WEARABLE NON-INVASIVE MONITORING OF INTRACRANIAL BRAIN MOVEMENT
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INTRODUCTION
The skull and the vertebral canal, along with the relatively inelastic dura, form a rigid container. The human brain resides inside this container with buoyancy and protection from the cerebrospinal fluid (CSF). Within this container, the brain actually floats in the CSF, reducing its actual weight of about 1400 grams to a weight of about 25 grams in the CSF suspension. Thus, the position of the floating brain within the intracranial space can vary (within several millimeters). We have recently demonstrated via Monte Carlo simulations that near-infrared spectroscopy (NIRS) can be highly sensitive to the depth at which brain tissue resides below the scalp surface. NIRS measurements during brain motion, however, are historically challenged by the similarly high sensitivity of NIRS to motion artifacts. Using our unique NIRS instrumentation, probe design and novel scalp/skull interference cancellation techniques, our preliminary tests suggest that it is possible to make NIRS exceptionally sensitive to shifts of brain position within the skull with simple body position changes or mild head movement.

METHODS
We have developed the NINscan series of wearable NIRS-based tissue hemodynamics monitors. Powered by three AA batteries, they record systemic and cerebral hemodynamics, acceleration and ECG continuously at a 250Hz sample rate for 24 hours. Using a sensor pad and experimental procedure designed to eliminate motion artifacts, we performed several head movement tests using NINscan, including nodding, ear-to-shoulder, and shaking. After cancellation of the superficial layer hemodynamic interference (from scalp and skull), we compared the intracranial hemoglobin concentration (proportional to volume of the brain within specific NIRS probing area) with the tri-axial accelerometer readings and quantify the intracranial brain movement.

RESULTS
Our preliminary results show that our NINscan devices and sensor—when combined with a novel physics model for light propagation in the head and suitable experimental procedures—can be made highly sensitive to motion of the brain inside the skull (Figure 1). The linear regression of intracranial HbT vs. acceleration gave Pearson correlation coefficient of \( r = -0.91 \), sensitivity (slope) = -3.5μM/g, and \( p<10^{-20} \). Our device is also selective to the direction of motion (Figure 2).

DISCUSSION
Once we validate a noninvasive, easy-to-use and sensitive index of the brain’s movement inside the skull, we will have a useful tool not only to potentially help investigate intracranial pressure and VIIP in spaceflight, but also for diagnosis and treatment of diseases such as brain edema, hemorrhage, tumor and particularly traumatic brain injury.

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