

BME205 Lab 3: Investigating the Impact of Different Forms of Concentration on Heart Rate and Blood Oxygen Saturation

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1 Introduction

In a modern world saturated with distractions, the ability to maintain intense focus is of increasing importance, particularly within the rigorous academic environment of Engineering Science at the University of Toronto (Gillespie 2025).

Pulse oximetry is a non-invasive method used to monitor these parameters by emitting red and infrared light through a peripheral site, such as a finger (Association 2021). The underlying principle relies on the different absorption spectra of hemoglobin, where oxygenated hemoglobin absorbs more infrared light and deoxygenated hemoglobin absorbs more red light (E. D. Chan, Michael M. Chan, and Mallory M. Chan 2013). By calculating the ratio of these absorbed wavelengths, the pulse oximeter determines the oxygen saturation level of the blood. This lab investigates the physiological shifts in heart rate and blood oxygen saturation (SpO_2) that occur when an individual transitions from a resting state to tasks requiring high levels of concentration.

I hypothesize that cognitively demanding tasks will increase heart rate relative to resting conditions, while SpO_2 will remain relatively stable due to homeostatic regulation.

2 Materials and Methods

This section describes the materials and methods that were used to conduct this lab.

2.1 Materials

The following materials, available through BME205, were used to conduct the experiment:

- BioCapture: Used for data collection and signal processing. It configures the BioRadio channels and provides visualization of the heart rate and SpO_2 data.
- BioRadio: A wireless physiological monitor that acts as the data acquisition unit, digitizing the signals from the PPG sensor and transmitting them to the computer via Bluetooth.
- Pulse Oximeter (PPG Sensor): Connected to the individual's finger to measure pulse and SpO_2 .
- Laptop/Computer: To run BioCapture and record files.
- Task Prompts: Mental math problems, the English alphabet, and an object for balancing on the head.

2.2 Data Processing

The raw signals captured by the BioRadio were processed in real-time by the BioCapture software using the following physiological principles:

- **Heart Rate (BPM):** The software utilizes a peak-detection algorithm on the PPG waveform to identify the systolic peaks. The time interval between consecutive peaks (T_{pp}) is measured, and the instantaneous heart rate is calculated as $BPM = 60/T_{pp}$ (Kazemi et al. 2022).
- **Oxygen Saturation (SpO_2):** This is derived using a ratiometric analysis of the red and infrared light absorption. The software calculates the "ratio of ratios" (R) of the AC (pulsatile) and DC (non-pulsatile) components of the two wavelengths:

$$R = \frac{(AC/DC)_{red}}{(AC/DC)_{IR}} \quad (1)$$

This value is then mapped to a calibrated SpO_2 percentage (Kirson and Koltjes-Edwards 2011).

2.3 Methods

The following steps were taken to complete the lab:

1. The subject's finger was cleaned with a sanitizing wipe, to ensure clean signals on the PPG.
2. After BioRadio was connected to the laptop with BioCapture, the PPG sensor was attached to the subject's finger, on the non-dominant hand.
3. Data was recorded for the subject sitting in a chair with eyes closed for approximately 30 seconds to establish a physiological baseline.
4. Physiological data was recorded for 60 seconds during three different activities to challenge focus:
 - Mental math: Solving arithmetic problems through a mental math website, where simple addition, subtraction, division, and multiplication are quizzed for one minute.
 - Physical focus: Balancing an object on the head while seated.
 - Cognitive retrieval: Reciting the alphabet backwards.
5. Recordings were saved as separate csv files for comparative analysis of heart rate and SpO_2 stability across conditions.

BME 205 Lab 3: Heart Rate, PPG & Blood Oxygen vs. Concentration
Physiological Response Across Four Conditions

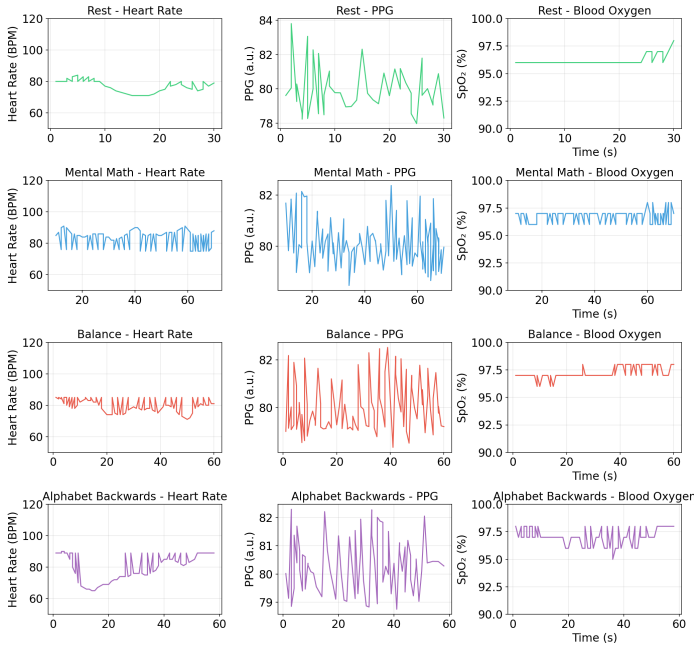


Figure 1: The composite view illustrates the transition from a stable resting baseline to the high-frequency pulsatile changes observed during the backwards alphabet reciting.

3 Data and Analysis

This section describes the data collected through heart rate, PPG, and SpO_2 monitoring. The averages for heart rate and SpO_2 values are recorded in Table 1.

Table 1: Summary of physiological results, where heart rate and SpO_2 averages were calculated across the full recording interval for each task.

Condition	Average Heart Rate (BPM)	Average SpO_2 (%)
At Rest	77.69	96.17
Mental Math	82.00	96.61
Balance Task	80.34	97.19
Alphabet Backwards	80.62	97.06

All four trials with heart rate, PPG, and SpO_2 data are shown in Figure 1.

The PPG, heart rate and SpO_2 levels were recorded for being at rest, as shown in the first row of graphs (green colouring) in Figure 1. The heart rate is relatively stable in the figure (77.69 BPM), with some noise at the ends. The SpO_2 levels are also relatively stable, at around 96 %, but rise to around 98 near the end.

The next row in Figure 1 (blue), shows the PPG, heart rate, and SpO_2 levels while solving mental math problems, which were completed for a minute through the “Mental Math Practice - QuantGuide” website (*Mental Math Practice - QuantGuide* 2024). While heart rate was noisy here, it had a value of around 82.00 BPM, higher than the previous resting heart rate. SpO_2 values exhibited greater variability

during the task condition, and reached peaks of 98 % more consistently than before.

The third row of graphs (red) shows the results from balancing an object on my head while sitting down. In these trials, heart rate was higher than resting condition but exhibited greater variability. Lastly, SpO_2 was less noisy than before but was consistently higher, more regularly at a maximum of 98 % or a flat 97 %.

The last row of graphs shows the results while reciting the alphabet backwards. Surprisingly, heart rate starts at 90 BPM, dips very low to around 65 BPM, then climbs back up. It achieves an average of 80.62 BPM, even though it had a much wider range, with higher maximums than before. SpO_2 data was noisy, averaging at around 97.06 %.

The graphical data obtained from BioCapture illustrate distinct physiological profiles for each condition. The observations I had for each graph are more succinctly summarized in Table 2.

Table 2: Physiological observations during rest and focus tasks

Condition	Heart Rate Observation	SpO_2 Stability
At Rest	Stable baseline with mean \sim 78 BPM; lowest of all conditions.	Highly consistent around 96.2%.
Mental Math	Elevated to \sim 82 BPM; highest among conditions; increased frequency of PPG peaks.	Slight increase to 96.6%; minor fluctuations.
Balance Task	Moderate increase to \sim 80 BPM; signal reflects steady physical focus.	Most stable; highest mean at 97.2%.
Alphabet Backwards	Elevated to \sim 81 BPM; irregular peak intervals consistent with cognitive retrieval effort.	Stable at 97.1% overall; possible brief dips during hesitations.

4 Sources of Error

Several sources of error may have influenced the measurements. Motion artifacts caused by small finger movements can introduce noise into pulse oximeter signals, particularly during cognitively demanding tasks (Han and Kim 2012). Additionally, the difficulty of mental tasks may fluctuate throughout the experiment, producing variable physiological responses. Measurement limitations of the consumer pulse oximeter ($\pm 2\%$ SpO_2 accuracy) may also obscure small differences between conditions (Silverston, Ferrari, and Quaresima 2022). Finally, the relatively short recording duration may allow transient fluctuations to influence the calculated averages.

5 Discussion and Conclusion

The transition from rest to cognitive tasks led to an increase in heart rate. The mental math condition produced the most

consistent increase in heart rate, suggesting sustained sympathetic nervous system activation associated with problem-solving (Health 2022). The recitation of the alphabet backwards showed higher variability, likely due to the "stop-and-start" nature of cognitive retrieval, where memory is not smooth and is rather a reconstructive process that occurs in pauses, flashes, or bursts (Frankland, Josselyn, and Köhler 2019). SpO_2 remained relatively stable throughout, indicating that while heart rate increases to meet demand, the body maintains high oxygen saturation during short-term cognitive stress.

While SpO_2 levels remained within the range of 96%-98% throughout all trials, a marginal increase was observed during focus-heavy tasks, peaking at 97.19% during the balance coordination task. This likely represents a compensatory respiratory response where increased tidal volume or breathing frequency, triggered by sympathetic activation, enhanced arterial oxygenation to support the metabolic demands of the prefrontal cortex during intense concentration (Zhang et al. 2022). However, *relatively*, SpO_2 remained stable (less than 1% increase) due to the relatively low metabolic demand of cognitive activity compared to physical exercise (Masamoto and Tanishita 2017). In healthy individuals, SpO_2 typically remains stable during routine cognitive stress because oxygen delivery is tightly regulated by respiratory and cardiovascular homeostasis. Significant decreases in SpO_2 generally occur only during extreme distress, panic responses, or in individuals with underlying respiratory conditions (Healthcare 2024).

This study successfully demonstrated that intense cognitive focus triggers measurable physiological responses. As hypothesized, heart rate increased significantly during tasks requiring focus compared to the resting state. While SpO_2 levels were maintained within a healthy range (95%-100%), the heart rate data confirms that "locking in" on a task is a physiologically demanding state characterized by heightened autonomic activity. Future engineering applications could utilize these biomarkers to develop "flow state" monitors that help students optimize their study habits based on real-time physiological feedback.

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