Effects of thermal environment on cognitive response in sedentary activities. A short revision

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ABSTRACT
The study about the influence of the thermal environment on cognitive response is fundamental to understanding better the connection between the basic variables and cognitive performance. This also helps the better understanding of safety situation, guidance and decision-making, especially to avoid critical situations. The main objective of this work is to relate the physiological with cognitive response, trying to find exposure limits covering both occupational settings and social environments in high temperatures. For this purpose, was used a systematic cross-linked search, relating several key words and search phrases in different electronic data bases with different criteria. According to the survey results, it`s clear the importance of studying the core temperature and the sweating rate to understand the relationship between the thermal environment and the cognitive response So, in this review, different topics are considered by different authors as fundamental for the study of thermal environment influence on cognitive response as: type of tasks, dehydration, brain, skin and core and temperature. It was concluded in relation to sedentary activities that the results are still questionable. However, this brief survey indicates that the cognitive response is affected by, at least, four parameters, core temperature, dehydration, psychological factors and the type of the tasks.

Keywords: Thermal Environment; Cognitive function; Heat; Alertness; Task.

1. INTRODUCTION

The present literature review is comprised within a broader project that aims to study the Human response to different conditions of thermal environment, which is being developed at the University of Porto, as part of the Doctoral Program in Occupational Safety and Health (DemSSO).

All human activity is influenced by the environment of the place where it is held. In this perspective, studies of the thermal environment are fundamental to better understand the integrators factors of different basic variables (air temperature, air velocity, relative humidity and radiant temperature, combined with clothing and metabolism) with the cognitive performance.

Cognitive performance is defined as a set of mental processes, such as information processing, learning, perception, memory and reasoning, alertness and troubleshooting. In this point of view, the cognitive aspects play a key role in security, guidance and decision making, especially to avoid critical situations (Faerevick, 2010). The psychomotor functioning (reaction time, movement time, speed of performance) has also been included in this concept (Antunes et al., 2006). On the other hand and according to Annunziat (2011) the cognitive functioning is also included in the concept of quality of life.

Health problems and heat stress as well as their impact on human activity, have been gaining an increasing importance internationally, both in organization and in research. However, despite numerous studies have been conducted to know the physiological answer to high temperatures and humidity and their consequences in health, the respective effect on cognitive functions remains ambiguous (Gaoua, 2010).

It is intended in this paper, to present the state of the art related to the influence of the moderate or hot thermal environment on cognitive response in sedentary activities. As a specific objective, it seeks to relate the physiological response to the cognitive response, trying to find exposure limits covering both occupational and social environments from moderate to hot environment. The relevance of this work is justified by the significant increase in the complexity of industrial tasks that require high cognitive level and the increase in sedentary jobs due to automation of the industrial processes. In this context, the importance of the issue stems from the high temperatures being a consequence not only of specific working conditions, but also due to natural conditions e.g, climate changes that remains a global problem in the fields of public health and economy.

2. MATERIALS AND METHODS

For this purpose, a systematic search was conducted and cross-linking multiple keywords as well as various search expressions in different electronic databases and with different criteria:

PubMed, - using simple search using the following Keywords: Thermal Environment, Cognitive Function, Heat and Cognition, Simple Mental Task and Mental Alertness, found a total of 228 papers, from which 37 related to cognitive were selected and further 7 of these were selected according to the purpose of research.

The research was also made in the search engine for scientific literature of FEUP (Met Lib) as listed in table 1, from the Advanced Meta Search option Goal of Library and information Services of the institution, in seven databases. The Key words used were Heat and Cognitive, having been chosen only those items on which those words were mentioned together. The area selected it was in the multidisciplinary and health category.

Table 1 – Advanced Meta Search results

Designation	Key Words	Results
Pub Med	Thermal Environment; Cognitive Function, Heat and Cognition, Simple Mental Task, Mental Alertness	228
Academic Search Complete	Heat and Cognitive	16
Compendex		2
Current Contents		18
ERIC		3
Inspec		1
Scopus		0
Web Of Science		31
Combined results		71

It was explored a database at a time, with only the subject of papers in the study at the Academic Search Complete (16) and Web of Science (31). Of these 47 articles were selected only those who had common points, taking into account the relevance of the study and were given priority published in the last decade, but with particular focus between 2007 and 2011, taking into account the meta-analysis by Hancok (2007). In the end total of 35 articles was left and including those found in Pub Med and from the search engine of FEUP which were analysed in detail.

3. RESULTS AND DISCUSSION

Based on the analysis of selected literature there is agreement among authors regarding the visible importance of studying the thermal environment on cognitive response. The World Health Organization (WHO) defines health as a state of physical well-being, mental and social and not merely the absence of disease and more recently conducted research to include cognitive functioning within the concepts of Quality of Life. The cognitive functioning, e.g. a series of mental processes including memory, attention, executive functions, language, and perception, plays a fundamental role in people's life, particularly in social and work independence, once many times well-being in a general way, and in general populations, remains incomplete because of cognitive difficulties, in addition and despite this general practice, cognitive impairment can also occur as a consequence of mood disorders or psychi-emotional distress (Annunziata et al. 2011).

The climate changes have a major contribute on this behaviour, and according Berry (2009) different aspects of climate change may affect mental health through direct and indirect pathways, leading to serious mental health problems, possibly including increased suicide mortality. According to the study the debate about the impact of climate change on human health has, very recently, included consideration of mental health. By increasing the frequency, severity and duration of adverse weather events, climate change will affect mental health via at least three ways. It will, firstly, directly affect mental health by inflicting more and worse natural disasters on human settlements which, typically, cause serious anxiety-related responses and, later, chronic and severe mental health problems. Secondly, it will increase the risk of injury and physical health problems which are causally and reciprocally related to mental health. Thirdly, it will endanger the natural and social environment on which people depend for their livelihoods and wellbeing (Berry et al. 2009).

As referred by Parsons (2003), to assess human thermal environments it may be necessary to quantify the environment (basic parameters), and its effects (physiological, psychological, and so on) and interpret the values obtained in terms of health, comfort and performance of those exposed. The present study, intends to relate the physiological response to the cognitive response. For that, the basic variables, mentioned in the introduction, can be quantified using measuring instruments; physiological responses can be measured using transducers connected to the body and psychological responses are quantified using subjective and behavioural measures. Concerning the cognitive performance, can be measured through tests of cognitive function (arithmetic, visual tracking and recent memory) (Ribeiro, 2010), among others.

As Parsons (2003) also asserts, in hot environments the body will sweat and core temperature may rise. The resulting distress or discomfort may lead to behavioural changes and affects cognitive performance, for example mental performance, information processing, memory and so on. Refers, as well, that many tasks and task components require both physical and cognitive function, like for example: reaction time, some type tasks may require perception, information processing, and physical action (manual).

In this review different topics considered by different authors were highlighted as key influence of the thermal environment on cognitive response: typed of tasks, dehydration, skin /core Temperature and Brain, being related to each other.

3.1 Kinds of tasks

Regarding sedentary activities, particularly in offices, different studies have developed research over the past years, as Sepanen (2005), Tanabe (2006), Tanaka (2006), Lan (2008), Parsons (2009), Than (2009) and Lan (2010), among others. After a selection of relevant issues and based on the results of several authors it can be seen that, over the years there has been a central controversy about the effects of thermal conditions and mental performance. Some authors like for example Pepler and Warner (1968) and Sundestrom (1987) reported; for their part, that mental performance is generally not affected by heat, others such as Wyon (1979), Parsons (2003) and Seppanen (2003) postulated that cognitive performance declines with heat. More recently O´Neal stated that the results obtained are in agreement with previous research suggesting that changes in cognitive function of individuals exposed to physical activity in hot environment can increase, decrease or change very little (O`Neal 2010). This paradox between results, occurs by interference from various factors, such as the type of task, characteristics of the worker, the level of motivation (Tanabe, et al. 2006), psychological factors and characteristics of buildings, severity of exposure to temperature, complexity and duration of cognitive task (Gaoua, 2010), among others.

Hancock (2007), in order to quantify the effects of thermal stress on human performance in their meta-analysis confirmed the negative influence of heat stress on performance. It was established, that cognitive performance was less affected than psychomotor performance and perceptual tasks, and in the latter case, it was important the task type, exposure duration and intensity of stressors. In addition the combined effect of intensity and type of task (perceptual, cognitive and psychomotor), and intensity, duration, performance task in the same three perspectives (perceptual, cognitive and psychomotor). The results confirmed the importance of the type of task, duration of exposure and intensity of stress indicators as *Key* variables to understand how the thermal conditions impact performance results were consistent with the theory that stress forces individual to allocate attention resources to assess and deal with the threat, which reduces the ability to process information relevant tasks.

According to the meta-analytical review (Pilcher et al. 2002), the effect of exposure to high temperatures results in an inverted U curve, function between performance and the degree of temperature exposure. However, this situation depends also on the type of task and the time of exposure. The results of this meta-analysis refers that temperatures between 21,11-26,62 ºC WBGT, results in a very little effect on performance. The short exposure to temperature and short tasks durations resulted in worse performance than longer durations and pre task temperature exposure of more than 60 minutes resulted in a substantial decrement in performance. It was suggested in the same data that industries that require workers to perform under hot temperature, should be aware of the potential negative effects of temperature exposure on performance.

3.2 Dehydration

Dehydration is a reliable predictor of impaired cognitive status (Wilson et al., 2003). The performance of both physical and mental tasks, can be adversely affected by heat and by dehydration. There are well-recognized effects of heat and hydration status on the cardiovascular and thermoregulatory systems that can account for the decreased performance and increased sensation of effort that are experienced in the heat (Maughan 2007).

It has long been known that dehydration negatively affects physical performance. Examining the effects of hydration status on cognitive function is a relatively new area of research, resulting in part from our increased understanding of hydration’s impact on physical performance and advances in the discipline of cognitive neuropsychology. The research available in this area, although scarce, asserts that decrements in physical, vasomotor, psychomotor, and cognitive performance can occur when 2% or more of body weight is lost due to water restriction, heat, and/or physical exertion. Additional research is needed, especially studies designed to reduce, if not remove, the limitations of studies conducted to date (Grandjean et al.,2007). As shown by Ribeiro (2010) is not only the physical performance that suffers damaged by dehydration but also the cognitive performance that is essential in team sports (Ribeiro, 2010). Other results confirmed the importance of hydration on cognitive function and it has been suggested the need for studies to monitor fluid intake for 24 hours before and during the experimental trials. The ability of individuals should be assessed before carrying out cognitive tasks. Like Grandjean (2007) refers increasing the understanding of the effects of hydration status on cognitive performance could be applied to health care, education, and other areas where cognitive performance is assessed and/or treatment is rendered.

Also Lieberman (2007) affirms that due to lack of data, definitive conclusions concerning the effects of fluid restriction on cognitive performance are not possible. However, it is clear that dehydration induced by exposure to heat, exercise and fluid restriction impairs cognitive performance and mood. Adverse effects are present at levels of dehydration of 1,3% of weight loss. Maugham’s study refers that provision of fluids of appropriate composition in adequate amounts can prevent dehydration and can greatly reduce the adverse effects of heat stress. There is growing evidence that the effects of high ambient temperature and dehydration on exercise performance may be mediated by effects on the central nervous system (Maughan 2007). Body water deficits or hypohydration (HYP) may degrade cognitive performance during heat exposure and perhaps temperate conditions (Adam, 2008). A critical deficit of 1% of body weight elevates temperature during exercise (Sawka and Montain, 2000).

Water and electrolyte balance are critical for the function of all organs and, indeed, for maintaining health in general. Water provides the medium for biochemical reactions within cell tissues and it is essential to maintain an adequate blood volume and thus the integrity of the cardiovascular system. During exercise in the heat, sweat output often exceeds water intake, resulting in a body water deficit (hypohydration) and electrolyte losses (Sawka, 2000). The same author refers that to support the contraction of skeletal muscles, physical exercise routinely increases total body metabolism up to 5–15 times the resting rate. Approximately 70–90% of this energy is released as heat, that needs to be dissipated to achieve body heat balance. The relative contributions of evaporative and dry (radiation and conduction) heat exchange to total heat loss vary according to climatic conditions. In hot climates, a substantial volume of body water may be lost via sweating to enable evaporative cooling.

Maughan (2007) emphasize that there is growing evidence that the effects of high ambient temperature and dehydration on exercise performance may be mediated by effects on the central nervous system (CNS). While the precise role of the CNS in the development of fatigue is yet to be determined, preliminary evidence supports a neurotransmission role in the fatigue process. A number of circulatory perturbations, including reduction in cerebral blood flow and increase permeability of the blood-brain barrier, may also influence performance when exercise is undertaken in high ambient temperatures, particularly in the presence of significant levels of dehydration.

Although a lot of studies were carried out, Grandjean (2007) refer that future research and challenges is also necessary to reduce ambiguity concerning the dehydration, for there are several potential confounders, like for example: extension of the dehydration phase; time of the day that neuropsychological assessment is conducted; macronutrient and micronutrient composition of the diet, as well as non-nutritive compounds; circadian rhythm; quantity and quality of sleep; individual differences (e.g IQ, resourcefulness, motivation, competitiveness, psychopathology).

3.3 Skin and Core Temperature

When skin temperature exceeds environmental temperature, heat can be lost to the environment through radiation, convection, and evaporation. Heat loss by conduction is negligible when exercising in open air, but becomes significant when immersed in water. Once environmental temperature exceeds skin temperature, evaporation is the only mechanism by which the body can lose heat. Sweating is evoked when core temperature rises and increases in proportion to core temperature, but the sweating rate is also influenced by skin temperature. Sweat evaporation will depend on the water vapour pressure gradient at the skin surface: this in turn depends on skin and environmental temperature and the relative humidity at the skin surface (Maughan, 2007).

According Parsons (2003) , core temperature has no definition. Nevertheless it is generally considered as internal body temperature or the temperature of the vital organs including the brain. If core temperature rises or falls, then there are practical consequences for the body in terms of health, comfort and performance. The main finding of Alonso et al (1999) studies was that fatigue during exercise in the heat was related to high internal body temperature. According Maughan (2007) a change in body temperature may be regarded as a failure of homeostasis or as a re-setting of the point around which regulation occurs. Small fluctuations are normal: over the course of the day, core temperature varies by about 1°C. During exercise, some degree of core temperature elevation is normal with the increase proportional to the absolute and relative (expressed as a fraction of VO_{2max}) power output. Rise in body temperature is also influenced by the environment. Core temperature rises faster in hot environments when power output is maintained at a constant rate, and a higher core temperature is observed at the point of fatigue.

O`Neal (2010), demonstrated that rates of unsafe behaviour and accidents in industrial environments increase both with the activity and the temperature rise. That is, when an environment exceeds 24ºC values (WBGT) and when the body´s core temperature exceeds 38ºC. Recognition of this situation, would allow supervisors to more effectively manage employees exposure and eventually make the workplace safer in cases where a mental error can result in an accident (O´Neal et al. 2010).The most serious consequence of exposure to intense heat is heat stroke which may be fatal. It is caused by a quick failure in temperature regulation, leading to an increase in the heat content of the body. The rectal temperature may be 40ºC or higher (Tanaka, 2006). Nevertheless other author refer that core body temperature is maintained within a very thin range of normality generally between36 and 39 ºC (96.8–102.2 ºF), even in extreme environmental conditions, through an intricate system integrating various physical and biochemical processes coordinated by the hypothalamus (Gonzalez 2010). Metabolic heat production and external heat sources are equally capable of elevating the core temperature during work in hot environments. However, core temperature elevation can be restricted to a safe and manageable level if heat loss mechanisms (sweating and skin blood flow) can be sustained or supplemented (Caldwel et al. 2011).Two major processes dissipate heat from core body parts to the environment. One is heat loss from the skin surface; another is heat transfer from core body parts to the skin. Since heat loss from the skin is inefficient in hot and humid environments, the contribution of core to skin heat transfer becomes relatively greater than that in neutral environments. The transfer of heat to the skin through the blood circulation is a product of skin blood flow, core-skin temperature gradient and the volume specific heat of blood (Taylor et al. 2008) by Wakabayash (2010).

3.4 Brain

The thermoregulatory responses to exercise and heat stress occur without conscious action by the brain, but this does not mean that brain is not aware of what is occurring or that it is not essential for conservation of function when exposed to theses stresses (Maughan, 2007).

Changes in brain activity with temperature have earlier been observed in humans on the basis of electroencephalographic (EEG) recordings and sensory evoked potentials (Nielson 2003). It is possible to monitor brain function through psychophysiological recording. Traditionally, much of this work has been based on arousal theory. Arousal may be assessed through central nervous system measures (the electroencephalogram or EEG) and autonomic nervous system measures such as increased skin conductance and heart rate (Matthews, 2000).The same author refers that several studies suggested that there is a curvilinear relationship between heat and vigilance, and that several reviewers have suggested that there is an optimum temperature range of around 27º- 32ºC for vigilance. The inverted – U relationship between temperature and vigilance is allusive of the Yerkes – Dodson Law. Decrements in performance at higher temperatures might be attributed to over arousal. However, there are difficulties for such an arousal theory explanation. The subjective effects of heat include anxiety, irritability, fatigue, drowsiness and loss of motivation. With regard to fatigue that can lead to accidents and cause errors. To measure performance three types of fatigue were distinguished: physiological, subjective and objective fatigue. Physiological changes during performance are not directly related to the brain`s consumption of energy during performance (Matthews, 2000).There is a close relationship between physiological and emotional reactions, and there are two traditional approaches to explain this correlation the Centralist (that is to suppose that both types of reaction are expressions of central brain systems - thalamus) and the Peripheralist (more psychological in character) (Matthews, 2000).

According to Ftaiti (2010) the development of fatigue is complex and determined by an intricate interplay between psychological and physiological factors. It was suggested in his study that, exhausting work in the heat induced a change in gross brain activity (alpha/beta ratio) compared to a longer, less thermally demanding exposure. Fatigue in the heat could be attributed to central factors as well as thermal, cardiac and hydro-electrolytic impairment, (Ftaiti, 2010).

The paradox of improving instead of deteriorating the mental performance under certain thermal stress levels is explained by the inverted U-shaped relationship between arousal and performance (Tanaka 2006).

High cerebral temperature may lead to alterations in motor drive that affect the ability to recruit sufficient muscle fibers to meet the demands of exercise. This effect may be mediated, at least in partly, by blood flow changes occurring in response to redistribution of cardiac output due to exercise-heat stress. It is clear that exercise, coupled with heat stress, results in a significant number of metabolic and circulatory perturbations within the brain (Maughan 2007). The changes in whole body fluid balance can directly influence the CNS, and this may potentially play role in the mental and physical performance deterioration observed with dehydration.

Tham (2009) concluded that cooling sensation activates the brain and excites the nervous system controlling thermoregulation and that activation of the sympathetic nervous system elevates mental alertness or arousal, a mental state preferred in performing tasks that require attention, endurance and energies. Tham (2009) asserts in his study that as correlate of catecholamines, salivary alfa-amylase may serve as an indicator of adrenergic activities under various thermal exposures, which could indicate the activation of the nervous system. Gaoua (2011) concludes that heat impairs memory, without change in the process of attention. Deficiencies found in cognitive function with hyperthermia and the beneficial effect of passive cooling of the head, are dependent tasks and suggest that exposure to hot environment is an important variable to consider for cognitive processes. These authors draw attention to the fact that the cooling of the head appears to be more efficient for the cognitive functions that involve the frontal area of the brain.

Sepänem (2006) in studies conducted to determine the performance indicators in offices, in activities such as, for example, word processing, simple calculations (addition and multiplication) and response time for customer call centers concluded that the temperature clearly affects the human response (Sepänen2006). Tham (2009) refers, in turn, the thermal environment in uncomfortable situations, can affect performance in office work. In trying to understand the mechanism of the link between air temperature and mental alertness through the perception and physiological responses, developed a study in this area. In this study, three office environments were simulated subject to the following temperatures 20 ºC, 23 ºC and 26 ºC, and findings related that both thermal comfort and thermal sensation changed significantly over time under all conditions of exposure. Moderate exposure to cold induced activation of the nervous system, demonstrated by the increased level of alpha amylase. Measures of mental performance in the study were obtained from various tests like, for example: arousal/alertness, concentration creativity and reasoning. The relationship between arousal/alertness and work performance is commonly described following the classic Yerkes-Dodson law which dictates that work performance improves with arousal/alertness up to an optimal point beyond which the work performance decreases (an inverted U curvilinear relationship).Association between arousal/alertness and work performance is also governed by the type of tasks under consideration. Tasks/works that emphasize on attention, endurance and energy usually require a higher arousal while those demanding thinking abilities are better performed under lower arousal state. Analyses of salivary biomarker focused on alfa- amylase, a correlate of catecholamines level in plasma secreted by activation of the sympathetic nerves. When released into the blood stream, catecholamines increases heart rate, blood pressure, breathing rate, muscle strength and mental alertness (Tham 2009).

Taking into account that with an uncompensated heat stress and the same core temperature (tc), the absolute heat load may be different among brain areas. It is therefore possible that environmental stress may affect cognitive abilities in different areas of the brain has suggested by Gaoua (2010) that in future rather than to categorize the tasks as “simple” and “complex”, it would be advisable to handle the complexity inside jobs.

4. CONCLUSIONS

Although there is agreement among authors regarding the perceived importance of studying the thermal environment on cognitive response and many studies have been carried out concerning the relationship between high temperatures and cognitive effect in certain professional activities, the results are still inconclusive. This paradox results, occurs by interference from various factors, such as the type of task, characteristics of the worker, the level of motivation (Tanabe et al. 2006), psychological factors and characteristics of buildings, severity of exposure to temperature, complexity and duration of cognitive task (Gaoua, 2010), among others.

However, literature review indicates that the cognitive response is affected by at least two parameters: the internal temperature and dehydration, in addition to other parameters related to psychological factors and the type of task. The type of task is also an important issue whether for the association between arousal/alertness that is commonly described following the classic Yerkes–Dodson law.

The differences in temperature and humidity can cause changes in the performance of workers at various levels, particularly in cognitive aspects, while being harmful to the health of workers. Factors such as internal body temperature and dehydration are highlighted, throughout this research, as key issues in monitoring the state of human beings to high temperatures. This scenario entails concentration problems, increased fatigue, illness, occupational safety and increased rate of risk. Gaoua (2010) found that cognitive function is more sensitive to environmental disturbances, especially thermal, than physiological tolerance and is influenced by changes in skin temperature. When there is significant increase in core temperature, the cognitive aspects can be affected. In order to proceed with further studies, the same author recommends discussion of results concerning exposure to heat, thermal loading and the resulting dynamic range of core temperature.

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