Students' blood pressure and heart rate in learning environments with thermal changes

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Abstract

The increase in global temperature in recent years (which is likely to continue) has the power to affect the temperatures of indoor workplaces. This increase may in turn, be reflected in human performance. The present article analyzes the relationship between air temperature, blood pressure and heart rate variation in students in a learning environment through Video Display Terminals (VDT), located in northeastern Brazil. The thermal conditions were analyzed during three consecutive days, according to ISO 7726: 1998; in the group of students who underwent changes in indoor air temperature, their blood pressure and heart rate were also measured. When the air temperature was of 20ºC, 24% of the subjects' heart rate exceeded 100bpm, while for 30 °C this number reached 51%. The results revealed changes in diastolic blood pressure and heart rate when air temperature increases.

1. INTRODUCTION

The permanent emission of greenhouse gases has been leading to a gradual increase in the average temperature of the earth's surface. This increase in the outside air temperature gives rise to an increase in the internal temperatures of the working environments (IPCC, 2007).

In an indoor environment, the thermal conditions are controlled to ensure, not only equipment's operability, but al-so the health and the comfort of its occupants (Bradshaw, 2006). Vimalanathan & Babu (2014) confirmed the importance of this concern with the indoor thermal environment. These authors concluded that air temperature influences more than lighting on the performance of office workers.

However, adverse environmental conditions, in addition to impairing productivity, can contribute to the onset of occupational diseases, as well as develop stress and dissatisfaction. Thus, the adoption of measures that promote thermal comfort and the well-being of workers can also play an important role in improving their performance.

Siqueira and Silva (2015) reported that, in association with the scarcity of information about the influence of temperature and humidity in learning environments, these same environments usually have technological and communicational innovations, commonly known as new ICTs. These devices, by itself, are sources of heat and therefore, can cause changes in mental performance and cardiovascular parameters.

It is thus important to investigate the effects of thermal comfort and discomfort on the performance and health of students, when they are in the exercise of their activities, observing changes in heart rate and blood pressure, in or-der to analyze the existence of an appropriate classroom environment.

One of the major systems of the human body is the cardiovascular. Its main function is the transport of materials be-tween all parts of the body, taking nutrients and removing the residues released by the cells. This system comprises the heart, blood vessels, blood cells and plasma. Fluids and gases flow through the vessels due to the existence of a pressure gradient, with the direction of flow being from the points with greatest pressure to those of the lowest one (Silerthorn, 2010). The heart is a muscular organ that contracts and relaxes cyclically. A cardiac cycle between the beginning of one beat and the beginning of the next has two phases, a period of diastole, during which the heart relaxes, and one of systole when the heart contracts. The mean resting heart rate (HR) is 70 beats per minute (BPM), however, normal values vary over a wide range. Stressful situations induce various physiological reactions in the nervous, cardiovascular, metabolic, hormonal and muscular systems. Chronic stress exposure may lead to system depletion. (Taelman et al., 2011).

Indoor temperature effect on the cardiovascular system has received attention from researchers and a relationship between cardiovascular diseases and environmental conditions (temperature and air quality) has been established (Wu et al., 2013). As result of intense exposure to heat, there is a reduction in blood pressure caused by peripheral vasodilation and loss of body fluids through perspiration. Human organism, increasing heart rate, compensates this pressure reduction overloading cardiovascular system.

This study aims to investigate heart rate and blood pressure behavior in college students submitted to changes in indoor temperature. Correlations between temperature and blood pressure variability were analyzed and a logistic regression model was developed to understand the relationship between the heart rate of the students and the indoor temperature.

2. METHODS

Heart rate (HR) and blood pressure (BP) are affected by environmental conditions depending on performed activity type (Lan, 2011; Silverthorn, 2010). Variations in HR are more sensitive to perception demands than attention (Liu & Lian, 2008). Wharton et al. (2006) also found a positive relationship between BP and the perfor-mance of visuospatial tasks (SBC 2010). In his turn, Lyngdoh et al. (2013) found an association between some cognitive functions and BP, though the associations were gender specific or, exclusively related to systolic BP (SBP) or to diastolic BP (DBP), thus precluding generalizations (Lundgren et. al., 2013).

This dependence on the performed activity may be related to the cortical area, which is activated during the execution of a task, and with the human body temperature control areas. Thus, the negative effects observed on health and performance when a subject exposed to hot environments might be caused by physiological mechanisms (Hjortskov et. al., 2004).

It should be noted that cardiovascular parameters are affected by cognitive activity. However, cognitive performance, in turn, may be also affected by these same parameters. This fact was exemplified in a study conducted by Lan et al (2011), who observed that reduced oxygenation (SpO2) may reduce cognitive function and consequently students' performance (Hjortskov et. al., 2004).

Although some studies have found only a relationship between performance and changes in HR and BP, Bernardi et al. (2000) found a reciprocal relationship between mental activity and stress that was associated with sympathetic activation of the cardiovascular system. This activation can be affected by the individual's breathing (Taelman et al., 2011).

Hjortskov et al. (2004) observed that mental stress during computer work leads to changes in HR and to a sustained increase in BP, and that these effects are reverted resting (Paschoal et. al., 2006).

Vuksanovic & Gal (2007) observed that changes in autonomic modulation are expressed in High Frequency (HF) spectral power, and are responsible for increasing HR under mental stress (SBC, 2011). Furthermore, Schnell et al. (2013) showed that thermal load levels, which are measured using the physiological equivalent temperature, are associated with Low Frequency (LF), and HF of spectral power levels (Maïmoun et. al., 2013)

Changes in electrocardiogram (ECG) are also associated with environmental variations. These changes do not have a linear trend when related to temperature and humidity, and may have higher values at low or high temperatures. Several authors (Vimalanathan & Babu, 2014; Lan et al; 2011; BC et al., 2010; Liu et al., 2008; Vuksanović & Gal, 2007) found that the LF/HF ratio was higher at discomfort levels than at comfort levels, when describing the association between cardiac activity and the thermal sensation of an indoor space occupant (Lan et al., 2011). The increase in the LF / HF ratio indicates that the activity of the Sympathetic Nervous System (SNS) is high.

The SNS stimulates automatic actions that allow the human body to react in stressful situations, speeding up HR and increasing BP, adrenaline and blood sugar concentration, activating the body's overall metabolism.

3. MATHERIALS AND METHODS

This study was carried out in a classroom (Figure 1), equipped with an air conditioning system, Video Display Terminals (VDT), computers and wireless technology, in a public university in the city of Teresina, in the state of Piauí, in the Northeast Brazilian.

Figure 1. Classroom with VDT

Indoor air temperature was adjusted to 20°C, 30°C and 24°C, respectively. All measurements were performed in the afternoon, when the external air temperatures, according to Brazilian National Institute of Space Research (INPE, 2015) were 37.7°C; 38.1°C and 39°C respectively.

Thermal and personal parameters were collected and the subsequent analyzes were performed. Data collection was divided into four stages:

(1) Equipment settings and students' arrival;

(2) Explaining of the research objectives and the questionnaires to be filled out;

(3) In each student the following parameters were measured: weight, height, initial blood pressure and initial heart rate;

(4) Filling in online questionnaires on personal and dietary aspects.

Data analyses was divided into five steps:

(1) Check of parameters normality through Shapiro-Wilk test;

(2) Application of variance analysis of one-way ANOVA test to verify if the means of cardiovascular parameters were equal between the three days;

(3) Tukey test application to check which days showed no difference between the mean values;

(4) Implementation of a descriptive graphical analysis to compare the behavior of the students' heart rates during the experiment with their ideal heart rate;

(5) Development of a logistic regression model to analyze the risk of heart rates exceeding 100 bpm (beats per minute) when the air temperature varies between 20-30 °C.

3.1. Ethical bases

This study was approved by the Ethics Committee, under number CAAE 15012913.1.0000.5188, in accordance with Resolution 466 of 2012 of the National Health Council. All the participants were informed about the study goals and signed an Informed Consent Form (ICF).

3.2. Sample

The original sample consisted of 79 students of higher education in several courses of the Engineering area. The inclusion criteria used for this research were college students who attended the three-day survey in a good general state of health.

3.3. Variables and research parameters

Table 1 shows the variables that were analyzed in this study and their respective parameters.

Table 1. Variables and research parameters

VARIABLES	Research parameters
Personal	Age (years)
	Sex (m/f)
	HR (bpm)
	BP (mm/Hg)
	FSBP (mm/Hg)
	ISBP (mm/Hg)
	FDBP (mm/Hg)
	IDBP (mm/Hg)
	ICF (bpm)
	FCF (bpm)
Thermal	T_a (°C)
	T_g (°C)
	T_{mr} (°C)
	ARH (%)
	AV (m.s^{-1})

HR – Heart Rate; bpm – Blood Pressure
FSBP – Final Systolic Blood Pressure
ISBP – Initial Systolic Blood Pressure
FDBP – Final Diastolic Blood Pressure
IDBP – Initial Diastolic Blood Pressure
ICF – Initial Cardiac Frequency
FCF – Final Cardiac Frequency
T_a – Air Temperature
T_g – Globe Temperature
T_{ar} - Average Radiant Temperature
ARH – Air Relative Humidity
AV – Air Velocity

3.3.1 Personal variables

Blood pressure was checked out before and after the end of the tests, using an automatic arterial-arm pressure monitor HEM-7220 model OMRON. Heart rate was checked during the activities using the heart rate meter POLAR FT07. The used equipment was validated according to the international protocol of the European Society of Hyper-tension. The procedures for the measurements were done in accordance with the recommendations described in the VI Hypertension Guideline. (SBC et al., 2010).

The maximum heart rates and the mean values of the measurements were recorded. The data was put directly into the computer, through the Polar Web Sync program. Regarding students metabolism, it was defined as being 70W / m2, since they were sitting and without physical activity.

3.3.2 Environmental Variables

The environmental variables: Air Relative Humidity (ARH), Air Temperature (Ta) and Globe Temperature (Tg) were measured using Thermal Stress TGD 300 from Instruterm, which allows recording data and its transfer to the computer to be processed through specialized software, or with the aid of computer spreadsheets. Regarding the equipment, it complies with the requirements of ISO7726: 1998.

4. RESULTS

A total of 60 male students (76.54%) and 19 female students (23.46%) with an average age of 22 years old (SD=2), average weight of 65.23kg (SD=7.08), average height of 1.72 meters (SD= 0.06) participated in the study. The thermal resistance of students' clothing was 0.42 clo, which is considered the ideal value for classroom activities (ISO 7730, 2005).

Learning environment thermal conditions of in the three days of experiments presented the following results:

(1) Air Relative Humidity average was 67.13% (SD=0.03) when air temperature was between 20 and 30 °C;

(2) Air Velocity had a constant value of 0.10 ms-1;

(3) Air temperatures, globe temperatures and average radiant temperatures were similar (first day, 20°C, second day, 24°C and third day, 30°C).

Results of the health conditions of the students during the experiments:

(1) The final systolic blood pressure (FSBP) 117.77 (SD=1,5) was greater than the initial systolic blood pressure (ISBP) 87.33 (SD=1.3);

(2) The final diastolic blood pressure (FDBP) 65.2 (SD=3.6) was similar to initial diastolic blood pressure (IDBP) 69 (SD=2.4);

(3) It was observed by analysis of variance that the averages of the data of the variables of Initial Cardiac Frequency (ICF), final diastolic blood pressure (FDBP) and Final Cardiac Frequency (FCF) showed differences during the experiments, p value <0,05.

Through the Tukey test (Table 2), it was observed that on day 1, when air temperature was around 20°C, the FDBP was higher than on day 2, when the air temperature was around 30°C, p-value <0.05. This did not occur with the Final Cardiac Frequency (FCF), since on day 1 (Ta=20°C) it was lower than on day 2 (Ta=30°C), p value<0.05.

However, the FCF on day 2 (Ta=30°C) was greater than at day 3 when air temperature was around 24°C, p-value <0.005. The difference between Final Cardiac Frequency (FCF) and Initial Cardiac Frequency (ICF) was higher on the day 2 (Ta=30°C) in relation to the day 3 (Ta=24°C). It was observed that in high temperatures the cardiac frequency shows significant change.

According to Figure 2, during the experiments in the learning environment with air temperature variations, the average heart rate (AHR) of each student was not close to the ideal heart rate (IHR). It was observed that at 20° C, the differences between AHR and IHR were more representative when compared to the differences between the frequencies when air temperatures were in the vicinity of 24°C. When the air temperature was around 30°C, the differences between the IHR and IHR were smaller.

Table 2. Tukey test – average differences

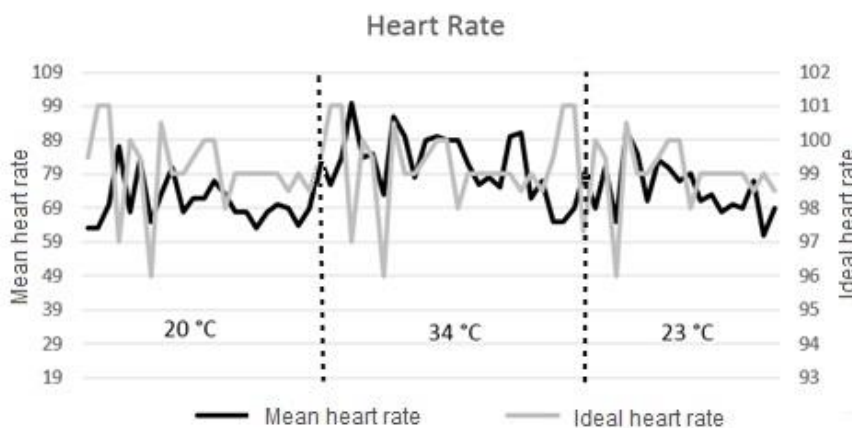| VARIABLES	(I) DAY	(J) DAY	(I - J) DAY	*p*-value
FDBP	1	2	7.318	0.002
	1	3	4.636	0.068
	2	3	-2.682	0.394
FCF	1	2	-12.59	0.001
	1	3	-3.182	0.321
	2	3	9.409	0.001
FCF - ICF	1	2	-3.455	0.05
	1	3	2.091	0.321
	2	3	5.545	0.001

Figure 2. Heart rate

4.1. Mathematical modeling - HR=f (T$_a$)

The model was adjusted with the air temperature (Ta) as independent variable and heart rate (HR) as dependent variable. An HR logistic regression model, as a function of air temperature (1) was created whose likelihood ratio test (LRT) was $\chi^2=188.88$ for a p-value = 0.001 <0.05.

From the model (1) and its graphic representation (Figure 3), it is observed that between 28 and 30°C there is a 45-51% probability of the heart rate exceeding 100 bpm. If all ranges are considered, comprising between 20 and 30°C, for each 1°C increase in air temperature in learning environments, the risk of heart rates passing 100 bpm is 10% ($e^{-0.108}$).

$$P(HR) = (1+e^{(3,21-0,108Ta)})^{-1} \qquad (1)$$

In summary:

(1) Student's initial heart rate, final diastolic blood pressure and final heart rate show differences when air temperature in the learning environment was 20°C, 24°C and 30°C;

(2) The final students' diastolic blood pressure after the experiment was higher when the air temperature in the learning environment registered 30ºC;

(3) At 30°C, a higher heart rate between the students was registered;

(4) With 20°C in the air temperature, 26% of the students presented a heart rate above 100 bpm;

(5) With 24°C in the air temperature, 35% of the students presented a heart rate above 100 bpm;

(6) With 30°C in the air temperature, 51% of the students presented a heart rate above 100 bpm;

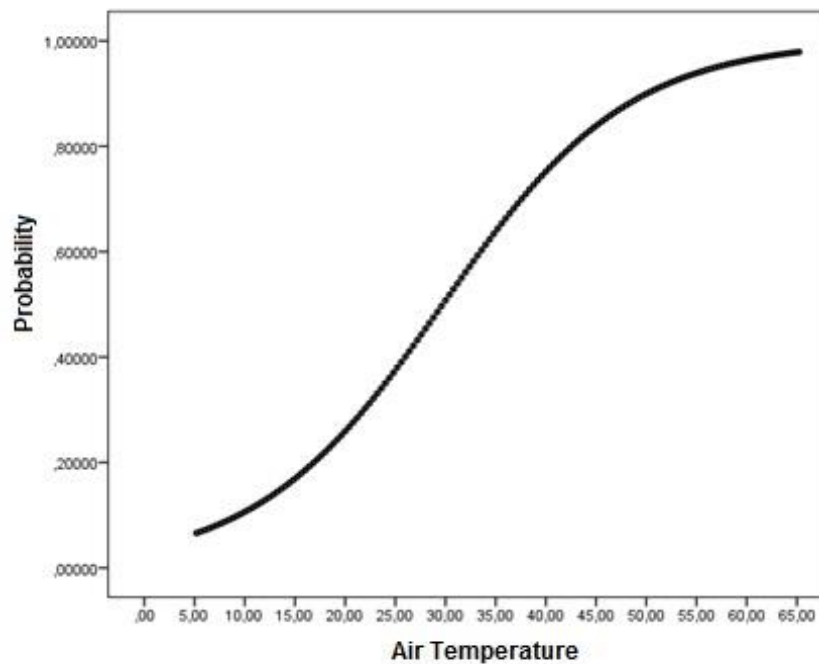**Figure 3.** Graphical representation

5. DISCUSSION

Although there were no significant changes in students systolic blood pressure during the three days of the experiment, it was verified that the proportion of participants with systolic blood pressure in the range corresponding to hypertension level 1 was higher on the day with lower temperatures (Ta=20°C), this corroborates with the studies of Brandão (2010). There were differences in diastolic blood pressure among the three experiment days, with Initial Systolic Blood Pressure (ISBP) being associated with a decrease in temperature.

The difference between final cardiac frequency (FCF) and initial cardiac frequency (ICF) was higher on day 2 (Ta=30°C) than in day 1 (Ta=20°C) and day 3 (Ta=24°C). It was observed that, at high temperatures, the heart rate shows significant changes, confirming with the studies of many authors (Vimalanathan & Babu, 2014; Silva, et al., 2015; Wu et al., 2013; Bernardi et al., 2000). However, when the temperature increases, the heart pumps a little more blood, so the pulse rate may increase, but usually no more than five to ten beats per minute. In addition, and in accordance with the American College of Sports Medicine (ACSM 2014), the ideal heart rate (IHR) and it of each individual shall not exceed 50%.

As consequence of the activation of the thermoregulation system, when subjects are submitted to environments that cause thermal discomfort by heat, results a peripheral vasodilatation and an increase of the sweating, in order to regulate body temperature (Charkoudian, 2016).

At the same time, this phenomenon causes an increase in the volumetric capacity of the circulatory system due to vasodilatation and a reduction in blood volume due to sweating. To compensate, the body reacts by raising heart rate in order to maintain blood pressure (Schlader and Wilson, 2016).

The relationship between heart rate and air temperatures for values between 20 and 30°C was assessed during the performance of cognitive tasks by the student sample. As a result, it was found that when air temperature reaches 30 ° C, the heart rate may pass 100 bpm, which means that the probability of tachycardia exists (Pastore et al., 2009).

Heart rate is quite sensitive to demands of sympathetic and parasympathetic systems and the variability in the heart rate is an adequate signal of adaptation that characterizes healthy individuals with efficient thermoregulation mechanisms (Vanderlei et al., 2009). However, a high heart rate at rest is a cardiovascular risk factor, even for healthy individuals. It may further aggravate any cardiovascular problems of an individual (Zhang, Shen, IQ, 2015, Böhm et al., 2010). In addition, high heart rate can cause symptoms such as palpitations, weakness and even dizziness, which can contribute to a feeling of discomfort, particularly in thermally non-neutral environments.

6. CONCLUSION

During the research, changes in blood pressure and heart rate correlated with different thermal conditions were recorded. Both variables showed changes, however, the most significant were in heart rate (HR). Although this is a relatively unexplored field, there may be adverse effects due to an increase in heart rate caused by prolonged exposure to high temperatures. Taking into account the experiments, slight variations in air temperature can affect heart rate.

If this problem is considered in a context of climate change and as it is known that in several states of Brazil, especially in the North and Northeast, individuals are subjected to high temperatures in their occupational activities, especially when performed in an environment without adequate air conditioning. It is therefore possible that it may in-crease the occurrence of cardiovascular diseases. Within this context, it is concluded that student's initial heart rate, final diastolic blood pressure and final heart rate showed differences for the different tested temperatures. That is, vary with temperature and is higher for high temperatures. Thus, the results of this work show a direct relationship between the increase in temperature and heart rate.

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