

fNIRS optodes

From an anatomical perspective, the adult brain is divided into five layers, arranged from outer to inner as follows: the scalp layer, cranial bone layer, cerebrospinal fluid (CSF) layer, gray matter layer, and white matter layer. Each layer of tissue possesses distinct spectroscopic characteristics and thickness, as illustrated in Table S1. Generally, during brain functional activity, it is assumed that, except for changes in the oxygen content in the gray matter layer (cerebral cortex), the concentrations of HbO and HbR in the other layers remain constant. In other words, the absorption coefficients remain constant, allowing the calculation of changes in the concentrations of HbO and HbR in the cerebral cortex using variations in emitted light intensity.

Table S1 Mean thickness of tissue layers in the occipital region of the brain in adults.

Main types of organization	Average tissue thickness (mm)
Scalp	5-10
Skull (of a dead body)	10-20
Cerebrospinal fluid	2
Gray matter in the brain	4-5

The average thickness of the adult brain's scalp layer is 5-10 mm. Although the scalp layer's blood may exhibit slight absorption of near-infrared spectroscopy signals, relevant studies indicate that the interference from the scalp layer is negligible compared to the impact of other layers of brain tissue components on spectroscopic signals and can be disregarded. The average thickness of adult cranial bone tissue is approximately 10-20 mm. Due to variations in the participants' movement states and postures, the thickness of the brain's CSF layer also undergoes changes, introducing interference to spectroscopic signal measurements. However, when the distance between the light source and detector is greater than or equal to the commonly used 30 mm in NIRS measurements, the variations in CSF layer thickness in near-infrared spectroscopy detection can be considered negligible. Additionally, the existence of individual differences in the specific thickness of various brain structure components will impact the accuracy of signal transmission, necessitating an investigation into Optode distances less than 30 mm, particularly considering variations in the thickness of brain structure components between adults and infants.

The protocol for setting the optode distance for different participants was designed to be flexible yet systematic to accommodate for anatomical variation while maintaining data quality. In our study, the setting of the optode distance follows the following protocol to accommodate variations in the head size and shape among different participants:

1. Standard Baseline: We established a standard baseline optode distance of 30mm based on prior research indicating the effective range for capturing cortical hemodynamic responses in adults.
2. Initial Assessment: Participants underwent a quick screening process where we assessed their head circumference and hair thickness — two factors that can influence optode placement and data quality.
3. Individual Adjustment Process: For each participant, we first positioned the optodes at the

standard baseline distance. We then performed a real-time quality check of the detected light signal at the baseline distance. If the signal-to-noise ratio (SNR) was sub-optimal, we would incrementally adjust the optode distance within the range of 10-55mm. The adjustment was in increments of 5mm to either increase the distance (in cases of thicker hair or larger heads) or decrease it (in thinner hair or smaller heads). This iterative process continued until an optimal SNR was achieved that balanced signal strength with the depth of penetration necessary to infer brain activity.

4. Participant Comfort: During the adjustment process, we also ensure the comfort of participants, avoiding excessive pressure on the hair or scalp to ensure the stability of signals during the experimental procedure.

5. Final Validation: Once an optimal distance was determined, we performed a series of short baseline functional tasks to validate the signal stability throughout the expected range of head movements and cognitive tasks involved in our study.

6. Documentation: All distances and adjustments made were meticulously recorded for each participant, ensuring that our methods could be replicated and the impact of the adjustments could be monitored and analyzed post hoc.

It is important to note that such individualized adjustments, while they do introduce an element of variability, are crucial for acquiring data of sufficient quality from all participants, given the diverse nature of human anatomy. We believe that this adaptive protocol does not compromise the reliability of our findings but rather strengthens the validity of our results by ensuring high-quality data acquisition across all subjects. We believe that such a protocol ensures that the photoconductive distance settings for all participants are both consistent and account for individual differences.