# Students' neurocognition changes during engineering design when thinking aloud

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# Background

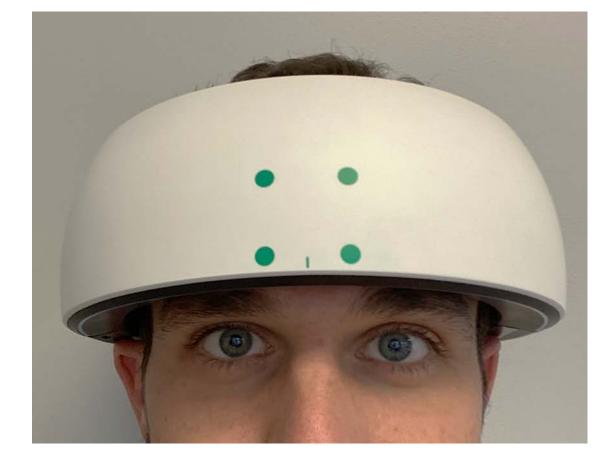
The purpose of this study was to measure the neurocognitive effects of think aloud when engineering students were designing. Thinking aloud is a commonly applied protocol in engineering design education research. The process involves students verbalizing what they are thinking as they perform a task. Students are asked to say what comes into their mind. This often includes what they are looking at, thinking, doing, and feeling. It provides insight into the student's mental state and their cognitive processes when developing design ideas. Think aloud provides a richer understanding about how, what and why students' design compared to solely evaluating their final product or performance.

Ericsson and Simon's (1980) seminal work on think aloud protocol suggests that this type of verbalization does not change cognition or mental state because the information is already being attended to by the designer. However, the influence of thinking aloud while designing is still debated (Fox, 2011). Thinking aloud changes perception about time (Hertzum and Holmegaard, 2015) and can delay solution generation (Sun, Li, and Zhou, 2020).

## Methods

Undergraduate and graduate engineering students (n=50) at Virginia Tech were randomly assigned to the think aloud or control group. Students in both groups were then outfitted with a functional near infrared spectroscopy (fNIRS) head band. fNIRS measures the change of oxygenated (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb), illustrated in Figure 1. An increase in oxy-Hb typically mirrors neuronal activity and implies the allocation of resources and nutrients by the cerebrovascular system.

Students in the think aloud and control groups were then asked to *design a personal entertainment system*. They were provided paper to sketch their design. The think aloud group was asked to think aloud while completing their design task. Prior to receiving the design instructions, students in the think aloud group learned how to think aloud. A member of the research team demonstrated how to think aloud about an unrelated design task. We evaluated the differences in the number of words on their design sketches, the time students spent on the design task, and changes in patterns of neurocognition.



igure 1: OBELAB Functional near-infrared spectroscopy (fNIRS).

### **fNIRS** Pre-processing

The raw data collected from our OBELAB fNIRS device was converted into the optical density. We then applied temporal derivative distribution repair (TDDR) motion correction. When used a 1000th order finite impulse response (FIR) bandpass filter with cut-offs between 0.01 – 0.25 Hz. We then applied the modified beer-lambert law to get hemoglobin concentration. These pre-processing steps are illustrated in Figure 2. We reviewed the pre-processed data for each student and removed students from analysis whose data included oxy-Hb more than two times outside the standard deviation. Data analysis included 20 students in the control and 21 in the think aloud group.

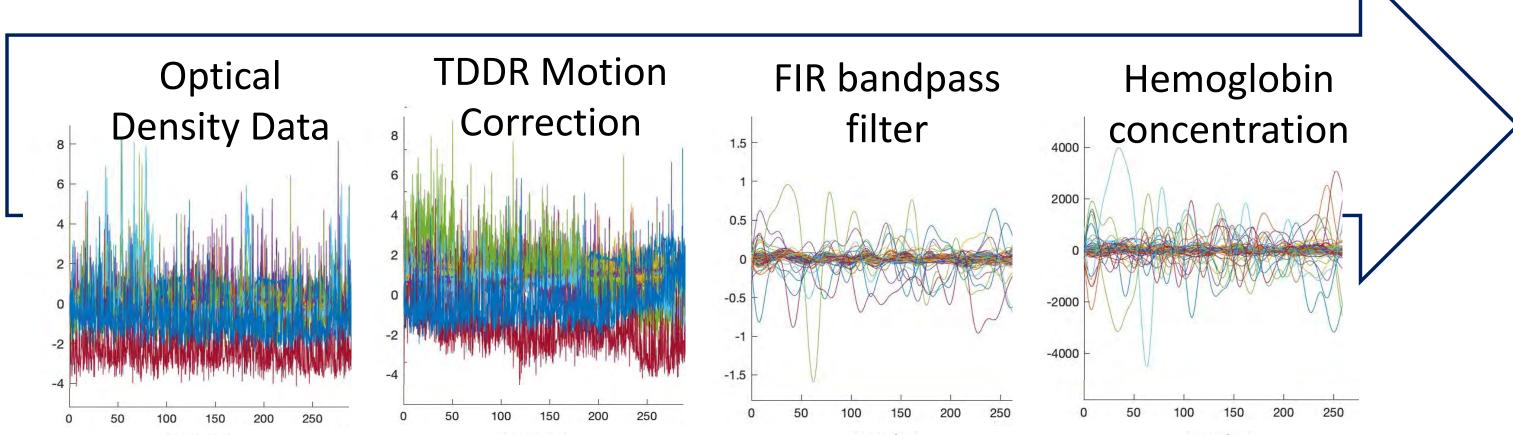


Figure 2: Pre-processing of raw fNIRS data.

## **Data Analysis**

We then regressed out, using the median time series data, of the 15 mm, short-channel activation, from the 30 mm activation. This was done to remove physiological artifacts including respiration and the Mayer wave. The channel differences are illustrated in Figure 3. We then compared the mean differences of oxy-Hb during the task between groups for each channel. The location of the channels is illustrated in Figure 4.

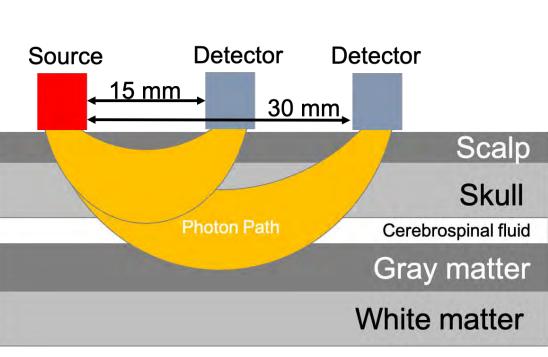


Figure 3: Light source and detector with short-channel separation.

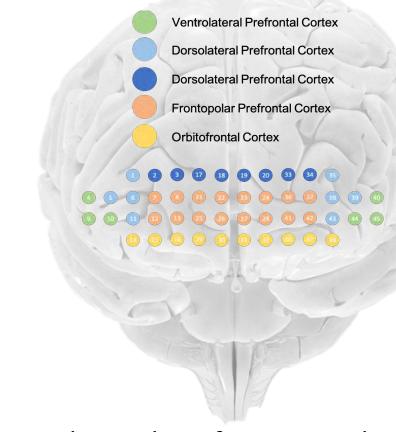
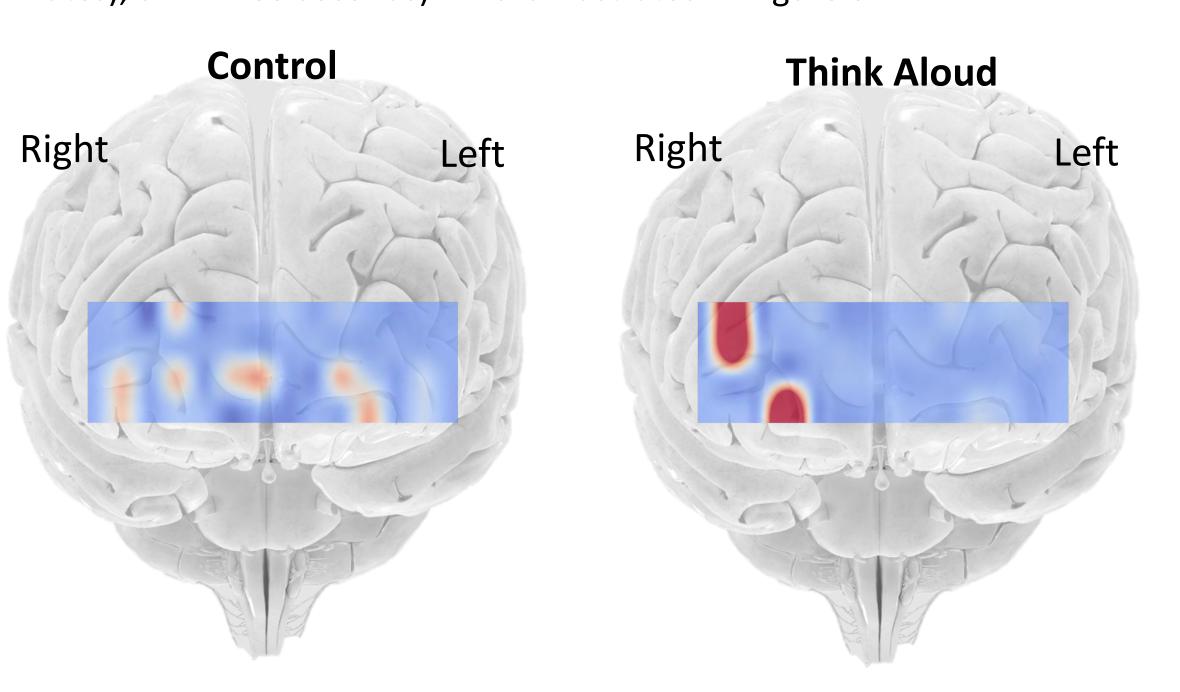


Figure 4: Channel configuration along the prefrontal cortex for OBELAB fNIRS.

## Results

Neurocognitive difference were observed in the right dorsolateral prefrontal cortex. The difference was significant (t = 2.14, p = 0.03) and is illustrated in the Figure 5. The time to complete the design task was also significantly different between groups. The control group spent more time (Mean = 590 seconds (9.8 minutes), STD = 316 seconds) designing (t = 2.94, p = 0.005) compared to the think aloud group (Mean = 348 seconds (5.8 minutes), STD = 183 seconds). This is illustrated in Figure 6.



800 Total Seconds and Seconds

Figure 5: Brain activation while designing. Red indicates elevated levels of oxygenated hemoglobin and blue indicates a decrease in oxygenated hemoglobin.

Figure 6: Think aloud group spent significantly less time designing compared to the control.

The design sketches produced from the control group included significantly (t = 2.07, p = 0.043) more words than the think aloud group. The average number of words from control group was 32.8 with large variability between participants. The standard deviation was 33.9 words. The average number of words from the think aloud group was 14.9 with a standard deviation of 19.78. Figure 7 represents the mean number of words and standard deviation for each group. Figure 8 includes example design sketches for both groups.

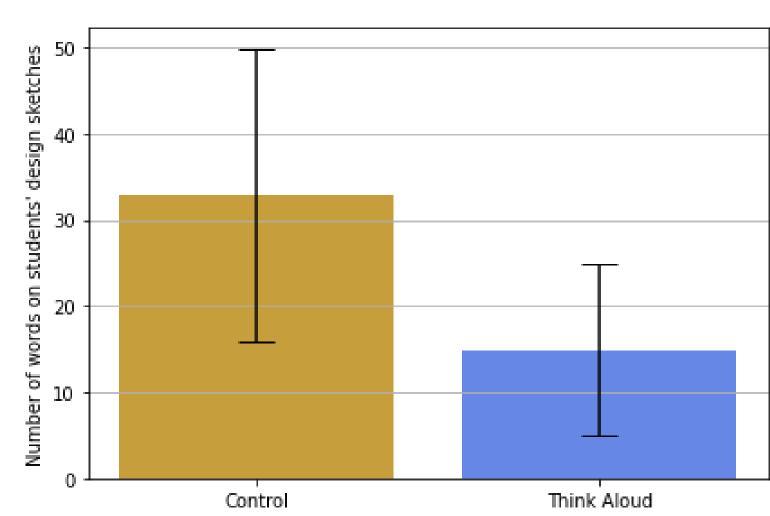


Figure 7: Average number of words included in design sketches for each group.

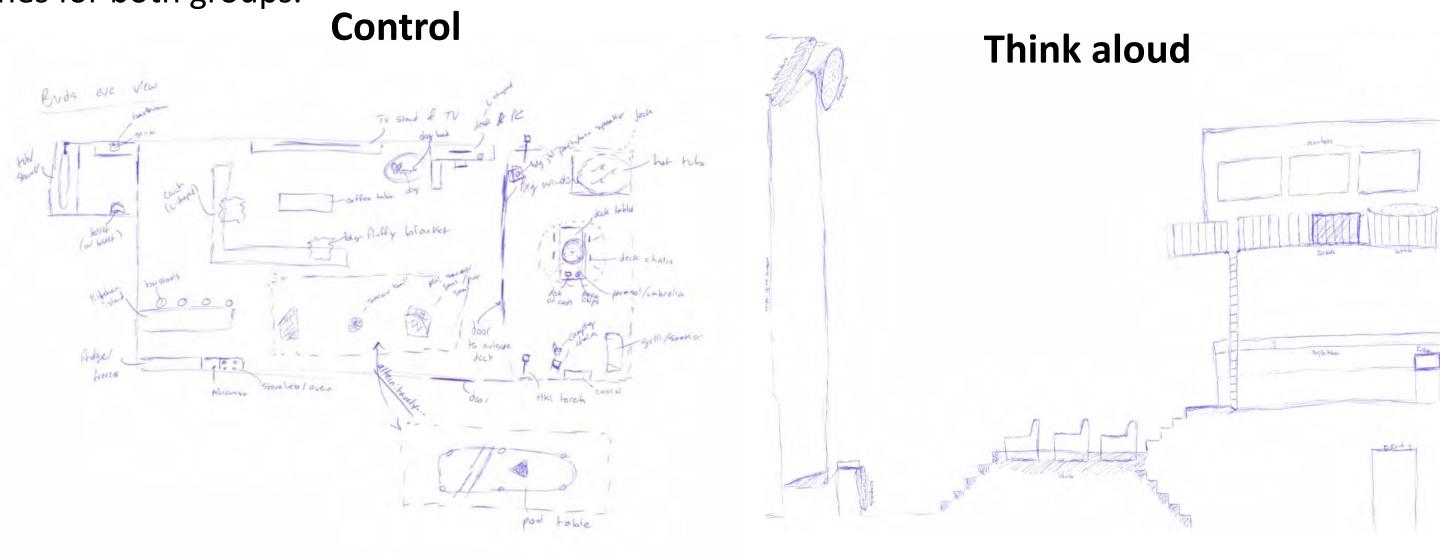


Figure 8: Example design sketches from each group. The design sketches from the control group included significantly more words that the think aloud group.

# Conclusion

We observed significant differences during design between students who were required to think aloud compared to those in the control group. This conflicts with Ericsson and Simon's (1980) seminal work on think aloud protocol. Students thinking aloud spent less time designing. They also included fewer words on their design sketches. The neurocognitive results contradict a prior fNIRS study measuring think aloud when solving math problems that found no differences (Pike et al., 2014). One explanation for our observed difference might suggest design is uniquely different than mathematics. It requires verbalization while accessing long-term memory. This type of verbalization and memory recall may not be represented in Ericsson and Simon's prior work or Pike et al. (2014).

The differences in neurocognition occurred in the right prefrontal cortex, specifically the right dorsolateral prefrontal cortex (DLPFC), illustrated in Figure 9. The DLPFC is generally associated with verbal and spatial working memory. Verbal working memory tasks are known to activate the bilateral DLPFC, whereas spatial working memory tasks predominantly activate the left DLPFC.

Dorsolateral prefrontal cortex (DLPFC)

Wentrolateral prefrontal cortex (VLPFC)

Medial prefrontal cortex (mPFC)

Figure 9: Brain regions in the prefrontal cortex (PFC).

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