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RESEARCH ARTICLE

MONITORING OF BLOOD AND INTRACRANIAL PRESSURE IN AVIATORS OF THE BRAZILIAN AIR FORCE SUBMITTED TO HIGH TRAINING LOADS IN FORCE SIMULATOR.

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Abstract

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Purpose: Intracranial pressure (ICP) is modulated by 3 components: brain tissue, cerebral blood and cerebrospinal fluid. The ICP waveform contains 3 upstrokes in one wave: P1 - Percussion: systole; P2 - Tidal: intracranial compliance; and P3 - Dicrotic: diastole. Pilots are known to experience headaches when flying frequently, particularly when undergoing the influence of high gravitational attraction (Gz). These headaches are caused by changes in ICP, however, the factors behind these changes are still unclear and could be linked to the Gz itself or the movements. Method: This study aimed to non-invasively monitor the ICP of cadets from the Brazilian Air Force Academy during maneuvers using the T-27 aircraft force simulator. Eighteen volunteers were monitored using two sensors-left and right parietal bones. Cadets performed 6 isometric maneuvers with the control stick for 1 minute each: 1) rest: no movement; 2) front: push the stick forward; 3) back: pull the stick back; 4) left: rotate stick to the left; 5) right: rotate stick to the right; 6) return to rest position. Data was recorded and analyzed using the Braincare Analytics System. Morphological analysis showed a normal ICP pulse waveform for all cadets. Result: No difference was found in the time to peak and the pulse area when comparing between the left and right sensors and between all maneuvers. Heartbeat values during the isometric movements were lower than when at rest. This could be the effect of the Valsalva maneuver. Conclusion: In conclusion, the ICP remained unchanged during isometric movements in the T-27 aircraft force simulator.

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Introduction:-

Intracranial pressure (ICP) is the pressure inside the skull and it is modulated by 3 components: brain tissue; cerebral blood; and cerebrospinal fluid (CSF). The relationship between these 3 components is constantly in balance (homeostasis) and maintenance of the ICP values depends on the preservation of intracranial volume .

The morphology of the ICP pulse is basically a modified arterial pulse . The ICP waveform has 3 distinctive peaks: the first peak (P1) is the effect of the arterial pulse on the choroid plexus; the second peak (P2), called tidal wave, depends on cerebral compliance and the reverberation of the P1 in the skull; the third (P3) or last peak is the result of the dicrotic curve followed by the aortic valve closing curve .

Brain self-regulation is very important in maintaining homeostasis. The adult brain needs 50mL of blood per 100g of brain tissue per minute . Above or below this limit, homeostasis is lost and regulation is then dependent on the mean arterial blood pressure (MAP) . This self-regulation is probably due to the smooth muscle myogenic behavior of the cerebral arteries, which contract in response to high pressure and dilate in response to decreased pressure .

Arterial blood pressure is modulated by the force of isometric contractions and these, in turn, can influence the way that pain is perceived. Pain sensitivity can be reduced by exercise training, and can be accounted for by the intensity of the blood pressure response . Pilots suffer discomfort, mainly in the spine region, due to the sitting posture adopted in the aircraft that can last from minutes to hours .

Therefore, as ICP is modulated by arterial blood pressure, which in turn could be influenced by exercise, could the isometric force performed by pilots during flight maneuvers be able to affect ICP?

Materials and Methods:-

The sample comprised of 30 healthy male volunteers, all cadets from the Brazilian Air Force Academy (AFA), located in Pirassununga, Sao Paulo state, Brazil. Volunteers were monitored and data recorded at a 100Hz sample rate using the Braincare Monitor 2.0 (Braincare Health Technology). A non-invasive intracranial pressure sensor, developed by the company Braincare Health Technology, was used and all data transmitted online to the Braincare Analytics System.

An T-27 aircraft force simulator was used to simulate 5Gz+ (± 300N), reproducing the actual mechanical force applied to the control stick for the four axes movements: rotate to the left, nose-up, rotate to the right, and nose-down.

The Braincare non-invasive intracranial pressure sensor was applied at both sides of the parietal bone to monitor the ICP of the volunteers. Cadets were instructed to perform 6 isometric maneuvers with the control stick: 1) rest: no movement; 2) front: push the stick forward; 3) back: pull the stick back; 4) left: rotate stick to the left; 5) right: rotate stick to the right; 6) return to rest position. Each movement was performed during 1 minute.

The ICP pulse was separated by identification of the local minimum values of the time series. Heart rate was calculated as the inverse measurement of pulse length. The pulse shape average was determined through alignment of the pulses using the maximum slope of the curve before the first maximum occurred. Thereafter, the pulse was normalized to the same extent in order to avoid the influence of different heart rates and maxima to mitigate the variability of the sensor sensitivity. Data analysis was conducted using the Braincare Analytics System, a custom python program that was developed based on the .

Statistical analysis was conducting using the nonparametric Kruskal-Wallis one-way analysis of variance for multiple comparisons, followed by the Mann-Whitney U test for double comparison, and nonparametric bootstrap confidence intervals (alpha=0.05, 1000 replications). The study was approved by the Research Ethics Committee (CAAE: 40667114.7.0000.5504) and financial support was received from the São Paulo Research Foundation (FAPESP - Process no. 2014/21803-7).

Results:-

The study cadet volunteers had the following characteristics (mean±SEM): aged 21.3±0.27 years, weight 72.8±1.75 kg and height 1.78±0.01m. It can be observed that the ICP pulse waveform did not change on either side of the parietal bone, where the sensor was positioned. When performing the flight maneuvers, the cadet ICP values were similar to when in the rest position. Figure 1 shows the ICP pulse waveform of 3 of the 30 cadets. No difference was found in the ICP between the two parietal sensors during the performance of all flight maneuvers used in this study.

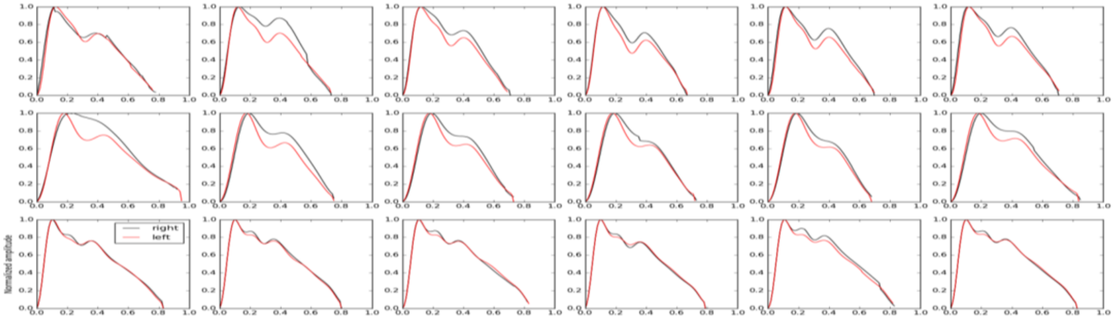

Fig 1:-Averaged pulse waveform as a function of the control stick position (rest, back, front.) for three cadets (1,2,3) for the right (black) and left (red) sensors.

Analysis of the normalized time to peak and the pulse area found no statistical difference, although one peak (right maneuver) of the time to peak values for the left sensor showed statistical difference when compared to the rest position. This difference could have been caused by fatigue. The normalized time to peak is the relative time of blood ejection from the heart. The normalized pulse area is the relative blood volume ejected from the heart at that pulse. This analysis indicates the ICP normalized waveform pulse at both sides of the sensor remained unchanged during the maneuvers (Figure 2).

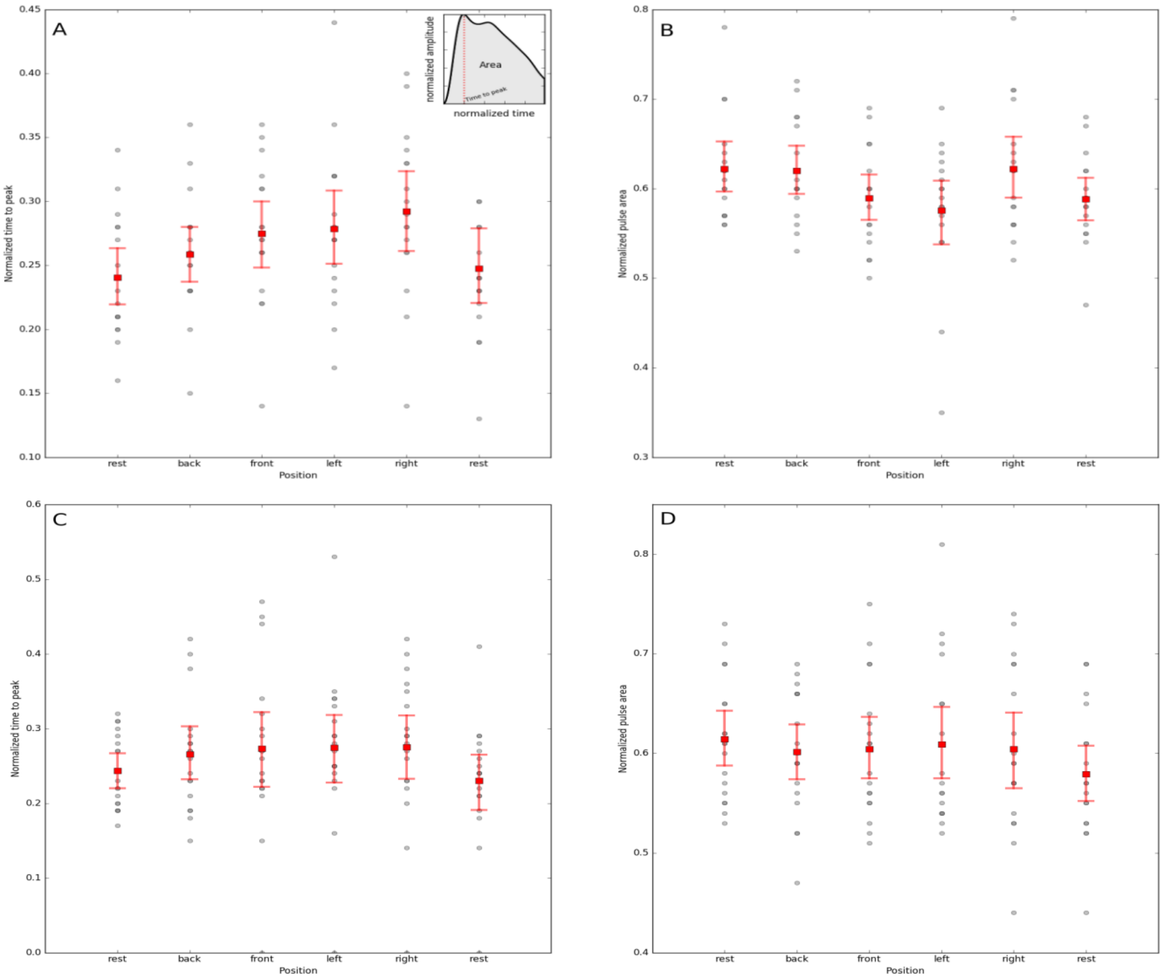

Fig 2:-Pulse waveform comparison as a function of the control stick position. The parameters of the pulse shapes analyzed can be seen in the inset graph in A. The pulses were normalized in extent (time) and amplitude. The normalized time for the pulse to reach its maximum can be seen in A (H=11.819, p=0.037) and C (H=6.55, p=0.2559), for the right and left sensor respectively. The areas of the normalized pulses are shown in B (H=6.09, p=0.296) and D (H=2.58, p=0.764). Sample size is 18 cadets. The red bars represent nonparametric confidence intervals (a=0.05, N=1000).

The ICP waveform peak-to-peak interval gives the heart rate. It can be observed that there is a decrease in heart rate during the maneuvers. This could be caused by the effect of the Valsalva Maneuver, which increases blood pressure for a short period of time and then decreases heart rate and systolic blood pressure. Sometimes, this decrease can lead to values that are inferior to the ones obtained at rest, which is illustrated Figure 3.

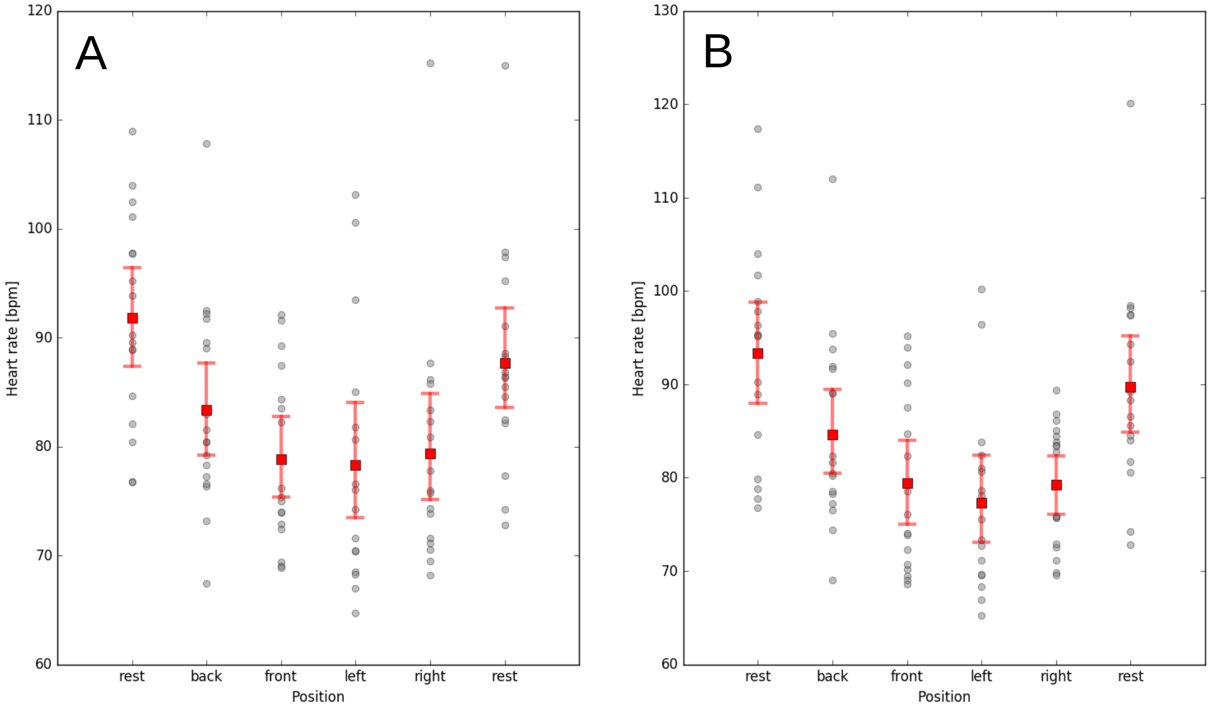

Fig 3:-Heartbeat as a function of the control stick position, for the right sensor **A** (H=37.38, p<0.01) and left sensor **B** (H=39.44, p<0.01). Sample size of 18 cadets. The red bars represent nonparametric confidence intervals (a=0.05, N=1000).

Discussion:-

The cardiovascular system is adapted to the strength of 1 Gz + (gravitational pull), and any change in this force disturbs homeostasis control mechanisms .

Exposure to increased acceleration Gz + has a profound effect on the cardiovascular system, which manifests itself primarily by visual symptoms and then at sufficiently high levels of acceleration, loss of consciousness. The circulatory disorder is the result of a simple physical issue applied to the fluid compartments within the body. Exposure to Gz acceleration produces large immediate changes in the distribution of pressure in the arterial and venous system, which, in turn, induces changes in blood flow. These initial perturbations evoke changes of compensatory reflexes that tend to reduce the magnitude of the initial effects .

Changes in intravascular pressure has no effect on the size of the blood vessels, since this size is determined by factors such as vascular pressure vessel distension capacity and the amount of blood available to fill it. In turn, changes in vessel size has significant effects on regional blood flow and the blood content. Thus, an increase in vascular pressure of the small arteries and arterioles below heart level will decrease in peripheral resistance and an increase in local blood flow. Meanwhile, a decrease in pressure in the vascular veins above the heart level may produce a total collapse of vessels and cessation of blood flow through them .

Blood pressure changes and redistribution of blood volume caused by exposure to high acceleration Gz produces reflex responses involving arterial baroreceptors and possibly also low-pressure cardiopulmonary and arterial chemoreceptors receptors. Reflections at the local level are also likely to influence the blood pressure response on exposure to acceleration. Thus, the baroreceptor reflex provides a compensation mechanism for increased acceleration. Exposure to high loads Gz + produces an increase in maximum heart rate, try the circulatory system to return blood to the heart. The venous return to the right heart begins to increase after 10 to 15 seconds of the start of exposure to the acceleration. Venous return continues to increase over the next 20 to 40 seconds. The cardiac output after 30-60 seconds of exposure to Gz + 4 is reduced by approximately 20% below the resting value.

Human tolerance depends on the magnitude of Gz load, its duration, intensity and where this load is applied. A non-adapted person can tolerate about an acceleration Gz 3 + for a few seconds, occurring the stiffening of muscles and great difficulty of blood return to the heart and brain. On the other hand there is an increase in blood flow to the brain (Gz -)., known about the variation of the PIC during load change positive or negative G.

Some experiments were carried out during the 2nd World War, based on skeletal muscle contraction pilots in combat flights. These experiments increased Gz tolerance 2 + or more. However there are risk factors involved with these maneuvers, such as increased blood pressure is common in military aviation pilots perform the Valsalva maneuver when exposed to Gz + load variations .

The Valsalva maneuver is a forced exhalation against a closed glottis. This action increases the intrathoracic and intra-abdominal pressure, so this increase in pressure is transmitted directly to the heart and great vessels, raising blood pressure. In accelerations + Gz, this maneuver helps maintain cerebral perfusion while minimizing the reduction in blood pressure at head level .

The protective effect of this maneuver is short. When blood pressure is high is started, but after a few cardiac cycles, pulse and systolic blood pressure begins to decrease, often at lower values than those found in the home. Therefore, if a Valsalva maneuver is extended by 3 to 4 seconds high acceleration Gz + Tolerance to be reduced .

The maneuver anti-Gz effort is widely accepted as a means of combining the beneficial effects of the techniques described above and overcome some of their detriments. It is a combination of muscular contraction with Valsalva maneuver performed rhythmically every 3 to 4 seconds. To gain maximum protection in the maneuver, muscle contraction must be sustained during exposure to Gz acceleration and not relaxed during breathing. subsequent exhalation and inhalation should be performed as soon as possible, since the blood pressure drops precipitously during this phase. Furthermore, there is evidence to suggest that the negative intrathoracic pressure generated during rapid inhalation may increase the venous return and thus improve cardiac output. This maneuver is the main Gz + protection factor for military aerobatic pilots and is used in conjunction with anti-Gz costumes by most of the crew of military jet aircraft

The studies found that show changes in Gz + load lead to variations in blood pressure and may cause these changes sequelae following exposure in long-term or even sudden illness in extreme situations, severe event occurs when pilots during flight.

Military pilots are capable of withstanding an acceleration of + Gz 9 for a longer period of time a person does not adapted for flight . The primary response to the pilot when exposed to changes in blood pressure, is the loss of the bloodstream gases, including oxygen. After 9 seconds subjected to high load + Gz, lack of brain oxygenation takes the driver to the loss of consciousness. In contrast, the increase in pressure and blood flow during charging Gz - can substantially increase the PIC. But the security parameters are not yet conclusive.

In the relatively small number of pilots from around the world who are regularly exposed to the acceleration Gz + at high altitudes. Although civilian aircraft are unable to sustain the acceleration due to thrust limitations and therefore its exposure to Gz load tends to be short, limited physiological sequelae. In a military setting, the exposure is dependent on the acceleration of aircraft operated type, however, most of the crew will be exposed to at least 3 to 4 Gz during the basic flight training. Exposure to acceleration Gz, often results in air combat maneuvers or attack flights to the ground, where the recovery diving and evasion missiles may force the pilot to carry out sudden changes in direction .

The effects that appear more easily during exposure to high acceleration Gz +, are caused by the impact of soft tissue, head, limbs and trunk. Among other cardiovascular effects caused by the increase of acceleration are: cardiac arrhythmias, rupture of skin capillaries forming petechiae, and specific endocrine responses, such as increased levels of adrenalin, noradrenaline and cortisol levels .

The first obvious manifestation of cardiovascular effects of exposure to Gz acceleration is vision. Changes in visual function became recognized by the crew as an important precedent in Gz + induced to impending loss of consciousness. Familiarity with visual symptoms is an important part of training for hypergravity crew. The default visual loss associated with the + Gz exposure is described in terms of "gray-out" and "blackout". Grey-out is generally described as a loss of vision cone, starting from the periphery to the central vision when in higher levels of acceleration Gz. The vision in the periphery is described as gray or black, but in practical terms, the subjects are unable to respond to a light stimulus presented in the affected part of the visual field. However, not all subjects reported visual symptoms identical, and there appears to be a subset of people who report a wide dimming much of central vision as peripheral simultaneously with apparent reduction in contrast sensitivity. Some also reported lines and shapes of various colors under these conditions.

Another symptom to highlight is the black out. It refers to the complete loss of vision with preserved consciousness, in distinction to the colloquial term for the loss of consciousness or fainting. Typically, the end result is the classic greyout pattern described above, wherein the view becomes narrow tunnel, until finally central vision is lost, while the auditory and mental processes are kept. The blackout occurs at higher throttle levels than those which cause gray-out

A little over Gz + acceleration is necessary to cause loss of consciousness. Under certain circumstances, the crew can use the warning symptoms of gray-out and blackout to prevent the loss of consciousness (G-LOC) in G-induced, performing corrective actions. However, at high levels of initial acceleration, these may not be present. The largest study to investigate the acceleration levels associated with visual symptoms was performed using 1,000 crew. This revealed that the blackout occurred 4.8 Gz +, followed by loss of consciousness 5.4 Gz +. However, there is great variation in the level of acceleration that the loss of peripheral vision occurs due to factors such as body height, physical condition, level of illumination of the visual field and, in particular, the degree of muscle relaxation. At moderate levels of acceleration, the intensity of visual symptoms often increases between 8 and 12 seconds after the start of acceleration. This deterioration is due to the compensation of cardiovascular responses to restore blood flow to the retina. Thus, during exposure to 5 Gz + blackout may occur after 6 seconds.

During exposure to acceleration, muscle activity can be susceptible to differences in brain activation with the return of blood to the brain, with constant variations in blood pressure .

The effect of hydrostatic acceleration, greater than about 3.5 + Gz lowers blood pressure in the brain to a value that under normal gravity would be less than required to maintain an adequate cerebral blood flow. Similarly, exposure to 4.5 + Gz, lowers blood pressure at head level to virtually zero.

The GZ acceleration is not well tolerated. During a Gz acceleration – the blood occurs in the direction opposite direction of the Gz + toward the head and upper body, raising blood pressure and reducing the heart rate.

The limit exposure to Gz load - is still unknown. The Gz load - is defined by discomfort in the head, swelling of the soft tissues of the face, petechiae, bleeding in subconjutiva and loss of consciousness .

Over the years, methods and equipment have been developed to increase the tolerance of human exposure to hazardous acceleration. The front protection to high accelerations is divided in two ways: voluntary action taken by the crew of aircraft, and Gz protection systems from the aircraft .

The benefits to be found by this research are not limited to aviation. Numerous medical benefits can also be purchased. The data found can increase the central nervous system tolerance to ischemic hypoxia, present results directly linked to neurological diseases (stroke) and cardiovascular disease (heart attacks and sudden death).

Conclusion:-

Although one time to peak value showed statistical difference between the rest and maneuver to the right position, no difference in the ICP parameters (time to peak and pulse area) was observed in the cadet volunteers. The conducted maneuvers caused no variation in the ICP measurements of the cadets, although the heartbeat rate decreased during the maneuvers when compared to the rest position. This reduction could be caused by the Valsalva Maneuver.

Future studies:-

Further research is to be conducted involving the measurement of ICP in combination with arterial blood pressure. Subsequently, cadet pilots will be monitored and measurements acquired during flight.

Competing interests:-

The authors declare that they have no competing interests.

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