INTRODUCTION

The objective of this study was to investigate the cerebral vascular autoregulation (CVA) process in adults with moderate to severe traumatic brain injuries (TBI) or multiple sclerosis in comparison to healthy adults during the Ni-back task. Functional Near Infrared Spectroscopy (fNIRS) was used to detect the levels of oxyhemoglobin (Hboxy), deoxyhemoglobin (Hbdeoxy), and total hemoglobin (Hboxy + Hbdeoxy) in the thalamus, pre- and post-central gyri, and parietal operculi (see Figure 1).

METHODS

Participants:
- Sub-groups: Healthy control (HC) subjects (N = 10), trauma brain injury (TBI) subjects (N = 6), and multiple sclerosis (MS) subjects (N = 4).
- Selection Criteria:
  - Between the ages of 18-55 years old.
  - No history of alcohol or drug abuse.
  - No history of Psychiatric Disorder.
  - Right Hand Dominant.
- No Neurological Disorder in the HC group.
- No other Neurological Disorder in the clinical groups.

The behavioral task (Ni-back test):
- Sessions were presented every three seconds, simultaneously in 24-second epochs.
- Four Conditions (0-back, 1-back, 2-back, 3-back).
- Each condition presented (sequentially randomized), 3 times.

Apparatus:
- Multi-channel continuous wave near infrared imager (NIRx Medical Technologies).
- 30 source and 30 detector optodes (900 channels).
- Simultaneous dual-wavelength measurement with near infrared light (900nm and 800nm).
- Optodes placed on forehead 10% above nasion in a 10 cm by 3 cm rectangular configuration (Figure 1).

Data analysis:
- Optical data low-pass filtered and normalized to a resting baseline mean value.
- Images of Hboxy, and Hbdeoxy, concentrations computed by using a first-order perturbation algorithm.\(^1\)
  \[ \text{Hboxy} = \text{Hboxy} - \text{Hbdeoxy} \]
- Six vascular autoregulatory states are defined, as shown in Figure 3, according to the sigmoidal signs of Hboxy, Hbdeoxy, and their sum.\(^2\)
- Each relational category reasonably corresponds to a different underlying state of oxygen supply/demand balance or imbalance.

Time fraction analysis:
- Autoregulatory state calculation (Figure 3) allows us to compute not only the state-dependent Hboxy and Hbdeoxy, concentrations, but also:
- The percentage of time each state spends in any of the six states.
- The percentage of overall time that each pixel spends in any of the six states.

RESULTS

- Inspection of images of Hboxy, time reveals consistent repeatable trends in the supply of oxygen to the prefrontal cortex during the Ni-back task (Figure 4).
- Direction of the trend is a function of task difficulty: Hboxy levels decline during the level challenging task (2-back), and increase most markedly during the most difficult (3-back).
- Oppositely directed trend is seen in Hbdeoxy vs. time data (not shown).

- Time fraction analysis:
  - Time interval compared are for the subject at rest, and while performing the 3-back task (Figure 5).
  - Spatial distributions of the six CVA-state existence-time percentages (Figure 7): One representative participant from each of the three groups.
  - All subjects show predominance of states 4 and 5 (i.e., increased blood volume) while the subject performs 3-back task.
  - Healthy control subject has a predominance of vessels in state 1 (balanced) during resting baseline.
  - Other controls also show predominantly the balanced states (not shown), either primarily state 1, primarily state 4, or a mixture of both.
  - TBI subject has significant percentages of states 1 through 4.
  - MS subject has similar time fraction spatial distributions for both the resting and 3-back periods.
  - Percentage of time spent in each CVA state: (Figure 8, Figure 9):
    - Group means and standard deviations, for each state and for baseline and 3-back time-intervals, are shown in Figure 8.
    - Only states 5 and 6 (oxygen excess) show statistically significant group differences.
    - Only HC group shows a significant difference between baseline and 3-back intervals, for state 6.
    - Impact of performing the task is lower for the other groups.
  - Co-registration of functional and anatomical images:
    - Volume used for image reconstruction was derived from a 3D structural MRI of an adult human head. Thus it is straightforward to overlay any optical image parameter onto the anatomy, without any need for a warping algorithm.
    - Image co-registration facilitates interpretation of optical feature information.
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CONCLUSIONS

- CVA state analysis, especially when residence-time percentages are considered, reveal statistically significant differences between all pairs of subject groups.
- The noted differences are found only in the oxygen-excess component (states 5 and 6) of the overall hemoglobin signal.
- Healthy control group also exhibits a significant task-induced change in average time fraction for state 5, and the other groups do not.
- States 5 and 6 constitute only a fraction of the integrated Hboxy response.
- Consequently, the effects noted above are too small to show up as statistically significant differences in the integrated signal.
- Only by resolving the latter into CVA states are the effects revealed.

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REFERENCES