaining the climatic conditions

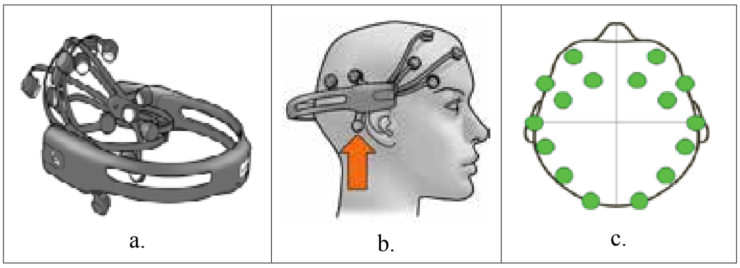
It is already commonly assumed that temperature and humidity conditions have a significant influence in terms of performance and fatigue development. In this context, the ability to control and manipulate these conditions in order to evaluate their effects is fundamental when assessing the extent to which these parameters influence the development of fatigue (Cheung, 2010).

2.2.2 Measurement of brain activity

Mental fatigue is a gradual and cumulative process also associated with reduced efficiency, reduced alertness and decreased capacity for mental performance (Grandjean, 1979; Cutsem *et al.*, 2017). These changes, reflecting the brain reaction to external stimuli, can be recorded through EEG (Lal & Craig 2001; Berka *et al.*, 2007). The brain's electrical activity is classified according to frequency bandwidths as mentioned (delta, theta, alpha and beta). The delta activity appears in the transition between drowsing,ess and sleep. Theta rhythm are associated with several psychological states including low levels of alertness and consequently are associated with a decrease in information processing. Alpha waves occur during daytime, particularly on the occipital cortex and can be clearly observed when the eyes are closed. When the eyes are open its wave amplitude range decreases. These rhythms are present both in alertness as on relaxation. The beta waves are associated with increasing arousal /alertness. These waves are still associated with the reaction time of motor tasks (Lal & Craig 2001; Borghini *et al.*, 2017).

For this protocol an Emotive SDK EEG device was used (Figure 1a). The electrodes must be installed in the standard positions: parietal and frontal temporal, as shown in Figure 1b. The head set / electrode has to be adjusted so that two reference electrodes are positioned in the mastoid area. The electrodes should be adjusted carefully to ensure a good contact. In Figure 1c each circle represents a sensor and its color the contact quality. When all sensors are marked in green, it means that the best overall contact quality has been achieved.

Figure 1a. Emotiv SDK EEGequipment and respective sensor location



Source: www.engr.ucr.edu

2.2.3. Skin temperature

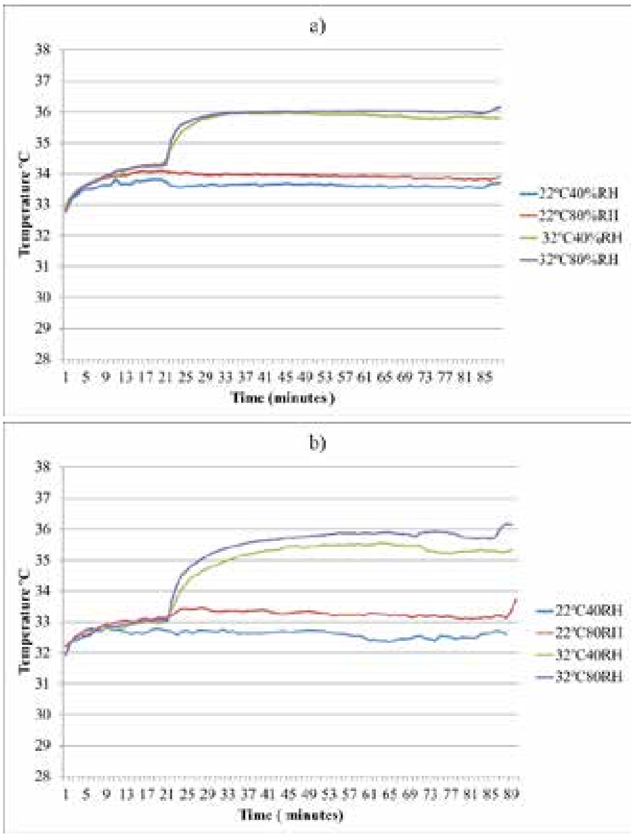
When the skin temperature exceeds the ambient temperature, heat can be dissipated through thermal changes by radiation, convection, conduction and evaporation. When the ambient temperature is above the skin temperature, evaporation is the only mechanism by which the body can lose heat. Sweat evaporation depend on the water vapor pressure gradient on the surface of the skin, which, in turn, depends on ambient temperature and relative humidity of the air. (Maughan *et al.*, 2007).

The overall relative power of the different EEG frequency bandwidths, and skin temperature (local and medium), and are sensitive and respond to the ambient temperature and the thermal sensations of the volunteers (Yao *et al.,* 2008). It is also important to note that both skin temperature and thermal sensation appear to reach a constant level approximately 20 minutes after exposure onset (Nagano *et al.*, 2005).

The experimental initial procedure consisted in recording the demographic and anthropometric data of each volunteer as well as the skin temperature in 14 points of the body according to ISO 9886: 2004, in order to evaluate its evolution over time. Before starting the test, the volunteer had two consecutive stabilization periods. The first 20 minutes period for a first stabilization took place in the laboratory space at a controlled temperature of 20 ± 1 ° C . The second 10 minutes additional period took place within the climatic chamber, for adaptation to temperature and humidity test conditions.

After analyzing the results of the temperature evolution in the fourteen points of the body defined by the referred standard, it was found that not all of them had the same levels of stability over time. Thus, since it is only intended to have an indicator that a balance between body temperature and ambient temperature has been reached, it has been decided, for reasons of comfort for volunteers, to reduce these measurements to the forehead and back of the neck (figure 2).

Figure 1b. Forehead (a) and Neck (b) mean temperature of 15 volunteers at different conditions of temperature and relative humidity



Source: Own Elaboration

2.3 Sedentary task

For the simulation of sedentary work, the GoNoGo Classic test is used for 60 consecutive minutes, with computer support. (Costa *et al.*, 2013d). This task requires the subject to click on a computer key when a stimulus appears (in this case the letter P) and not reacting when another stimulus occurs (in this case, the letter R) and this simple decision is repeated by volunteers for as long as it is determined.

3. PROTOCOL DESCRIPTION

One of the main concerns in the design of this protocol is to minimize the possibility of bias, considering bias any deviation that prevents a result to be considered incontestable (Gerhard, 2008). In the next few pages the essay protocol will be presented systematically with a sequential summarized description of the different steps to be followed and its justification, whenever it is considered justified.

Stages prior to the tests:

1. Project design for approval in ethics committee.
   The Helsinki Declaration, in its 7th Revision in 2008, Articles 20, 21 and 22, declares the right of individuals to self-determination and to make informed decisions about participation in research, both at the beginning and in the course of the research.
2. Elaboration of the informed consent document to be read and signed by each of the subjects submitted to the test, According to Annex A of ISO Standard 12894: 2001.

3. Selection of the sample according to the following criteria, in order to minimize bias:
   a) Gender - the sample should be all of the same gender or have a significant number of subjects of each gender;
   b) Defined age group(s);
   c) Have an equivalent professional activity;
   d) Not be a smoker;
   e) Band(s) of defined body mass index(es);
   f) Have a stable weight in the last six months;
   g) Be a habitual consumer of breakfast;
   h) Be unmedicated;
   i) Have a good general health;
   j) Do not have a disease register in the last 12 months.

The sample itself is one of the most common bias factors. The selection bias, a statistical base error caused by a bias in sampling, can occur when a group with certain influent characteristics is selected more frequently than other groups in the sample. This may produce imprecise conclusions if the selection bias is not identified. For example: if a global response is to be achieved and one gender predominates over the other; if the age distribution or professional activity of the sample does not match the population to be studied.

Other types of bias may arise from mixing in the same sample individuals with different behaviors, such as smoking habits and sleep / wake cycles, as well as substance use with a direct effect on behavior or wakefulness, such as alcohol, tea, coffee, some types of medicines, psychotropic substances or others. In the case of tests that can be performed under different temperature and humidity conditions, a sample with individuals with different values of Body Mass Index (BMI) may also be a bias factor due to the different physiological response to different temperatures, in particular at more extreme temperatures.

4. Operation test of each equipment and of all the steps of the protocol, for training the procedures and verification of any failures;
   These tests are important not only to dismiss problems as simple as the state of the battery charge, the operation of the support software or the adhesion of the adhesives to attach the sensors to the skin, as well as to avoid any hesitation with the volunteers during the tests.
5. Detailed explanation to each volunteer of all test procedures;
   a) Explain the functioning of the Climate Chamber;
   b) Detailed explanation of the test, as well as its purpose;
   c) Explain what a skin temperature sensor is;
   d) Explain what an EEG is;
   e) Explain that they will respond to a thermal sensation questionnaire with three questions (Table 2):
      - Question 1 - determines the sensation vote on the ASHRAE scale, which can be directly comparable to the PMV Thermal Comfort Index measure, as described in ISO7730: 2005.
      - Question 2 - reflects the feeling how the volunteer would like to feel at the moment.
      - Question 3 - reflects the “state of health” at the end of the test.
   f) Explain the volunteer’s necessary prior preparation:
      - Type of clothing to wear: shorts, t-shirt, slippers;
      - Report that there is a robe available for warm clothing before and after completing the tests;
      - Hygiene care of the body and head;

1. Importance of bringing the scalp clean and without any trace of softener, gel or foam;
2. Importance of bringing clean skin so that the sensors can adhere as better as possible;

- Caring on feeding during test days as well as days prior to testing (avoiding changes in diet, in the consumption of alcohol, coffee and tea);
- Rest conveniently on test days;
- Report if any medicine was taken prior to test.

g) Present the emergency contact list;
h) Explain the procedures in case of emergency;
i) Record the volunteer's data in the database and schedule the trials by mutual agreement;

Explanation of each trial detail to each volunteer is not only a way of passing information, but also of creating bonds of trust with the researcher. The knowledge of the different stages of the test and what is supposed to feel in each of them, helps to control the stress levels of a trial that besides being relatively long, needs to be repeated several times under different environmental conditions. From the experience in the application of this protocol, the first trials should be conducted on thermal comfort conditions. This can help to prevent frictional discomfort among volunteers with the consequent reduction of the sample number during the tests.

The volunteers are tested one by one in each of the previously defined conditions. All tests must be performed in the morning and at the same time, before the subject performs any other activity, in order to avoid variations in the initial conditions of the tests.

Main protocol:

6. Volunteer reception in the laboratory;
7. Informed consent statement read and signed by the volunteer;
8. Completion of the initial questionnaire (to verify if there are conditions to start the test);
   If the volunteer has not had a good night's sleep or any other bias factor has been identified the test should not be performed;
9. Completion of the thermal sensation questionnaire (Table 2);
10. Wear the test clothes (shorts, shirts and slippers);
    The use of clothing with the same level of protection is an important factor in that it allows all volunteers to perform the tests under the same conditions avoiding biases at this level.
11. Placement of the sensors for measuring skin temperature at two points: Forehead and neck;
12. Stabilization of the skin temperature for at least 20 minutes before entering the climatic chamber, with real-time temperature verification from the sensors placed;
    During this period, the volunteer should remain seated to minimize metabolic oscillations;
13. Enter in the climatic chamber.
    The entrance must be fast to minimize temperature fluctuations inside the chamber;
14. Sit the volunteers comfortably in front of the computer;
15. Stabilization of the skin temperature for at least 10 minutes, with real-time verification of the values. During these 10 minutes:
    a) The volunteer should respond to the thermal sensation questionnaire (Annex 1),

b) The researcher should place the EEG equipment on the volunteer, making sure that all the sensors are emitting properly the signal,
c) After placing the equipment, remember the volunteer to remain as quiet as possible, avoiding to move the head (head movement can cause noise in the signal);

16. Start the test which should take 60 minutes, using a single battery of cognitive tests (GoNoGo type) throughout the test;
    It is expected that during this test some volunteers will experience periods of drowsiness or even sleep. All these periods should be recorded in order to later help in the interpretation of the values obtained from the EEG.
17. At the end of the trial, the volunteer must complete the thermal sensation questionnaire again;
18. Disconnect and remove EEG equipment from the volunteer's head;
19. Exit the camera;
20. After leaving, the volunteer should wait at least 10 minutes outside the chamber to stabilize the body temperature, wrapping himself in a robe;
21. Remove the temperature sensors;
22. Collect and make copies of all data generated during the test.

Table 2. Thermal sensation questionnaire (based on standard ISO 10551:1995)

1- Indicate in the scale how you felt when you entered the camera:						
Hot;	Warm;	Slightly Warm;	Neutral;	Slightly Fresh;	Fresh;	Cold;

2- How would you like to be now?		
Hot;	Neutral;	Fresh;

3- Have you experienced any of the following symptoms?										
Somnolence;	Seasickness;	Vomiting;	Dizziness;	Chills;	Anxiety;	Fatigue;	Apathy;	Loss of motor coordination;	Other, Which?	None.

Source: Own Elaboration

4. ADVANTAGES AND LIMITATIONS OF MENTAL FATIGUE TESTS

This work presents a protocol for conducting tests that allow the identification of the effects of temperature and humidity variations on mental fatigue. The research carried out so far has identified the fundamental parameters to be monitored, as well as the necessary equipment to perform the monitoring in real time and continuously. The individuals submitted to the tests will know the respective physiological response in different environmental conditions, which may help them or others in future professional and other options. For the general population, greater knowledge in the area creates conditions for better choices in terms of living and working conditions. Knowledge in this area can also contribute to a safer working environment, particularly in tasks where possible cognitive errors can lead to accidents.

The main constraints are, firstly, the need for material and human resources with a relatively high level of technology, in particular for the analysis of results, which requires specific technical and scientific expertise, in particular EEG data analysis, processing and interpretation. Secondly, it requires participants to perform several tests of relatively long duration, about two hours per test.

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