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Effects on Human Heart & Breathing Rates by Face Mask-Wearing, During Short Periods of Exercise

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This experiment focuses on the cardiorespiratory effects of face mask-wearing during short periods of exercise. Analyzing how face masks affect heart and breathing rates is relevant during the COVID-19 pandemic, as there is mis-information regarding how face masks work and what impact they have on an individual's physiology and health. This lab was designed for remote learning in an introductory biology course but could be easily modified for in-person instruction. To participate, students need only one face mask (e.g. N95, surgical, cloth, etc.) and internet access. Students independently measure their own heart and breathing rates after exercising with and without a face mask. Student data is pooled to increase sample size for statistical analysis and for community building. Utilization of a peer-reviewed manuscript that examined similar physiological parameters collected from clinicians wearing medical masks aided in hypothesis formation, as well as a deeper understanding of this experiment.

Keywords: physiology, heart, lungs, exercise, remote learning, inquiry-based learning, journal reading

Introduction

Designing a simple hands-on lab experiment for remote learning was a challenge that had to be addressed when on-campus learning was derailed due to the COVID-19 pandemic that spread throughout the world in 2020. This lab exercise was developed for a human physiology unit in a first-year undergraduate introductory biology laboratory course so that students who were learning remotely could participate in data collection and analysis with limited access to equipment or supplies; however, it could also be easily adapted for an in-person learning lab. This lab also allowed students to develop and test their own hypotheses after reading scientific literature, and asked students to address misconceptions for which there was little scientific evidence, furthering their critical thinking skills.

Specifically, this lab activity addressed misconceptions around face mask-wearing mandates which were meant to contain the spread of the SARS-CoV-2 virus, a respiratory virus which caused a devastating global pandemic in 2020. SARS-CoV-2 spreads between people through respiratory viral droplets that are released into the air by infected people when they cough, sneeze, or talk (Centers for Disease Control and Prevention, n.d. A). One main mechanism for stopping the spread of respiratory droplets is wearing a face mask, and many countries adopted face mask mandates during the pandemic as one mechanism to slow the spread of infection by SARS-CoV-2. Despite a lack of credible scientific evidence, rumors developed that mask-wearing might impact cardiorespiratory physiology by causing oxygen deprivation. To investigate these rumors, students were first asked to read primary literature which described physiological parameters measured from medical workers with and without medical-grade face masks (we asked students to read an article that would be appropriate for first-year undergraduate students -- we chose Roberge et al., 2010). After reading this article for homework, students were assigned to work in groups and asked to use the information from the article to help them develop a hypothesis about how wearing a face mask might affect their own physiological parameters while doing short bouts of activity. They then collected data to test their hypothesis by measuring their own heart and breathing rates after performing jumping jacks with and without face masks. We chose these physiological parameters since students were already familiar with them and because they did not require any special equipment to measure. Thus, the only materials a student needs to complete this activity is access to one type of face mask and access to a statistical analysis program to analyze pooled class data (we used Google sheets to pool data and to perform paired *T*-tests).

Student Outline

Objectives

Independently collect heart and breathing rate physiological data
Utilize a peer-reviewed journal article to aid in forming a hypothesis
Use statistics to analyze data with a paired samples design

Introduction

By the end of May 2021, the corona virus of 2019 (COVID-19) pandemic was reported to be responsible for the deaths of more than 3.5 million people worldwide (World Health Organization, 2021). COVID-19 is a respiratory disease that is caused by the novel coronavirus named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Although the origin of the virus is still being researched, it is believed SARS-CoV-2 originated from a bat coronavirus (Zhou et al., 2020; Wacharapluesadee et al., 2021). The outbreak began in Wuhan, China and some data suggest that there was a link to a large seafood and live animal market, providing further evidence for the virus' spillover origin; however, other data suggests that the virus was in existence before the Wuhan market outbreak (Liang et al., 2020). Symptoms of people infected with SARS-CoV-2 range from none (asymptomatic) to mild (fever or chills, dry cough, muscle and body aches, sore throat, loss of taste or smell) to a type of respiratory lung failure called acute respiratory distress syndrome (ARDS; fluid is leaked from the smallest blood vessels of the lungs into the tiny air sacs where gas exchange between the lungs and blood occurs, leading to severely low blood oxygen levels), to dysfunctions in multiply organ systems, including the brain, heart, liver and kidneys (Zaim et al. 2020).

Human-to-human transmission of SARS-CoV-2 spread rampantly across the world, infecting people in more than 200 countries by summer of 2020. Current research indicates that SARS-CoV-2 can spread between people through droplets of the virus (viral droplets) that are released into the air by infected people via coughing, sneezing, or talking (Centers for Disease Control and Prevention, n.d. A). The expelled viral droplets can then be picked up by another person through the air via breathing, especially in indoor areas that are poorly ventilated, or touching surfaces called fomites (e.g. doorknob) that viral droplets have landed on, whereby a person touches an infected fomite with their fingers and then unknowingly transfers the virus to their mouth, nose or eyes (Centers for Disease Control and Prevention, n.d. A).

SARS-CoV-2 can affect people of all ages, but the virus typically results in only moderate flu-like symptoms (e.g. cough, fever, along with difficulty breathing) for the majority of people it infects. Unfortunately, older people and people with certain underlying health conditions, such as obesity, cancer, chronic obstructive pulmonary disease, and Type II diabetes mellitus, are at higher risk of developing severe symptoms of COVID-19, if they become infected with SARS-CoV-2 (Centers for Disease Control and Prevention, n.d. A). In the U.S., Centers for Disease Control and Prevention also reported higher risks from the virus for Black, Indigenous and People of Color

(BIPOC) as compared to White or non-Hispanic persons. For example, as of August, 2020, compared to White or non-Hispanic persons, Black people were 2.6 times more likely to be infected by the virus, 4.7 times more likely to be hospitalized due to the virus, and 2.1 times more likely to die from the virus (Centers for Disease Control and Prevention, n.d. B).

While scientists were working on developing and testing vaccines to help prevent the spread of COVID-19, as well as drugs to cure the disease, severe measures/restrictions were put in place in many countries to aid in slowing the transmission rate of SARS-CoV-2, such as closing non-essential businesses and schools, restricting travel, testing symptomatic (and asymptomatic) individuals, quarantining people with COVID-19 using shelter-in-place orders, and, arguably the most important restriction, creating mandatory face mask-wearing policies. Government-mandated orders for the use of facial masks and social distancing were found to be correlated with significant decreases in the daily growth rates of SARS-CoV-2 infections in the U.S. (Lyu and Wheby, 2020). In addition, analyses across 194 countries found the lowest death rates from COVID-19 to be within countries that have cultural norms or government policies favoring the use of face mask-wearing as personal protective equipment (PPE) to help reduce the spread of COVID-19 (Leffler et al., 2020).

The most common PPE for the nose and mouth used by healthcare workers are the N-95 filtering facepiece respirators (FFRs) and surgical masks. However, due to the short supplies of these types of PPE, the World Health Organization (WHO) recommends people of ages 12 or older should wear a snuggly-fitted non-medical face mask (fabric mask) that is comprised of 3-layers when in public areas where COVID-19 is widespread and physical distancing of at least 1 meter is not possible. WHO also recommends the public to wear face masks without valves because the presence of the valves may result in an infected person spreading SARS-CoV-2 during exhalation. WHO also recommends that the public not wear face masks when exercising for long periods of time because as the fabric of a mask becomes wet from sweat, it may make it challenging to breath (World Health Organization, 2020).

Throughout the COVID-19 pandemic, health care workers have been protecting themselves by wearing N-95 FFRs. As discussed in the article by Roberge et al. (2010), there is no evidence that N-95 FFRs cause oxygen deficiency nor carbon dioxide intoxication when worn properly by medical providers. But as mentioned above, WHO recommends that the general public should not wear face masks during exercise because they may make it difficult to breathe if the masks become wet from sweat. As part of today’s lab, you will examine how heart and breathing rates are affected by wearing face masks (N95s, surgical masks and/or non-medical (fabric) masks), while performing short periods of exercise – 30 jumping jacks. A comparison between the effects of wearing a face mask on heart and breathing rates during the short period of exercise will be statistically analyzed using paired *T*-tests in Google Sheets, as each subject will record heart and breathing rate data both with and without a face mask. This is a study design that to our knowledge has not yet been presented in the scientific literature.

For homework, you read a peer-reviewed journal article describing physiological parameters measured by medical workers wearing and not wearing N95 FFRs (Roberge et al., 2010). Before you begin your experiment, you will use the information in the article and knowledge or observations of the masks that will be included in your study to help you form a hypothesis about how face masks tested in this study will affect breathing and heart rates during short periods of exercise (remember to include a biological rationale for your predictions). Before you start to collect data, you will discuss your hypothesis with your small lab group members to refine your thinking. Remember that hypotheses are predictions about questions you do not know the answer to that are developed by building on data/information that others have gathered. Because you do not know the answer to your question, your data may support or refute your hypothesis. In addition, your data may be difficult to interpret for reasons that you did not understand before beginning your experiment. It is not important whether you collect data that supports or refutes your hypothesis, or is difficult or easy to interpret. Rather, it is important that your hypothesis was developed in a thoughtful and data-driven manner, and that you appropriately analyze your data and draw thoughtful and accurate conclusions. With guidance from your lab instructor, your lab class will develop/refine an experimental procedure that will test your hypothesis.

Methods and Data Collection

Part A: Hypothesis forming

Use the information in Roberge et al. (2010) and what you have learned about the cardiorespiratory systems prior to this lab, as well as general information about the masks that will be included in this study, to aid in forming a hypothesis for how heart and breathing rates may differ between wearing and not wearing a face mask during a short period of exercise (30 jumping jacks). As a reminder, you will investigate the effect of face mask-wearing as a group by having everyone exercise both with and without a face mask.

1. Record your hypotheses for how face masks worn in this study will affect heart and breathing rates during short periods of exercise in the space below.

Part B: Measuring Baseline Heart and Breathing Rates

Prior to collecting data on how face masks affect heart and breathing rates during short periods of exercise, you will measure your baseline (resting) heart and breathing rates while standing. Baseline data is important to collect as you will need to ensure that your heart and breathing rates are at baseline (resting) values prior to testing the effects of how wearing a face mask affects these physiological parameters during short periods of exercise.

1. Stand in the upright position for ~3 minutes while remaining mostly motionless. This waiting period is important as your heart and breathing rates may be altered by postural adjustments at the start of this data collection period.

2. Record your baseline heart rate (pulse) by gently holding the tips of your second and third figure of one hand along the inner (medial) wrist of the opposite arm or hold the tips of those fingers adjacent to the trachea on either side of your neck, along the path of your carotid arteries and veins. Once you have located your pulse, record your pulse over a 15 second period. Enter this data into Table 1 under Column 2 and appropriate row (see below).

3. While still standing and remaining motionless, count your total number of inhalations over a 15 second period. Enter this data into Table 2 under Column 2 and appropriate row (see below).

   For Part C and D below-- the two experimental trials/conditions in this study-- one half of the group will proceed to complete Part C followed by Part D, while the other half of the group will proceed in completing the trials in the opposite order. Collecting data as a group using this experimental data collection design will help eliminate any potential effects that the order of completing the experimental trials may have on the subject's physiological parameters that are measured in this study.

   You will also need to ensure your heart and breathing rates are at baseline values prior to switching to starting Part C or Part D. This may require a 10- to 15-minute waiting/recovery period in order for elevated heart and breathing rates to return to baseline values after exercising.

Part C: Measuring Heart and Breathing Rates Without a Face Mask Post-Exercise

In this part of the lab, you will measure heart and breathing rates while exercising without a mask.

1. Measure your heart and breathing rates for 15 seconds to ensure that they are similar to baseline values (measured over a 15 second period). If you just completed Part D, you may need to repeat this step at 5-minute intervals until you find baseline values for both heart and breathing rates.

2. Perform 30 jumping jacks WITHOUT a face mask (remain standing) then immediately measure your heart rate over a 15 second period. Record this data in Table 1 under Column 2 in the row named "Heart Rate Post-Exercise: No Mask". Proceed to the step below as quickly as possible.

3. Remain standing and count your total number of inhalations over a 15 second period. Record this data in Table 2 under Column 2 in the row named “Breathing Rate Post-Exercise: No Mask”.

Part D: Measuring Heart and Breathing Rates With a Face Mask Post-Exercise

In this part of the lab, you will measure heart and breathing rates while exercising with a mask.

1. Measure your heart and breathing rates for 15 seconds to ensure that they are similar to baseline values (measured over a 15 second period). If you just completed Part C, you may need to repeat this step at 5-minute intervals until you find baseline values for both heart and breathing rates.

2. Perform 30 jumping jacks WITH a face mask snuggly fitted over your mouth and nose (remain standing), then immediately measure your heart rate over a 15 second period, without touching/moving your mask. Record this data in Table 1 under Column 2 in the row named “Heart Rate Post-Exercise: With Mask”. Proceed to the step below as quickly as possible.

3. With your mask still on (remain standing), count your total number of inhalations over a 15 second period. Record this data in Table 2 under Column 2 in the row named “Breathing Rate Post-Exercise: With Mask”.

Table 1. Heart rate data.

Variable Observed	Measured Over 15 seconds	Estimated Per Minute	Difference From Baseline (rate: per minute)
Baseline Heart Rate			
Heart Rate Post-Exercise: No Mask			
Heart Rate Post-Exercise: With Mask			

*To calculate a change in heart rate the baseline heart rate should be subtracted from the heart rate recorded during an experimental trial/condition. Example: heart rate post-exercise with no mask (units: per minute) - baseline heart rate (units: per minute).

Table 2. Breathing rate data.

Variable Observed	Measured Over 15 seconds	Estimated Per Minute	Difference From Baseline (rate: per minute)
Baseline Breathing Rate			
Breathing Rate Post-Exercise: No Mask			
Breathing Rate Post-Exercise: With Mask			

**To calculate a change in breathing rate the baseline heart rate should be subtracted from the breathing rates recorded during an experimental trial/condition. Example: breathing rate post-exercise with no mask (units: per minute) - baseline breathing rate (units: per minute).

Part E: Calculating the Change in Heart and Breathing Rates Based on Baseline Values

In this part of the lab you will determine the change in heart and breathing rates for the experimental trials based on your baseline data.

1. Complete Column 3 in both Table 1 and 2 by converting your physiological data recorded over 15 second periods to rates per minute (e.g. multiply your baseline heart rate recorded over 15 seconds by 4 to estimate your baseline heart rate per minute).

2. Complete Column 4 in both Table 1 and 2 by subtracting your baseline data from each of your experimental data sets. These results provide you with the change in heart and breathing rates for exercising with and without a mask based on baseline values (units: per min).

Part F: Analysis and Graphing of Pooled Data

In this part of the lab, you will pool, analyze, and graph data using Google Sheets.

1. Navigate to the shared group spreadsheet (Google Sheets) to enter your change in heart and breathing rate data (data from Column 4 in Table 1 and 2). Your data should be entered onto the shared spreadsheet within a single row and under the appropriately named column headers in order to avoid errors in data analysis. Your instructor will let you know when everyone's data has been added/shared to the spreadsheet, so that you can begin to analyze and plot the pooled data (see steps below) from your own computer, while following important guidance from your instructor.

2. After all group data has been added to the shared spreadsheet, click on the arrow located on the TAB of the data sheet and select > Copy To > New Spreadsheet. This will make a copy of the spreadsheet on your own Google Drive.

3. A window that says "Sheet copied successfully" will appear. Click on "Open Spreadsheet". The copied spreadsheet should open in a new window. Change the default name of the spreadsheet from "Untitled Spreadsheet" to something for your reference. As a reminder, you will use the data sheet saved to your own Google Drive to analyze the data from your own computer.

4. Follow the guidance provided by your instructor for how to use the average function in Google Sheets to calculate the mean change in heart and breathing rates for both experimental conditions in this study:

   Mean function is: " =average(cell range)"

5. Follow the guidance provided by your instructor for how to use the standard deviation function in Google Sheets to calculate the standard deviation of the mean change in heart and breathing rates for both experimental conditions in this study:

   Standard deviation function: "=stdev(cell range)"

6. Follow the guidance provided by your instructor for how to use the paired *T*-test function in Google Sheets to perform two paired *T*-tests in order to compare the following:
   A. Effect of mask wearing on mean heart rate during short period of exercise**:**
      mean change in heart rate without a mask vs mean change in heart rate with a mask
   B. Effect of mask wearing on mean breathing rate during short period of exercise**:**
      mean change in breathing rate without a mask vs mean change in breathing rate with a mask

Paired t-test function: "=ttest(range of cells for one data set, range of cells for second data set, 2, 1)".

The "2" represents a two-tailed test, since we are looking at data above and below the mean values; and the "1" represents that we are performing a paired *T*-test. A critical p-value of 0.05 will be used to determine if your p-value is significant for both paired *T*-tests.

7. Follow the guidance of your instructor for how to create two bar graphs for your data. One graph will display the mean change in heart rate for the two experimental conditions and one graph will display the mean change in breathing rate for the two experimental conditions.

Questions to Answer After Data Collection

1. Why did you perform a paired *T*-test rather than a two-way *T*-test to analyze the data collected in this study?
2. What is the purpose of recording baseline data and ensuring that each subject's heart and breathing rates were at baseline values prior to exercising with or without a mask in this study?
3. What was the *p*-value for the paired *T*-test that you performed to determine if there was a difference between the mean change in heart rates while wearing and not wearing a face mask during short periods of exercise? Explain your answer with specific details and include whether or not these findings supported your original hypothesis.
4. What was the *p*-value for the paired *T*-test that you performed to determine if there was a difference between the mean change in breathing rates between wearing and not wearing a face mask during short periods of exercise? Explain your answer with specific details and include whether or not these findings supported your original hypothesis.
5. How would you improve the data collection methods or design of this study?
6. What factors may have played a role at an individual level in regards to the mean change in heart and breathing rates, during exercise while wearing and not wearing a mask, as compared to baseline values?
7. Describe other experimental designs that you would use to further explore how face masks affect heart and breathing rates.
8. Based on your results, if you were going to exercise at low intensity inside a gym with other people and did not expect to sweat a lot, would you recommend wearing a mask in an area where COVID-19 was prevalent? Explain your answer.

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Materials

A computer with access to a statistical analysis program (we used Google Sheets to perform paired *T*-tests). Each student will also need access to one type of face mask and a timer or clock with seconds values. No other specialized equipment or reagents are required.

Notes for the Instructor

This activity was designed for first year introductory biology students with minimal background knowledge required. However, we assumed some prior knowledge from our students based on where this lab fell in our semester long course. Students were assumed to have knowledge of basic statistical tests - we asked students to analyze their data using paired *T*-tests to compare the effect of face masks on both heart and breathing rates. Students also needed to know how to read and interpret a basic scientific literature article so they should be familiar with the IMRaD structure of scientific journal articles.

This activity was designed to be performed remotely but would be easily implementable in person. While many variations of this experiment can be envisioned, the version we describe here asks students to compare their heart and breathing rates after exercising with and without wearing a mask. We asked our students to provide their own masks, but if face masks were not readily available, disposable masks could be provided. Alternatively, we have also taught this lab by asking students to consider the impact that the type of face mask might have on heart and breathing rates after exercise. To do this, students performed jumping jacks with and without wearing a particular type of mask (e.g. medical grade versus cloth). The type of mask that was available to each student was collected ahead of time and student groups were created based on mask type to make comparisons during data analysis.

One issue that arose while teaching this lab for the first time was that some students' heart rates went down after exercising in their second session (e.g. while wearing a mask). Some students interpreted this to mean that masks affected heart rate. However, another explanation is that students were tired after their first round of jumping jacks and performed their second round much less vigorously. This is an important aspect of study design that should be considered during data collection (for example; have half the students exercise with a mask first and the other half exercise without a mask first) or should be discussed as a class after data collection is finished to avoid mis-interpretation of the data. The first time we taught this lab, we used this unexpected result as an opportunity to discuss the importance of experimental design.

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