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P6_1 Increase in Human Brain Power as a Result of Cranial Frill Cooling

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Abstract

This paper outlines the effects of having a small cranial crest of frills containing thin blood vessels to aid with cooling of blood from the brain. We have calculated the increase in brain temperature that such a crest would facilitate to be $1.97°C$ which corresponds to an increase in brain power of $83W$ or 689%. We have commented on the biological implications of this and deduced that in terms of physics this is a viable mechanism.

Introduction

In the popular science fiction universe Revelation Space [1], a faction of humans called the Conjoiners have augmented their brains to increase processing power and memory in order to have technological and intellectual superioty over the other human factions. As this increased brain power produces heat in excess of a normal human brain these Conjoiners have changed their cranial structure to include a crest of frills which act to increase heat loss and prevent their augmented brains from overheating.

In this paper we apply some simple calculations to measure brain power increase when introducing a simple cranial crest, we do not discuss the feasibility of such human modification.

Calculations

We shall consider a crest of frills through which all blood from the brain flows before returning to the body; the only function of the crest being to act as a heat sink for this heated blood. To examine the effects of having such a crest we first must consider the current heating effect the brain has. It has been estimated that the brain consumes $12W$ [2] of power, P, normally, and we can safely assume the vast majority of this is converted into heat, as the brain does not produce significant amounts of energy in any other form. Given some physical quantities we can relate this to a temprature difference between blood entering the brain and blood leaving the brain, $\Delta T_{blood} = T_{out} - T_{in}$, where T_{in} and T_{out} are the temperatures of the blood going into and out of the brain respectively. For our calculations we will assume $T_{in} = 37°C$ [3].

The volumetric blood flow rate F through the brain is given as $700 ml min^{-1}$ [4] or $1.17 \cdot 10^{-5} m^3 s^{-1}$ and the blood specific heat capacity c_b as $3600 J K^{-1} kg^{-1}$ [5]. We also take the density of blood to be $\rho_b = 1060 kg m^{-3}$ [6]. Assuming a Conjoiner must also have their value of T_{out} to be similar to that of an average human, we first calculate T_{out}.

$$T_{out} = T_{in} + \frac{P}{\rho_b F c_b}. \tag{1}$$

The third term in Eq. 1 is the change in temperature of the blood which is represented by the power of the brain over the specific heat of blood per unit volume multipled by the flow rate. Using our given values, Eq. 1 returns a value for T_{out} to be $37.25°C$ and this is now assumed to be the temperature that is safe to return to the body. Based on the descriptions of these Conjoiners in the books, we will assume the frills have a total volume of $V = 2.5 \cdot 10^{-4} m^3$, and a surface area of $A = 0.1 m^2$, and that the frills are comprised of many blood vessels of diameter $5 \cdot 10^{-3} m$.

The rate of change of temperature of a blood element in the frills is then given by,

$$-\frac{dT}{dt} = \frac{1}{mc_b} \frac{dQ}{dt}, \tag{2}$$

where $dQ/dt = kA\Delta T$ is the amount of thermal energy radiated per unit time t and m is the mass of blood in the frills. ΔT is simply $T - T_{air}$, T_{air} representing the temperature of the air, assumed to be $10°C$, and k is the thermal radiation constant for human skin, which we take to be $27.3 W K^{-1} m^{-2}$ [7].

Eq. 2 is a simple differential equation with a solution of $T = T_{air} + Ce^{-\frac{kAt}{\rho V c_b}}$, where the constant C is found by setting $t = V/F$, the time taken for blood to pass completely through the frills. We then set $T = T_{out}$ as we calculated this temperature to be safe for return in to the body and hence this gives $C = (T_{out} - T_{air})/e^{-\frac{kA}{F\rho c_b}}$.

Now we can then calculate the temperature of blood between the brain and the frills, T_{mid} by substituting the constant back into the solution for Eq. 2 and setting $t = 0$:

$$T_{mid} = T_{air} + \frac{T_{out} - T_{air}}{e^{-\frac{kA}{F\rho c_b}}}. \tag{3}$$

Eq. 3 then returns a value for T_{mid} to be $38.97°C$. Substituting T_{mid} into $P = (mc_b \Delta T_{blood})/t$, where ΔT_{blood} now represents $T_{mid} - T_{in}$ we can finally calculate the new power consumed by this augmeted brain as $P = 95W$, an increase of $83W$ or 689%.

Conclusion

It is difficult to measure brain processing capability, and even more difficult to relate this to the heat output of the brain. As such we cannot conclude whether such cooling frills would be capable of improving brain function; however we can conclude that even relatively small frills do give a considerable increase to the amount of heat the brain can safely generate. Despite our calculated blood temperature of $38.97°C$ being considerably above normal core temperature for a normal human, it has been shown that primate brains can survive prolonged exposure to a temperature of $44°C$ with no signs of obvious irreversible changes [8].

References

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