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The Brain Entropyand Temperature

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ABSTRACT

The study was on the brain entropy and brain temperature. The study simply reviewed the research work of other researchers to arrive at a reasonable conclusion of how temperature can impair brain entropy. The brain is the central focus of mental health and the functionality of the brain is a function of brain entropy. The brain entropy is a function of brain temperature. The brain entropy is inversely proportional to temperature. It was discovered that removal of heat from the brain decreases the brain temperature which in turn enhances brain entropy. This heat removal from the brain can be achieved through increase in cerebral blood flow, decrease in intracranial pressure (ICP), increase in the cerebral perfusion pressure (CPP), increase in the blood vessels radius, increase in the heat conductivity of the tissue, short characteristic length and decrease in the blood viscosity and if $T_a << T$ i.e. the arterial blood temperature is much less than brain temperature, heat will be removed from the brain. The following were discovered to promote brain entropy enhancement: decrease in temperature, decrease in brain size, and increase in nerves density that gave compressibility to be less than one. Brain entropy is also enhanced when the deviation of internal variation from the equilibrium is small, the system maintain thermodynamic equilibrium signified high brain entropy (or decrease in the brain temperature). The brain efficiency is said to be 100%, if the brain is able to maneuver all the neurons in each of the cells to involve in information processing. The probability that the whole neurons are involved in the formation processing is 1, which is equal to the probability of the whole brain. The probability that all the brain nerves will be engaged in the information processing and transmission depends on the brain temperature. Entropy is then the ability of the brain to conveniently maneuver even the complex incoming disorder to get useful information and to relay the information through neurons for decision making. The entropy predicted by the Sackur–Tetrode equation approaches negative infinity as the temperature approaches zero (i.e. the brain attains black hole characteristics or Sun at its expiry period).

KEYWORDS: *Brain entropy, brain temperature, Cerebral Blood Flow and Cerebral Metabolic rate*

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1. INTRODUCTION

We cannot discuss mental health without employing brain functionality and its relation with temperature because brain is the central focus of mental health and the functionality of the brain is a function of brain entropy. The brain entropy is a function of brain temperature. The Brain as a part of the body and its temperature basically depend on and correlates with body heat temperature T^0 (Eugene, 2010). The normal body temperature, also known as normothermia or euthermia, is the typical temperature range found in humans. The normal human body temperature range is typically stated as $36.5^0C - 37.5^0C$ $(97.7^0F - 99.5^0F)$ (Karakitos et al 2008, Simmer 1988). When the body temperature is below or above the normal temperature it is called hypothermia or hyperthermia respectively. The brain hyperthermia which is the increase in brain temperature due to accumulation of heat in the brain because the heat cannot properly dissipate to the external environment due to the following:

- Increase in the body core temperature
- Decrease in the arterial blood flow
- Decrease in the heat removed from the brain

In summary hyperthermia is due to a combination of excessive heat production (metabolism) and insufficient heat loss.

The brain is the most important organ for an organism's survival being the part of the body that regulates physiological functions and behaviors. The brain regulates metabolism, cerebral blood flow, temperature, water and ions content of the body. The brain activity has been known to have connection with temperature and relationship between brain metabolic activity and temperature are always interactive, the brain cell metabolism is a major determinant of brain temperature and any minor change in brain temperature can result in significant changes in the neural cell metabolism and therefore in brain functions (Segolene M et al 2012). Changes in brain temperature could occur in temperature-stable environment, due to body exposure to other medium of heat production. The alterations in brain activity are the primary causes of intra-brain heat accumulation. Brain temperature can be induced by drugs that affect brain metabolism and heat dissipation to the external environment. Especially, drug that induced Hyperthermia and this could be neurotoxic. The effect of temperature induced drug is strong in environmental conditions that limit heat dissipation, thus resulting in pathological brain hyperthermia and this also depends on drug's dose and route of administration, the neuroactive drugs either increase or decrease brain temperature both within (35-39 ^{0}C) and exceeding the range of physiological fluctuations (Kiyatkin, 2013)

The brain contain 2% of human body mass and account for 20% of the human total oxygen consumptions at rest and all energy used for brain (neuronal) metabolism is finally transformed into heat (Squ 2012, Ire-Segolene, 2012). Therefore, intense heat production appears to be an essential feature of brain metabolism activity. Brain as a part of the body and its temperature basically depend on and correlates with heat body temperature T^0 (Eugene, 2010).

Although metabolic heat is intensively produced in brain tissue, it is effectively removed from the brain via circulation to the body and to the external environment and brain temperature remains relatively stable. The major cooling mechanism of the brain is inflow of colder arterial blood to the brain that comes from the lungs and outflow of warmer venous blood from the brain that travels again to the lungs and skin surface for dissipation to the external environment.

The inflow of colder blood to the brain and outflow of the warmer blood regulates the brain temperature (Laptook et al, 2001); thereby maintaining heat brain balance such that the brain baseline temperature can be maintained. So there is always compensation for any change in the brain baseline temperature. The excessive exposure to heat with impeded removal through the cerebral circulation can lead to accumulation of heat in the brain. When heat accumulation exceeds removal in the brain, temperatures may exceed 40 ^{0} C, and this will potentially impair the ability of brain to function e.g. the ability of soldiers and athletes to sustain normal work intensity (Dennis 2003, Nybol et al 2004, Rasmussen et al 2004, Palmer et al 2003)

While brain cells seem to tolerate well low temperatures, multiple studies suggest that high temperature (>40.0 ^{0}C) has destructive effect on the brain cells. The fluctuation in brain temperature is an important factor to determine the stage of brain health, even at stable ambient temperature, fluctuation can be experienced as a result of exposure to various temperature challenges, spontaneous changes in activity states of the brain and during different behaviors. Although changes in blood circulation seems to be an important factor that determines brain temperature fluctuations, neural activity and intra-brain heat production appears to be the primary cause of brain temperature increases.

Increase in brain temperature, is also responsible for greater blood flow, because more blood flow is needed for cooling process. The metabolic process usually accompanied by heat production and as well increase local temperature can result into great blood flow. Generally, increase in blood circulation that accompanies functional brain activity removes heat from brain, since the blood that circulates to the brain is colder than the brain temperature; therefore increase in the blood flow decreases brain temperature. The temperature of the perfusion arterial blood flow is normally lower than that of the brain, and blood flow through the brain is an important route of heat removal from the brain. So for brain temperature to be on the higher side, we need decrease in the blood flow. It is only when cerebral blood flow is markedly decreased that we can have increase in the brain temperature

Since some of the heat generated by the brain is removed by the circulation, it would be expected that a decrease in the cerebral flow could increase brain temperature (Christopher, 1998)

The brain temperature could exceed its normal physiological levels due to the following conditions:

- Intense heat production in the body (up to 10x). When the heat cannot dissipate outside, changes in temperature will be higher.
- When heat dissipation from skin is blocked, heat will accumulate in the brain and body and both temperature going up high level
- Drugs abuse: that increase metabolism and decrease heat dissipation.
- Extreme increase in the environmental temperature
- The arterial blood flow temperature increases higher than brain temperature.
- Changes in the brain temperature are therefore determined by the following:
- Neural Activity (brain activity)
- Brain Metabolism
- Thermal influence by the body
- Arterial blood flow

Temperature could be viewed as a factor that directly affects brain cells, neural activity, cerebral blood flow, permeability of brain-blood barrier, brain water, ion content, thus strongly modulated neural functions. Brain hyperthermia or brain temperature impact can be seen manifesting in a number of common human diseases including: head trauma, stroke, epilepsy, mood disorders, headaches, and neurodegenerative disorder (Huan et al, 2014).

Entropy is another quantity in our brain (Brain Entropy), which can be affected by temperature. The effects of temperature on human brain entropy can be positive or negative depending on the amount of temperature of the surrounding. Temperature is a physical quantity that measures the mean kinetic energy of the Vibrational motions of matter's particles. Its role is to control the transfer of energy between the system and other ones which it is thermally coupled. Temperature is an intensive property shared by all the constituents of a system and independent of system size. Together with potential energies of the particles, and other type of particles energy in equilibrium with these, it contributes to the internal energy within a substance. Temperature T is defined as the inverse of the entropy variationΔS, with respect to a variation of the energyΔE at fixed volume (David Papo, 2013).

$$-\frac{1}{T} = \frac{\partial S}{\partial E} \text{ .... } 2.10$$

Mean entropy decrease with increase in temperature and increase with decrease temperature. Entropy is inversely proportional to temperature. The brain Entropy decreases with increase in the temperature.

2. Method

We used mathematical Formulas to explain how the brain entropy can be affected by temperature and extent to which increase in brain temperature can damage brain entropy, brain information entropy, brain efficiency and the networkability of nerves cells.

3. Analysis

3.1. Mathematical Explanation (1): Brain temperature, Oxygen Extraction Fraction and Heat Removal

According to Alexander et al (2006):

If we consider the unchanging temperature of the arterial blood i.e. Arterial blood temperature does not change, then

$$T_b \rightarrow T_b^{'} = T_b + \Delta T \text{ .... } 1.1$$

$$\Delta T = T_m^{*}[OEF^{'} - OEF] \text{ .... } 1.2$$

$$T_b = T_a + T_m \text{ .... } 1.3$$

$$T_m = \mathrm{T_m^{*}} \cdot \mathrm{OEF} \text{ .... } 1.4$$

Where T_b is the brain temperature, ΔT define the amount of heat removed from the brain, OEF oxygen extraction fraction, T_a Arterial blood temperature and T_m defines the quantity by which brain temperature (T_b) exceeds arterial blood temperature(T_a).

From equation (1.4), if the oxygen extraction is high the T_m will increase that will lead to increase in the brain temperature. The amount of oxygen in the blood and the amount of oxygen extraction during metabolic process greatly determine the level of the brain temperature and brain entropy. Once brain functional activity changes, we expect changes in OEF either to activated or deactivated states and we at this time expect brain entropy to change due to the changes that occur in the brain temperature.

As blood flow increases in the activated region to a large extent than the oxygen consumption, the OEF decreases leading to the local decreases in the brain temperature. The fact is that when OEF decreases, the term in the bracket in equation (1.2) increases, then ΔT increases i.e. large amount of heat is removed from the brain resulting into decrease in the brain temperature equation (1.1). This will improve brain entropy. If the blood flow decreases in the activated region than the rate of oxygen consumption, the OEF increases leading to local increases in the brain temperature. The fact is that when OEF increases, the term in the bracket in equation (1.2) decreases, then ΔT decreases i.e. less amount of heat is removed from the brain resulting into increase in the brain temperature equation (1.1). These impair brain entropy.

Equation (1.1) can be expressed as

$$T_b = T_b^{'} - \Delta T \text{ .... } 1.5$$

As the OEF in equation (1.2) decreases, with increase in the blood flow, the heat removed from the brain by the blood flow increases. ΔT, defines the amount of heat removed from the brain. So, as ΔT increases, the brain temperature T_b in equation (1.1) decreases. So, brain entropy is enhanced. $\left(Brain\ entropy \propto \frac{1}{Brain\ temperature}\right)$

While increase in OEF in equation (1.2), with decrease in the blood flow, the heat removed from the brain by the blood flow decreases. ΔT, defines the amount of heat remove from the brain. So, as ΔT decreases, the brain temperature T_b in equation (1.45) increases. So, brain entropy is impaired. $\left(Brain\ entropy \propto \frac{1}{Brain\ temperature}\right)$

3.2. Mathematical Explanation (2): Cerebral Metabolic Rate of Oxygen, Oxygen Extraction Fraction, Cerebral Blood Flow and Arterial Oxygen Content

The equation

$$CMRO_2 = OEF \cdot CBF \cdot Ca \text{ .... } 1.6$$

$CMRO_2$, is the Cerebral Metabolic Rate of oxygen, OEF is the oxygen extraction fraction consumption in metabolism, CBF is the cerebral blood flow, Ca is the arterial oxygen content. From the above there is a strong relationship between the change in the cerebral flow (CBF) and in the cerebral metabolic rate of oxygen ($CMRO_2$). It was long assumed that changes in cerebral blood flow (CBF) and in the cerebral metabolic rate of oxygen ($CMRO_2$) are tightly related in both resting and active brain states (Mark A.M. et al., 2001). The mathematical models of oxygen delivery to the brain have been described in which disproportionally large increase in CBF is necessary to sustain even small increase in the ($CMRO_2$). The small increase in ($CMRO_2$) favors brain entropy positively with large increase in CBF, because the brain will have reduced temperature. When the brain surface is colder than the arterial blood flow or cerebral blood flow (CBF) brain entropy is positively enhanced, but when brain surface with higher temperature than the arterial blood flow or cerebral blood flow impact brain entropy negatively.

3.3. Mathematical Explanation (3): Fraction of Oxygenated Hemoglobin in the Capillary, Fraction of Oxygenated Hemoglobin in the Artery and Fractional Distance Down Capillary.

From equation

$$\Delta T = T_m^{*}[OEF^{'} - OEF] \text{ .... } 1.2 \text{ (repeat)}$$

$$S_c = S_a(1 - f_c \cdot OEF) \text{ .... } 1.7$$

The equation (1.2) is defined above, while equation (1.7) can be defined as follows:, S_c is the fraction of oxygenated hemoglobin in the capillary, S_a is the fraction of oxygenated hemoglobin in the artery, f_c is the fractional distance down capillary.

At the end of the capillary the oxygen content has been reduced by the total extraction or OEF.

Combine the two equations by mathematical manipulation we should have

$$\Delta T = T_m^* \left[OEF' - \frac{1}{f_c}\left(1 - \frac{S_c}{S_a}\right)\right] \quad \text{......} 2.51$$

- If the amount of S_a the fraction of oxygenated hemoglobin in the artery decreases with increase in arterial blood flow, $\beta = \left(1 - \frac{S_c}{S_a}\right)$ will decrease, then $\alpha = \left[OEF' - \frac{\beta}{f_c}\right]$ will increase, leading to increase in $\Delta T = T_m^* \alpha$. The brain temperature T_b decreases: from
$$T_b = T_b' - \Delta T.$$

The brain entropy is positively enhanced. The decrease in the oxygenated hemoglobin in the artery reduces metabolic heat production.

- If the amount of S_a, the fraction of oxygenated hemoglobin in the artery increases, $\beta = \left(1 - \frac{S_c}{S_a}\right)$ will increase, then $\alpha = \left[OEF' - \frac{\beta}{f_c}\right]$ will decreases, leading to decrease in $\Delta T = T_m^* \alpha$. The brain temperature T_b increases $\left(T_b = T_b' - \Delta T\right)$.

The brain entropy is negatively impacted (brain entropy is impaired). The increase in the oxygenated hemoglobin in the artery metabolic heat production thereby increases the brain temperature.

According to Alexander et. al (2006) "it was demonstrated that the task- induced temperature response with changed sign (from positive to negative) after brain tissue had been artificially heated and the brain surface baseline temperature became higher than the arterial blood flow temperature. When the brain surface is colder than the arterial blood flow or cerebral blood flow (CBF) brain entropy is positively enhanced, but when brain surface with higher temperature than the arterial blood flow or cerebral blood flow it impact brain entropy negatively.

The assumption that the fractional changes in the blood flow is always greater than the change in oxygen consumption leads to the conclusion that the sign of the temperature change is always opposite to the sign of blood flow change: when blood flow in the activated region increases, the temperature decreases, whereas when blood flow in the deactivated region decreases, the temperature increases.

The above 'Alexander' statement can be written as follow: The change in the brain temperature is opposite in sign to the change in blood flow, while the change in the brain entropy is proportional to change in blood flow. i.e. when the blood flow in the activated region increases, the brain temperature decreases, but the brain entropy increases (i.e. entropy increases with increase in the blood flow). While the blood flow in the deactivated region decreases, the brain temperature increases, but the brain entropy decreases (i.e. entropy decreases with decrease in the blood flow). The maximal temperature effect is reached in the extreme case when the blood flow changes (decreases) whereas oxygen consumption (Metabolic heat production) remains unchanged.

3.4. Mathematical Explanation (4): Heat Conductance within the Brain and Heat Exchange

Here we are considering heat conductance within the brain and heat exchange with the Environment. The Static Bio-heat equation will applies specific for brain.

$$K \cdot \nabla^2 T + q - q_r = 0 \quad \text{......} 1.8$$

Where,
First Term
$T = T_{(r)}$, describes the temperature distribution in the brain as function of position (r)
K, is tissue thermal conductivity
The second term
q, describes heat generated by metabolic process and is determined by the local blood flow, oxygen concentration $[O_2]$ in the blood and (OEF)-oxygen extraction fraction.

$$\boldsymbol{q = (\Delta H^0 - \Delta H_b) \cdot [O_2].\rho F.OEF} \quad \text{......} 1.9$$

Where, ρ is the tissue density
The third term
q_r, is the heat removed by the blood flow. Here, the assumption is that the blood temperature equilibrates with the tissue temperature in the capillary bed. This term is proportional to the temperature difference between arterial blood T_a and tissue T

$$\boldsymbol{q_r = \rho F \rho_b C_b (T - T_a)} \quad \text{......} 1.10$$

The temperature inhomogeneities in the brain have a characteristic length Δ depend on the blood flow F

$$\Delta = \frac{K}{(\rho \rho_b C_b F)^{\frac{1}{2}}} \quad \text{......} 1.11$$

Equations (1.10) and (1.11) can become

$$\boldsymbol{q_r = \left(\frac{K}{\Delta}\right)^2 (T - T_a)} \quad \text{......} 1.12$$

From equation (1.8) if $k = 0$, the tissue conductivity is ignored

$$q = q_r$$

The amount of metabolic heat generated, the same amount is removed from the brain by the blood flow.

From equation (1.10 or 1.12), if $T = T_a$, $q_r = 0$, the brain temperature is equal to Blood flow temperature. The brain and the blood flow will be at thermodynamic equilibrium with each other with temperature T or T_a, shows that blood flow removes no heat from the brain. The brain temperature remains constant. The brain temperature will be high because no heat is removed will lead to brain entropy degradation. If the degradation is severe it can lead to mental illness or ill-health.

The expressions: $q = \boldsymbol{q_r}$, $\boldsymbol{T = T_a}$, $\boldsymbol{(T - T_a) = 0}$, $\boldsymbol{\Delta T = 0}$, $\boldsymbol{\frac{\partial T}{\partial T_a} = 1:1}$ **and** $\boldsymbol{\frac{\partial q}{\partial q_a} = 1:1}$ are of the same expression.

$$\Delta T = T_m \left(\frac{OEF'}{OEF} - 1\right) \quad \text{......} 1.13$$

If the blood flow and oxygen Extraction Fraction (oxygen consumption) increases or decreases proportionally their ratio $\frac{OEF'}{OEF} = 1$ and $\Delta T = 0$. If there is no temperature change it means brain temperature remains unchanged. During changes in functional activity or activated region in deep brain region, change in temperature ΔT depends on the changes in the OEF (oxygen Extraction Region) with AFR (Altered-flow Region).

If $T_a << T$, heat will be removed from the brain. The brain temperature will be reduced reduced, it will leading to brain entropy enhancement.
From equation 1.12)

$$\boldsymbol{q_r} \propto \boldsymbol{K^2} \text{……………………………………}1.14$$

The heat removed from the brain is proportional to the square of the thermal conductivity of the tissue. The higher the thermal conductivity of the tissue, the greater will be the amount of the heat that will be removed from the brain. The thermal conductivity will also have effect on the brain entropy as it has effect on the brain temperature.

$$Brain\ temperature \propto \frac{1}{q_r}$$

The higher the thermal conductivity of the tissue, the larger the heat removed from the brain, then the lower the brain temperature. Since the brain entropy is inversely proportional to the brain temperature, the brain entropy is then proportional to the amount heat of removed from the brain.

$$brain\ entropy \propto q_r$$

The brain entropy is enhanced with decrease in the brain temperature followed by corresponding increases in the amount of heat removed from the brain which is just a function of the blood flow.
And

$$\boldsymbol{q_r} \propto \frac{\boldsymbol{1}}{\Delta^2} \text{……………………………………}1.16$$

The heat removed from the brain is inversely proportional to the square of the characteristic length. The characteristic length Δ defines the extent of the area, surrounding any specifically defined region of altered blood flow or heat generation. The region where blood flows or heat generation is altered is called "Altered-Flow Region (AFR). With the present of Altered-Flow Region (AFR) there exist inhomogeneity boundaries. The heat generation and blood flow differs when moving from deep brain region to brain surface region. Substantial temperature change will be observed in any specifically defined region of Altered Flow Region. The brain entropy will change in the two mediums of crossing. If the characteristic length is short, the heat removed will be high. But with the longer characteristic length, the heat that will be removed from the brain will be reduced. It might be possible that the blood might have acquired heat energy because of the frictional force between the flow and the capillary or there is reduction in the flow due to increasable characteristic length.

3.5. Mathematical Explanation (5): Cerebral Blood Flow, Cerebral Perfusion Pressure, radius of blood vessels, dynamic viscosity of the blood, length of the blood vessels and the Intracranial Pressure

Hagen-Poiseuille Equation for Laminar Flow (Alifia T et al., 2001). The laminar flow simply means that non-turbulent flow of the blood is assumed and that blood vessels assuming to be undergoing streamline flow in parallel layers (laminae)

$$CBF = \frac{\pi \Delta P r^4}{8\mu l} \text{………………………………………}1.15$$

Where
CBF, Cerebral Blood Flow
ΔP, the pressure gradient which is Cerebral Perfusion Pressure (CPP)
r, the radius of blood vessels
μ , the dynamic viscosity of the blood
l, the length of the blood vessels
π, the mathematical constant

The Intracranial Pressure (ICP) also plays an important role in the effectiveness of Cerebral Perfusion Pressure (CPP). Whatever that can cause changes in the Intracranial Pressure (ICP) or increase the ICP above a critical level is not tolerated because it results in a decrease in the Cerebral Perfusion Pressure (CPP) of the brain. Once there is decrease in the CPP, the Cerebral Blood Flow (CBF) decreases. Decrease in the CBF decreases the brain cooling process, the extraction of heat or removal of heat from the brain will be impaired. According to Rossi S (2001), the cerebral perfusion pressure (CPP) increases significantly by active cooling compared to the normothermic and hyperthermic groups.

Lack of active cooling process is due to reductions in the CBF that acts as heat removal from the brain. We expect that an increase in the ICP seen at the same time with the increase in the brain temperature is sustained by a rise in the cerebral blood volume. The numbers of psychiatric patients that we see to have positive association with the increase in the temperature may be due to the fact that increase in the temperature affects the ICP of the patients because change in temperature can affect potentiality of the intracranial pressure.

The ICP is the constant pressure in the brain box, which the volume of the content inside must be fixed i.e. the volume of the brain and the constituents inside the bony cranium must be fixed and not to be compressed. Increase in the relative humidity been measured by pressure ratio can increase the ICP by compressing it, and this compression can lead to reduction in the radius of the blood vessels which in turn reduces the cerebral blood flow.

Increases in the temperature and relative humidity have been seen to increase the ICP and increase ICP reduces the CPP ($i.e. \Delta P$). Increase in the ICP reduces the radius of the blood vessels. From the equation above we can see that:

$$CBF \propto \Delta P \text{ ………………………………………………………} 1.18$$

$$CBF \propto r^4 \text{ ………………………………………………………} 1.19$$

If the CPP decreases with increased ICP due to the increased temperature, the ΔP will decrease which decreases the CBF and if the blood vessels radius (r) reduces with increase in the ICP, the cerebral blood flow will decrease. The reductions of the cerebral blood follow due to decrease in the vessel radius and decreases in the CPP (or ΔP) will subject the body into hyperthermic conditions (extreme temperature), that can impair brain entropy leading to mental ill-health. Increase in the viscosity will reduce the CBF, because increase in the ICP reduces the radius of the blood vessels, this compresses the blood in the vessels thereby increasing the frictional forces between the blood constituents (i.e. Viscosity increases) that will reduce the flow of blood (the flow rate will be impaired). The rate of cerebral metabolic production will not correspond with blood flow, since there is reduction of blood flow due to viscosity, the heat removal will not be effective, and then heat will be accumulated in the brain that can lead to mental health.

3.6. Mathematical Explanation (6): Kinetic Theory

From the kinetic theory our brain has constituents which it is made up, and these constituents are made of molecules even the cerebral blood is made of molecules. During increase in the temperature these molecules in the brain can be subjected to higher motion due to increase in the pressure in the brain box. The non-turbulent blood flow can turn to be turbulent and couple with increase in the ICP; this can generate fluctuations in the distance between the brain neurons leading to neurotransmitters impairment. Also, if the turbulent situation of the blood flow is vigorously enough, it might likely exert over pressure in the blood vessels that can lead to the bursting of the brain blood vessel.

$$P = \sum n_\alpha k T_\alpha \text{ .... } 1.17$$

This is equation of imaginary box containing plasma at temperature T and taking brain molecules contained in the box of bony cranium to be n constituent of the brain. This is the sum of the pressure due to increase in temperature on each molecule, because each constituents of brain that were affected by the increase in the temperature will equally contribute to the brain pressure. From the equation, increase in the temperature increases the brain pressure (P =ICP). This signifies that there is an increase in the intracranial pressure (ICP), decrease in the cerebral perfusion pressure (CPP), decrease in the blood vessels radius (r), decrease in the cerebral blood flow (CBF), decrease in the brain heat removal, increase in the brain hyperthermic conditions, decrease in the brain entropy, decrease in brain entropy information and finally impairment of the brain or brain damage resulting into mental ill-health. It is also important to know that increase in temperature and relative humidity can enhance the intracranial tensions and create more difficulties in the brain functionality to those whose intracranial pressure is already raised.

3.7. Mathematical Explanation (7): Probability Distribution

So, we are seeking a probability distribution of states ρ_i that maximizes the discrete Gibbs entropy. (Jaynes 1965, Pasko et al 2018)

$$S = -k_B \sum_i \rho_i In \rho_i \text{ .... } 1.20$$

The probabilities of all states add to unity:

$$\sum_i \rho_i = 1 \text{ .... } 1.21$$

The probability distribution

$$\rho_i = \frac{1}{Z} e^{-\beta E_i} \text{ .... } 1.22$$

$$InZ\rho_i = -\beta E_i = -\frac{1}{K_B T} E_i \text{ .... } 1.23$$

The probability distribution will be affected by temperature increases.

The W, In Boltzmann's equation is a probability or number of real microstates in a system. In short, the Boltzmann formula shows the relationship between entropy and the number of ways the atoms or molecules of a thermodynamics system can be arranged. We can narrate the situations as follows:

- Macroscopic states – Brain as whole
- Microstates – Brain Cells
- Sub-States – Brain Nerves (Nerves in each Cells)

When all brain neuron involved in the information processing will have maximum brain entropy, the brain system is at equilibrium. A system assumes a configuration of maximum entropy at thermodynamics equilibrium; this is in accordance with the second law of "Thermodynamics". This simply means that all the brain neuron was activated and involved in the information processing task and the probability that all neuron involved in the information process is one.

Boltzmann gave a microscopic definition of the entropy as a logarithm of the number of microscopic states that share the values of physical quantities of the macroscopic state of the system

$$S = K_B \, InW \text{ .... } 1.24$$

And later, Gibbs gave another definition of entropy via probabilities of microscopic states of the system (Laudau et al 2011, Kittel 1958, Reif 1967, Feynman 1972).

The active states of the cells/neuron (microscopic state) determine the health of the brain (macroscopic state). If the probability distribution is affected by temperature increases we will expect that the probability that all neuron effectively participated in the task will be affected. The probability that the whole brain neuron will be involved in the information processing will decrease with increase in the temperature. A change of energy leads to the activation of many states (i.e. activation of neuron to performed task) and thus to a large change in the number of activated neuron quantified by entropy and that high temperature corresponding to low sensitivity of entropy to variation in energy.

If the whole neurons are involved or the brain is able to maneuver all the neurons in each of the cells during information processing, the brain entropy can be said to be efficient and effective. The probability that the whole neurons are involved in the formation processing is 1, which is equal to the probability of the whole brain. The entropy of the brain probability is 1 without any abnormalities.

The microstates of energy less than or equal to the macroscopic energy is allowed (Pasko 2018). It simply means the neurons energy dissipated in information extraction from a particular message cannot be more than the brain entropy energy. The probability that neurons involved in the functional activities of the brain during information processing is either less than or equal to the expected probability of the brain. If the probability is less than one the whole neurons are not involved in the information processing. If the neurons energy is less then, the full brain capacity is not utilized.

3.8. Mathematical Explanation (8): Entropy Define the Equilibrium and Non-Equilibrium of a Brain

We considered that Entropy defines the Equilibrium and Non-equilibrium of a Brain

The field of non-equilibrium statistical mechanics is concerned with understanding these non-equilibrium processes at the microscopic level and that the new idea key to non-equilibrium development was the replacement of the external thermodynamic environment by internal control (Hoover et al, 2005).

Let there be

- Constitutive variables $x_1, x_2, \dots, x_n$ that are used to fix the equilibrium state, considered to be stable
- A set of variables $\epsilon_1, \epsilon_2, \dots$ that are called *internal variables* determine the non-equilibrium state.

So the main property of internal variables is to measure the non-equilibrium of the system and their tendency to disappear from equilibrium; the local law of disappearing can be written as relaxation equation for each internal variable:

$$\frac{d\epsilon_i}{dt} = -\frac{1}{\tau_i}\left(\epsilon_i - \epsilon_i^{(0)}\right), i = 1,2, \dots \qquad 1.25$$

Where $\tau_i = \tau_i(T, x_1, x_2, \dots x_n)$ is a relaxation time of corresponding variables of ϵ_i. That is each of the constitutive variables $x_1, x_2, \dots x_n$ used to fix equilibrium has its corresponding internal variables $\epsilon_1, \epsilon_2, \dots \epsilon_n$ that can be used to define their corresponding relaxation time. It is convenient to consider the initial value ϵ_i^0 equal to zero (Pokrovskii, 2013)

We have

$$\frac{d\epsilon_i}{dt} = -\frac{\epsilon_i}{\tau_i}, i = 1,2, \dots, \qquad 1.26$$

If, $\tau_i \gg \epsilon_i$, $\frac{d\epsilon_i}{dt}$ negatively small, the variation of the internal variable over time is small, i.e. the non-equilibrium state is very small, the system is said to maintain is equilibrium. But if, $\tau_i \ll \epsilon_i$, $\frac{d\epsilon_i}{dt}$ is large, the variation of internal variable overtime is large, the thermodynamic system tend toward non-equilibrium.

We can relate this to the brain entropy which is measure of disorder in a system. Entropy of the system in non-equilibrium is a function of the total set of variables.

$$S = S(T, x_1, x_2, , x_n;\ \epsilon_1, \epsilon_2, \dots)$$

Equation above can be written in terms of entropy

$$\frac{d\epsilon_i}{dt} = -\frac{\epsilon_i}{S_i}, i = 1,2, \dots, \qquad 1.27$$

In terms of temperature, been inverse of entropy

$$\frac{1}{T} = \frac{1}{T}(T, x_1, x_2, , x_n;\ \epsilon_1, \epsilon_2, \dots)$$

$$\frac{d\epsilon_i}{dt} = -\frac{\epsilon_i}{S_i} = -\epsilon_i T_i, i = 1,2, \dots, \qquad 1.28$$

The internal variable in terms of chemical reactions appear to be measures of incompleteness of chemical reactions, i.e. it is the measures of how much the system of the chemical reactions is out of equilibrium (Pokrovskii 2005 and 2013). The internal variables in term of brain entropy appear to be the neurons. This is the microstates (neurons) that determine the states of the macroscopic system (brain). The brain entropy equilibrium is attained when all the neurons are in full participation in information processing. So, the numbers of neurons engaged by the brain determines the efficiency/deficiency of the brain.

If, $S_i \gg \epsilon_i$, $\frac{d\epsilon_i}{dt}$, negatively small, and if the temperature is small from equation (1.13), the rate at which the internal variation deviated from the equilibrium will be small, the system maintaining thermodynamic equilibrium signifies high brain entropy i.e. the brain system being a thermodynamic system keeps it equilibrium, this indicates that the entropy captures all the neurons during information processing. the rate at which the internal variable deviates from the total internal variable during or after information been processed is small. The possible number of neurons not engaged in the processing work is small. The brain is of high entropy, the brain entropy is said to tend toward equilibrium. The brain has little or no deficiency. If $S_i \ll \epsilon_i, \frac{d\epsilon_i}{dt}, negatively\ large$, and if the temperature is high from equation (1.13), the brain system as a thermodynamic system tends toward non-equilibrium, the internal variables i.e. neurons not fully engaged in the brain's activities.

The non-equilibrium state of the brain can be regarded as brain disorderliness i.e. mental disorder and other related mental illness such as: psychosis, schizophrenia, depression epilepsy etc. Drug abuse or alcoholic usage can cause neurons disorder because the usage can exacerbate brain temperature without corresponding heat dissipation resulting into hyperthermia that can cause mental illness (organic mental).

The brain information capacity is related to brain entropy. The brain entropy is the process of how information is spread in the nerve connectivity of the brain i.e. degree at which brain engaged the brain neurons during its activities i.e. information processing. According to Christian (2018), Basic Neuroscience teaches us how individual brain cells communicate with each other, and is a vital part of brain.

The neuroscientists also deal with information processing that happens within and between neutral networks across the entire brain. So the information processing that happens within and between neutral networks across the entire brain led to the importance of brain entropy. When information can be processed with the engagement of nearly all the nerves in the brain, the brain system is said to be equilibrium, signifying high entropy. High temperature reduces brain entropy, the information process capacity will be low. The brain has low degree of processing information i.e. there is impairment of brain, leading to mental health. Not all nerves can be connected, or there is breakdown in the nerves connectivity network. Since Nerves are signal processors across the entire brain, at high temperature the nerves can become abnormal and malfunction, leading to noise in the brain. This might be the cause of sudden madness, hallucination. We have heard of cases where people run mad complaining of hearing noise or strange voice in their brain. All these are due to connectivity break down of the nerves network. Even the computer system sometime break down when the temperature is high, affecting the electronic connectivity, damage some chips that will lead to malfunctioning of the computer, not able to sense signal, access printer or receive commands etc. At low temperature, we have high entropy according to the equation above, signifying high equilibrium. The information process across the brain is fully connected to all brain's nerves. At low temperature there is interaction between the molecules of the nerves. The brain system is now behaving like non-ideal or quantum gas. The entropy energy is now in quantize or discrete package of energy rather than the continuous flow of energy. The nerves can easily process the information in terms of quantum energy dissipated and spread by the entropy and send the information in term of quantum energy to other nerves maintaining the chain of connectivity to billions of brain's nerves.

3.9. Mathematical Explanation (9): Sackur-Tetrode Entropy

The Sackur–Tetrode entropy S equation can also be conveniently expressed in terms of the thermal wavelength Λ:

$$\frac{S}{kN} = In\left[\frac{V}{N\Lambda^3}\right] + \frac{5}{2} \text{ ....} 1.29$$

where V is the volume of the gas, N is the number of particles in the gas, U is the internal energy of the gas, k is Boltzmann's constant and In is the natural logarithm. It has been stated that low temperature enhances brain entropy. What then will happen to brain entropy as the temperature approaches zero? From equation (1.29) the validity of Sackur-Tetrode equation occurs at

$$\frac{V}{N\Lambda^3} \gg 1$$

But if, $\frac{V}{N\Lambda^3} \ll 1$, **the** entropy will turn to negative infinity, this also is abnormal. As low temperature is approaching or temperature tending toward zero the Sackur-Tetrode equation begin to break down and the brain system being a thermodynamic system begins to behave as a quantum gas. By referring to quantum mechanical state in system, it turns out that if one can count the number of quantum mechanical states available to a system at given (fixed) energy- in other words, counting all the possible configurations that result in the same total energy, the entropy is proportional to log of the energy (Tom, 2013). The entropy predicted by the Sackur–Tetrode equation approaches negative infinity as the temperature approaches zero. Just like the Sun at maxima entropy becomes dead star or black hole. Sun at Maximal entropy will then begin to behave like black hole of high gravity, it will swallow all objects or energy or signal but will not allow any substance to escape, not give out energy again. In relation to brain entropy at a negative value it can absorb information but not process it or neither can information escape from it. The signal is stored in the brain but cannot relay the signal. The absolute zero corresponds to the theoretical state in which particles have no energy at all (Zeeya, 2013), since entropy is inversely proportional to temperature, the entropy will be at infinity at zero temperature. Like the Sun that will reach maximal entropy after expirations of its energy. At point of high entropy no energy shall be dissipated again. Moving into sub-absolute zero ream matter begins to display odd properties (Philippa et al, 2013). The fact that low temperature required is required for proper brain entropy enhancement, while temperature lower than normal or brain baseline temperature can bring adverse effects. Once brain has completed a particular task, it has used the normal entropy required for the tasks, no energy dissipation after completing the task.

3.10. Mathematical Explanation (10): The Compressibility Factor (Z)

The ideal gas law describes how gases vary with temperature and pressure, but most gases exhibit non-ideal behaviors and gas compressibility factor is used to quantify this difference between real and ideal gas (Army 2018, Ynnus et al 2004, Smith 2005)) i.e. the deviation from the ideal gas behavior can be quantified (Zucker, 2002) or described by a dimensionless quantity, a parameter called the compressibility. This can be used to explain the condition of high and low entropy. The Compressibility Factor (Z) is simply the ratio of the Molar Volume of the gas to the molar volume of an ideal gas at the same temperature and pressure.

$$\boldsymbol{Z} = \frac{\boldsymbol{V_m}}{\boldsymbol{V_m^0}} \text{ ....} 1.30$$

Where, V_m, Molar Volume of the Gas and V_m^0, Molar Volume of an ideal Gas

The molar volume is the inverse of number of particles per unit volume. This can be translated to number of neurons per unit volume, which is the neuron density. The compressibility can be expressed as follows similar to (Liley P.E 2011)

$$\boldsymbol{Z} = \frac{\boldsymbol{V_m}}{\boldsymbol{V_m^0}} = \frac{\boldsymbol{\rho_m^0}}{\boldsymbol{\rho_m}} = \frac{\boldsymbol{RB_m}}{\boldsymbol{RB_0^m}} = \frac{\boldsymbol{T_m}}{\boldsymbol{T_m^0}} = \frac{\boldsymbol{S_m^0}}{\boldsymbol{S_m}} \text{ ....} 1.31$$

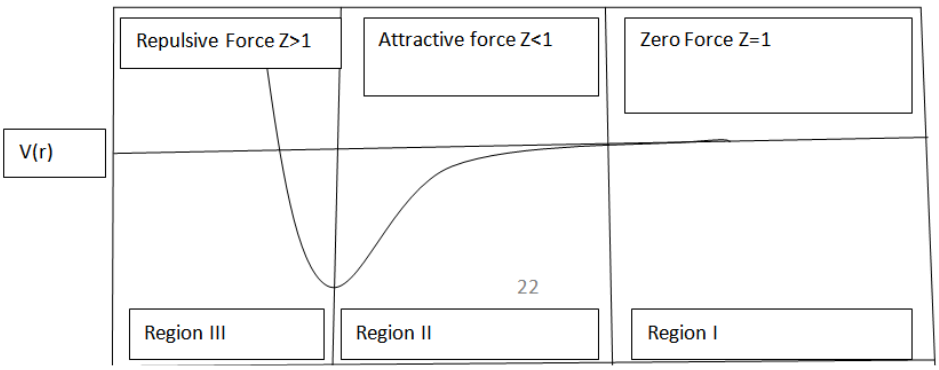

Figure 1.1: Potential and Compressibility Curve

- Increase in temperature, increases Relative Brain size (RB_m), decline in Nerve density (ρ_m) and decrease in the entropy (S_m) gives

$$Z > 1$$

From the potential curve above, it is repulsion force-no potential molecular attraction: ideal gas situation (McQuarrie (1999). The distance between the molecules of the neuron is sufficiently of great distance compared with size of the neuron. Even when brain size increases, the distance between neuron to neuron may increase. From equation 1.18) this is Low entropy. Analogically, the nerves or neurons are repulsive; spreading of information and the ability of the brain to coordinate received information or signal and integrate them is impaired. This kind of entropy is meant to process message that contains information with little uncertainty i.e. low disorder system or system with regularity and orderliness. Low entropy is needed for such message because it is more compressible, easy to manipulate or easy to comprehend (Samuel et al, 2014).

- Decrease in temperature, decrease the brain size, and increase the nerve density, gives

$$Z < 1$$

From the potential curve above, it is attractive force- that is potential molecular attraction: Thermodynamics quantum gas or non-ideal gas situation (McQuarrie D A 1999, Amy Lange 2018). This is higher entropy. Analogically, the nerves or neurons undergo force of attraction on each other; spreading of information and the ability of the brain to coordinate received information or signals and integrate them are enhanced. This kind of entropy is meant to process message that contain information with high degree of uncertainty i.e. high degree of disorderliness system or system with irregularity, chaotic and disorderliness. Higher entropy need to process such message that contain information with high degree of uncertainty because it is not easily compressible, not easy to manipulate or non-easy to comprehend (Samuel et al, 2014)

- When there are constant temperature, constant brain size, and constant nerves density

$$Z = 1$$

No change in entropy, the rate of change in entropy is zero, since the energy transfer depends on the temperature then the rate of energy transfer with respect to temperature will be zero

$$\frac{\partial Q}{\partial T} = dS = 0$$

No interaction between the nerves (even the nerves molecules), no connectivity between the nerve and no spread of information. The information received will be like pool of water stagnated, even with channel of flowing, it cannot still flow because no energy (kinetic energy) or force to make it flow. Temperature have vital role to play in human mental health as one of the major climate parameters. Since increase in temperature can reduce brain entropy, then temperature at extreme level impair entropy resulting into mental health disorder. Also Glenn (2018) gives similar illustration of order and disorder, to see how regular and irregular in the series, i.e. is the series ordered or disordered? Perfectly ordered series $(5,5,5,5 \cdots\cdots), (5\ 3, 5\ 3,5 \cdots) \ (5414, 5\ 4\ 14, 5)$ given the value of 5 preceeding and ensuring sequence are perfectly predicable. The entropy of highly predicable series is small, close to zero, indicating lack of variation or disorder. With unpredictable series such as $(3{,}109, 7, 5 - 22\ \cdots)$ given the value 5, the rest of the series are difficult to predict. The entropy of unpredictable series is large, indicating a high amount of variation or disorder. Entropy is then the ability of the brain to conveniently maneuver even the complex incoming disorder to get useful information and to relay the information through neurons for decision making.

Neurons are in principle able to relay larger quantities of information (Alexander et al., 2011) and information is defined in terms of entropy as a measure of uncertainty or freedom of choice when selecting message (Alexander G.D et al., 2011). Brain entropy can be seen as a measure of a shortest computer program that can encode and reproduce stimuli or signal.

Every message contains information. How much information contained in a message and the quantities of information that can be extracted from the message is an important factor in determining the ability of the brain to process information from a given message. The Brain information entropy quantifies the information contained in a message.

3.11. Mathematical Explanation (11): Brain Information Entropy

Information entropy quantifies information contained in a message (a sequence) sample from X, whereas I(X) is the information content. The surprise,

$$I(x_i) = -\log_2 p(x_i) \ldots\ldots 1.35$$

Quantifies the information conveyed by occurrence of event x_i (Jin, 2014).

For every message, there is uncertainty, as the information is being extracted from the message, the uncertainty reduces. The primary objective of the information entropy is to reduce uncertainty. As the uncertainty in the message is reducing the events become easily predicable i.e. extraction of information from the signal message reduces the uncertainty.

Let I(X) be the information content contain in a sample X, and $\left(I(x_i)\right)$ information entropy or the surprise from particular uncertainty with probability $p(x_i)$

$$I(x_i) + \log_2 p(x_i) \neq 0 \ldots\ldots 1.32$$

$$Ix_1 + Ix_2 + Ix_3 + Ix_4 + Ix_5 + \log_2 p(x_i) = I(X) \neq 0 \ldots\ldots 1.33$$

The possible events of Discrete Radom variable X of the information entropy $x_1 \cdots x_2$

$$I(X) - [Ix_1 + Ix_2 + Ix_3 + Ix_4 + Ix_5 + \log_2 p(x_i)] \neq 0 \ldots\ldots 1.34$$

Information entropy of every event will be added to the previous information entropy, thereby decreasing the total information content I(X) contained in a message. The increase in the additional information entropy reduces the uncertainty, while the brain entropy required to process information of remaining uncertainty reduces. Temperature serves as quantity to reduce uncertainty in order to reduce entropy while the energy released by the brain during information extraction or processing increases. The energy released is equivalent to the brain entropy energy used up. In everyday usage, the word "information" refers to the amount of novelty transmitted in a message – data that enables us to choose among alternatives.

In its quantitative, technical meaning, the information in a message refers to the reduction in uncertainty associated with a presupposed probability distribution of possible events. In this sense, information is a function of both the contents of the message and of an *a priori* assumption concerning the relative likelihood of possible events (Marshall, 2011)

A low probability event has a high surprise measure. In an event sequence, if events are predictable, the uncertainty of the event is low and thus the information entropy of this sequence is low (Jin, 2014). The probability that message contain information

$$p = \frac{1}{W} \quad \text{……………}1.36$$

$$W = 10^{\frac{E}{KT}} \quad \text{……………}1.37$$

If,

$$P = \frac{1}{W} = 10^{-\frac{E}{KT}} \quad \text{……………}1.38$$

Thus, when the data source has a lower-probability value (i.e., when a low-probability event occurs), the event carries more "information" ("surprisal") than when the source data has a higher-probability value. Increase in the brain temperature increases the probability value i.e. the probability increases with temperature because uncertainty decreases with increased temperature and probability is inversely proportional to the uncertainty. The information entropy decreases, because with decrease in the uncertainty, decrease in the uncertainty means less information will be extracted, decrease in the information entropy i.e. the probability increases with temperature because uncertainty decreases with increased temperature and probability is inversely proportional to the uncertainty. For an event to be highly predictable meaning: (i) The event uncertainty is low (ii) The probability of the message contained in the information is high (iii) The information entropy is low.

As the temperature increases, the number of active microstates or uncertainty reduces. If the Information content increases with increase in the number of uncertainty, then information content in message will decrease with increase in temperature. The information entropy can be impaired also with increased temperature.

From above it was said that Entropy is then the ability of the brain to conveniently maneuver even the complex incoming disorder to get useful information and to relay the information through neurons for decision making and neurons are in principle able to relay larger quantities of information (Alexander et al 2011). Also, from the above entropy is a function of macroscopic state (Pasko et al 2018). Information entropy must have profound relation with the neuron, since neurons are in principle able to relay information. Therefore the ability of the brain to involve the whole neurons in processing and transmitting information defines the entropy of the brain. The more of the neurons involved, the greater will be brain information entropy. If we regard brain as a macroscopic system and neurons as a microscopic state (although cells lying with the brain and neurons lying within the cells), but we regard cells as microstates contained in the brain macroscopic state while the neurons can be regarded as sub-microstates in the brain macroscopic system. For simplicity the whole neurons (billions of Neurons in whole brain) can just be taken as microstates contained in brain macroscopic system

3.12. Mathematical Explanation (12): Brain Efficiency

Efficiency of the brain can be defined as:

$$\eta(x_i) = \frac{\sum \rho(x_i)\log_b \rho(x_i)}{\log_b n} \quad \text{……………}1.39$$

x_i, number of neurons that participated in information processing,i, 1,2,3……..,n

n, total number of nerves or neurons in the brain

$\sum \rho(x_i)\log_b \rho(x_i)$, This is the Entropy that particular number of neurons participated in the information processing.

$\log_b n$, This is the maximum Brain Entropy.

If all the brain nerves are engaged in processing information, then we have

$$\sum \rho(x_i)\log_b \rho(x_i) = \log_b n \quad \text{……………} 1.40$$

The efficiency is 100% if not it will be less than 100% i.e. not all brain nerves are involved in the information processing. The 100% efficiency can be referred in a situation when all brain cells and nerves are involved in the information extraction and transmission. Since the increase in temperature can affect probability distribution of nerves system and numbers of nerves involved in the information processing, the brain efficiency cam be impaired by the increase in temperature.

The probability that all the brain nerves will be engaged in the information processing and transmission depends on the brain temperature. In information theory, entropy is the measure of the amount of information that is missing before reception and is sometimes referred to as Shannon entropy that studies the amount of information in a transmitted message.

4. Discussion and Findings

The change in the brain temperature is opposite in sign to the change in blood flow, while the change in the brain entropy is proportional to change in blood flow i.e. when the blood flow in the activated region increases, the brain temperature decreases, but the brain entropy increases with increase in the blood flow. While the blood flow in the deactivated region decreases, the brain temperature increases, but the brain entropy decreases with decrease in the blood flow. If $T_a << T_b$ i.e. the arterial blood temperature is much less than brain temperature, heat will be removed from the brain. The brain temperature is reduced, leads to brain entropy enhancement. The heat removed from the brain is proportional to the square of the thermal conductivity of the tissue. The higher the thermal conductivity of the tissue, the larger the heat removed from the brain, then the lower the brain temperature. Since the brain entropy is inversely proportional to the brain temperature, the brain entropy is then proportional to the amount of heat removed from the brain. The heat removed from the brain is inversely proportional to the square of the characteristic length. If the characteristic length is short, the heat removed from the brain will be high. But with the longer characteristic length, the heat that will be removed from the brain will be reduced. When characteristic length is short brain entropy will be enhanced. It was discovered also that increase in the intracranial pressure (ICP), decrease in the cerebral perfusion pressure (CPP), decrease in the blood vessels radius (r), decrease in the cerebral blood flow (CBF), decreases heat removed (ΔT) from the brain leading to increase in the brain hyperthermic conditions which eventually leads to decrease in the brain entropy and brain entropy information. These entire phenomenon (ICP, CPP, CBF, r andΔT) were factors or parameters that can cause brain impairments or brain damage tending toward mental ill-health. If the whole neurons are involved or the brain is able to maneuver all the neurons in each of the cells during information processing, the brain entropy can be said to be efficient and effective. The probability that the whole neurons are involved in the information processing is 1, which is equal to the probability of the whole brain. The entropy of the brain probability is 1 without any abnormalities. The probability that all the brain nerves will be engaged in the information processing and transmission depends on the brain temperature. In information theory, entropy is the measure of the amount of information that is missing before reception and is sometimes referred to as Shannon entropy that studies the amount of information in a transmitted message. As the rate at which the internal variation deviated from the equilibrium is small, the system maintains thermodynamic equilibrium signifying high brain entropy. The entropy predicted by the Sackur–Tetrode equation approaches negative infinity as the temperature approaches zero. Decrease in temperature, decreases the brain size, and increases the nerve density, gives compressibility to be less than one($Z < 1$). The message is not easily compressible or coded or decoded. Higher entropy is then demanded to extract useful information from the message. Entropy is then the ability of the brain to conveniently maneuver even the complex incoming disorder to get useful information and to relay the information through neurons for decision making.

5. Conclusion

The following factors/parameters determine the functionality of the brain entropy and any significant fluctuation of these parameters will lead to fluctuation in the brain entropy functionality.

- Oxygen extraction fraction
- Blood flow
- Metabolic heat production (oxygen consumption)
- Thermal Conductivity of the Tissue
- Characteristic Length
- Ambient Temperature
- Altered-Flow Region
- Relative humidity
- Brain size
- Nerve density

Whatever affects the brain temperature, affects brain entropy most especially those activities that can escalate brain temperature. For example: Increase in metabolic production (or increase in oxygen consumption or increase in oxygen fraction) without corresponding increase in blood flow increases brain temperature and decreases the functionality of the brain entropy. Generally the above listed parameters will to some degree affect brain temperature through their activities which in-turn affects brain entropy. Brain functionality is a function of brain entropy and this brain entropy depends on the brain temperature. The brain temperature can be varied with the brain metabolic rate, blood flow or cerebral metabolic rate, body temperature and ambient temperature. High (or elevated) temperature impairs brain entropy and in turn disrupts brain functionality. The increasing temperature affects the neurons functionality to process and transmit signals. The ability of the brain to extract or process information (brain information entropy) from a given message or uncertainty can be greatly impaired as the brain temperature increases. The impairment of brain entropy, brain functionality, brain information entropy can generate any of the mental health illnesses such as: psychosis, schizophrenias, depression, epilepsy, drug abuse etc. Therefore the role of temperature in the occurrence of mental illness cannot be ignored and that climate change or extreme weather events are another factor that can elevate or exacerbate ambient temperature.

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