Breath-holding cools the human brain

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Target audience

Physicists working in MR thermometry, physiologists, and clinicians studying therapeutic brain-cooling.

Purpose

Brain temperature is known to be promptly down-regulated in a wide variety of animals in response to environmental stress. In diving animals it presents by way of a constellation of neuroprotective reflexes known as the dive response. Breath-holding (apnea) is a vital component for manifestation of this response.[1] The aim of this study was to determine if apnea in humans can cool the brain.

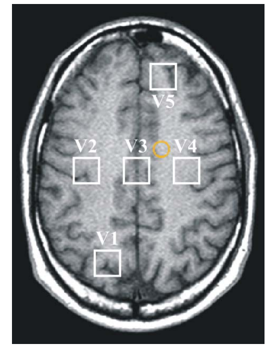

Fig.1: Voxel's positions.

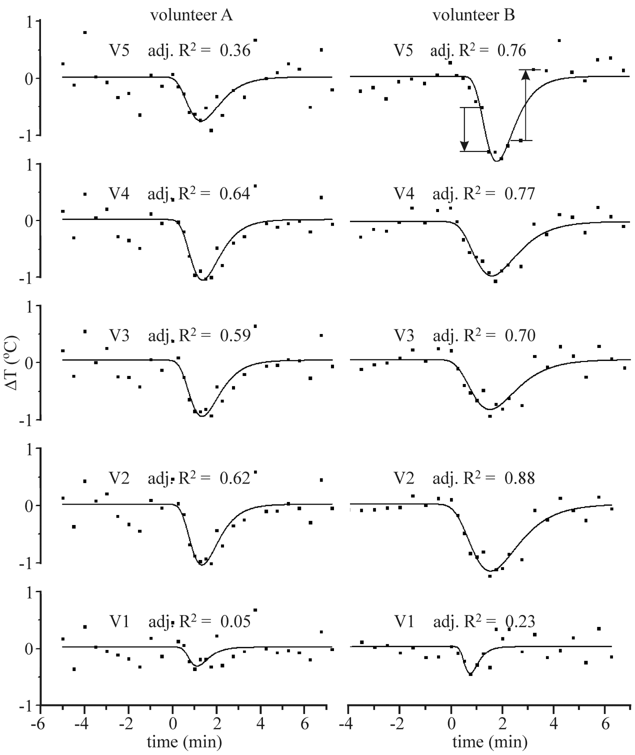

Fig.2: Brain temperature changes of two volunteers during apnea. Figure 1 shows voxel positions. Apnea started at the time t = 0 min.

Methods

Four experienced breath-hold divers and one normal volunteer participated in this study. Median age of volunteers was 43 years (range: 30–49). Brain temperature changes were monitored using a phase-difference method[2] on a 1.5 T scanner (Achieva, Philips). 2D rf-spoiled gradient echo sequence was applied (FOV 280×280 mm; acquisition matrix (256, 128); TR/TE 40/6 ms; slice thickness 6 mm; bandwidth/pixel 125.4 Hz; 2 acquisitions). Magnetic field homogeneity was improved by first order shimming. The experiment began with normal breathing together with 8-10 baseline records. Subjects initiated an apnea after a partial exhale to functional residual capacity (time, t = 0 min); apnea lasted from ca 30 to 105 sec. Mean phase was averaged from the voxels V1-V5 (15×15 pixels) (Fig. 1). After corrections for magnetic field drift caused by shim heating effects,[3] temperature changes were computed using the brain-water chemical shift coefficient -0.019 ppm/°C.[4] Temperature changes ΔT were fitted by a function $y = y_0 + A\exp[-\exp(-z)+z+1]$ where y_0 is offset; $z = (x - x_c)/w$; A, w, x_c are amplitude, width, and peak position, resp.

Results

Figure 1 depicts voxel positions V1-V5. Representative brain temperature changes of volunteer A (left panel) and B (right panel) are shown in Fig. 2. During apnea brain temperature decreased about 1 °C in ca 70-80 seconds in voxels V2-V4 and returned to baseline upon termination of apnea. Random, reversible movements of the head were the reasons for higher dispersion of the brain temperatures of volunteer A. Irreversible artefacts involving the stepwise reduction or increase in relative brain temperatures (arrows) can be seen in the frontal lobe of volunteer B. These discontinuities originated from involuntary rotation of the head in feet-head direction. Rotational movement of the head was less pronounced in the region close to the rotation axis (voxels V2-V4). Hence, only temperatures originating from voxels V2-V4 were considered. Figure 3 shows relative temperatures at the end of apnea. Each experiment represents three temperature points from voxels V2, V3, and V4. From Fig. 3, it follows that apnea decreases brain temperature by -0.6±0.1 °C/min at $0.3 \leq t < 1.1$ min. Brain temperature reaches plateau -1.0±0.1 °C at t > 1.3 min.

Discussion

Previous studies indicate that deep brain temperature, T_b, depends mainly on, metabolic heat production, temperature of incoming arterial blood, T_a, and heat removal by cerebral blood flow (CBF).[5] If over a brief period of apnea heat-exchange with the environment is neglected, the equilibrium between heat production and removal results in $T_b = T_a + T_m$, where T_m is the temperature shift caused by metabolic heat. We hypothesize that human brain cooling during apnea is caused by a decrease in metabolic heat production and increase in heat removal by CBF. This effect is triggered by apnea per se, and probably accentuated by the depletion and accumulation of blood O_2 and CO_2, respectively.

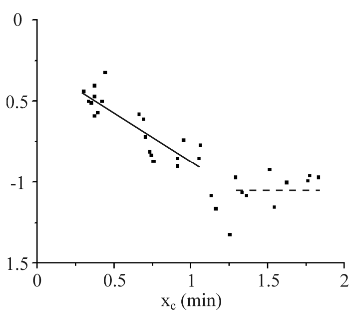

Fig.3: Amplitude (A) of the relative brain temperature at end apnea (x_c).

Conclusion

The simple act of breath-holding decreases human brain temperature by ca 1 °C in ca 70-80 sec. The response is prompt, and reversible. This study demonstrates, for the first time, that humans, like other diving mammals, have an in-built neuroprotective capability to promptly down-regulate brain temperature in a non-pathologic manner. Further studies are needed to clarify the mechanisms behind this phenomenon.

References

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