

# My Journey with Sleep: Powered by WHOOP

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**Abstract**— The purpose of this project was to provide both a big-picture view on sleep performance and a microscopic view on the author’s personal sleep habits. This project links some of the modern research on sleep with the author’s personal experiences and data, hoping to provide both a theoretical and practical perspective on how to improve sleep quality and how this impacts physical and mental health.

**Keywords**— sleep, wearable fitness devices, data visualization, python, R, sleep efficiency.

## I. BACKGROUND

Everyone is familiar with sleep; all humans spend somewhere between a third and a fourth of their lives asleep. However, most people pay little attention to how or why we sleep. The National Institute of Health [1] identifies four major stages of sleep. Stage 1 is a short crossover period from wakefulness to sleep, and Stage 2 is a period of lighter sleep that precedes deeper stages of sleep. Both stages are types of non-rapid eye movement (REM) sleep. Stage 3 is the last non-rem stage, and is commonly known as slow wave sleep (SWS). The last stage, REM sleep, is when we dream. Most research suggests that the latter two stages — SWS and REM sleep — are the most important restorative stages.

The first wearable fitness trackers came in the form of mechanical pedometers in the 1700s [2]. Such devices were used to approximate the distance travelled in a day. Benjamin Franklin is one of the first notable people to use such a device. The modern fitness tracker took its first steps in 1965 when Dr. Yoshiro Hatano — who at the time was researching ways to fight obesity — suggested that approximately 10,000 steps in a day create a proper balance between caloric intake and expenditure [2]. Many modern wearable devices still utilize this 10,000 step suggestion. Fitness trackers have evolved into modern devices such as Fitbit, Garmin, and Apple Watch, smart devices that can send data directly to our phones and the internet.

As a college athlete, I am always looking for new performance edges. Whether that be a new exercise in the weightroom, a new food or supplement, or new drill on the field, I am always looking for ways to improve myself both mentally and physically. In late 2018, my teammate and friend Madden Pikula showed me a fitness wearable called WHOOP that emphasized sleep and recovery. At the time, WHOOP was much smaller than it was now, but I was drawn in by the scientific approach to training. When I first started, I was surprised by just how poor some of my sleep habits were, and how they were impacting my physical recovery. Over the past two years, WHOOP has driven me to drastically improve my sleep performance, and I have enjoyed great performance benefits over that span.

## II. TECHNOLOGY USED

A wide range of technologies were used during this project. It is an amazing time in which powerful software is completely open-sourced to the public. Some of the most powerful code in the world is available to students in Sioux Falls, South Dakota. Technology also exists that can produce hundreds of data points on our health in a matter of seconds.

### *The WHOOP fitness wearable*

The WHOOP company is “on a mission to unlock human performance [3].” They looked at the wearable market and created a wearable device specifically geared towards athletes. The WHOOP fitness wearable measures the user’s heart rate 24/7 to provide a near constant stream of data for the user. Having been a WHOOP member for over two years, I now have years of personal data tracking my heart rate, activity, and sleep. The WHOOP wearable device generated the data used in this project.

Both the R and Python programming languages were used for this project. The reticulate package in R allows for the use of both R and Python in a single R Markdown file. This allowed for the data collection and some data processing to be done in Python with most of the visualizations being created using ggplot and R. Both the pandas package in Python and the tidyverse package in R were used to process data. The final dashboard for the project was created using Python Dash.

### III. DATA COLLECTION

The author's personal WHOOP data was used for the analysis and visualizations of this project. Data was also collected from WHOOP member Isabel Sommers. Isabel's data was used minimally in this project, as she has only been a member for a few months, so there was less data to work with. Collecting this data involved jumping through some hoops, which are described in this section of the paper.

#### *Retrieving my personal data from WHOOP*

Due to the personal nature of WHOOP data, the company places a priority on privacy. WHOOP protects the privacy of current and past members' data. While these protections help make WHOOP a trustworthy company, they also make it difficult for members to access their data outside of their own structured applications. I have spent a lot of time with customer support over the years working to gain access to my data, and my attempts have been unsuccessful.

In my third year as a WHOOP member, I decided to try a different approach. The WHOOP web application (app.whoop.com) is built out using a Single Page Application (SPA) and an Application Programming Interface (API) to the backend server. The SPA + API format is commonly used in modern web applications. The frontend client-side SPA communicates with a backend server through an API. With the proper API requests, it is possible to mimic the frontend application and communicate directly with the backend server. A WHOOP member, Jürgen Kreileder, wrote a script to do just this [4]. With his permission, Jürgen's script was modified to pull WHOOP data

directly from the API into both R Studio and Python Dash.

A few modifications were made to the script provided by Jürgen. The biggest change was to convert the script into a function that could be reused throughout the project. Five variables were set as parameters in order to make the code more flexible. The username and password combination was abstracted in order to allow me to pull data from multiple WHOOP users. The start and end dates of the data were also parameterized to allow for more flexible data collection. The backend api url was also abstracted, although only the cycles endpoint was really used for this project. Modularizing the WHOOP api request code granted more flexibility when pulling the data for this project.

#### *Formatting the WHOOP API request*

Once the data was collected, I worked to convert the data from an api response into a pandas dataframe and eventually an R dataframe. The python requests module has a json() function that returns the data in json format. From there, pandas has a json\_normalize() function that converts a json object into a pandas dataframe. This worked well in places where the data was flat, but so much in areas with more dimensionality such as the sleep statistics. As I needed many of the sleep statistics, I wrote a lambda function to pull statistics from the sleep.sleeps data. With this function I was able to abstract my respiratory rate and all of my sleep cycle durations to allow for better access to these statistics during my analysis.

### IV. THE WHOOP EQUATION

WHOOP focuses on three core pillars: sleep, strain, and recovery. How much strain you put on your body, how much sleep you get, and how well recovered your body are three pieces of an interrelated system. When combined, these metrics provide a more holistic view of your physical health and fitness. This is exactly the picture that WHOOP is attempting to provide for their members.

#### *Sleep*

WHOOP measures not just how much you sleep, but also how well you sleep. While most people only tend to focus on the total quantity of sleep, the quality of

sleep obtained is just as important. WHOOP allows members to see their time spent in different sleep stages, as well as the time spent awake each night. People can expect to lose anywhere from 30 to 90 minutes of sleep a night on average due to latency and disturbances in bed [3].

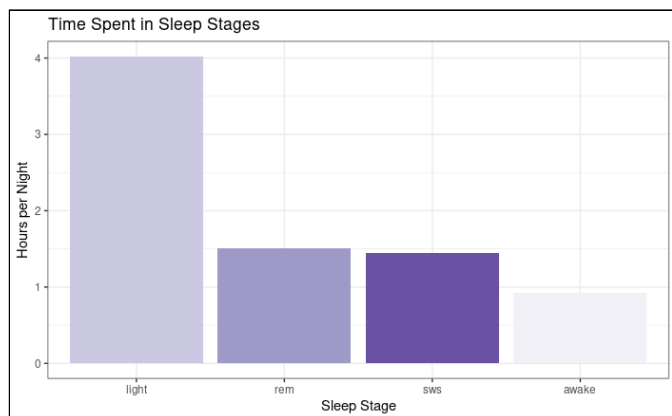


Fig. 1 Average Time Spent in Different Sleep Stages (T.J. Liggett)

WHOOP enables users to measure their actual amount of sleep rather than just time in bed. As a student-athlete, sleep is an important time for me for both physical recovery and memory consolidation. Figure 1 shows the average amount of sleep I get in each of the major stages. I get an average of about 4 hours of light sleep, 1.5 hours of both REM and SWS sleep, and spend about an hour awake per night.

#### Strain

Many wearable devices use measurements such as calories burned or steps taken to portray physical activity. These metrics provide limited benefit for athletes, and are not an accurate measure of the physical toll that an athlete puts on their body. I have always been skeptical of wearable fitness devices for this reason.

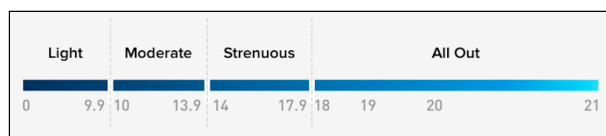


Fig. 2 The WHOOP Strain Scale [5]

One of WHOOP's biggest innovations comes in the form of the strain measurement. WHOOP measures the total cardiovascular load of an individual, called their

daily strain [3]. This allows users to measure the cardiovascular intensity of their workouts, as well as everyday activities. Strain is measured on a logarithmic scale from 0-21, which is shown in Figure 2. Strenuous exercise typically measures somewhere between a 14 and an 18, while light exercise is usually below a 10. It should be noted that cardiovascular load is more accurate than calories or steps in measuring exertion, but might not accurately measure the strain on your body induced from an activity such as lifting weights.

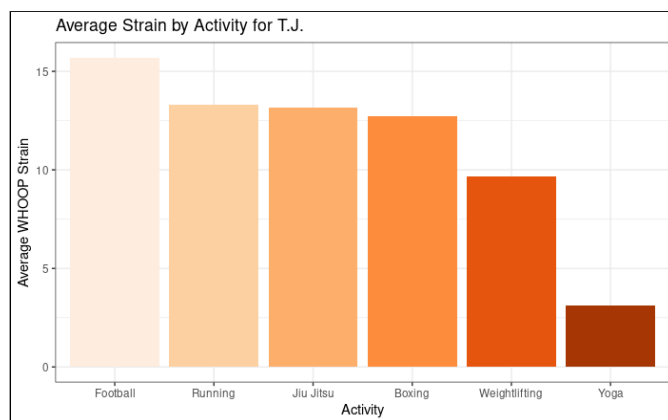


Fig. 3 Activity Strain for T.J. Liggett

Figure 3 and 4 show the average strain for each workout activity for T.J. Liggett and Isabel Sommers, respectively. More strenuous activities such as football, running, and jiu jitsu typically have a strain between 14 and 16, although I have had football practices that have gone over 18. While typically a lighter activity, it is interesting to note that Isabel registers a light workout when she coaches volleyball. WHOOP shows that sometimes our daily activities like work can create measurable strain and impact recovery.

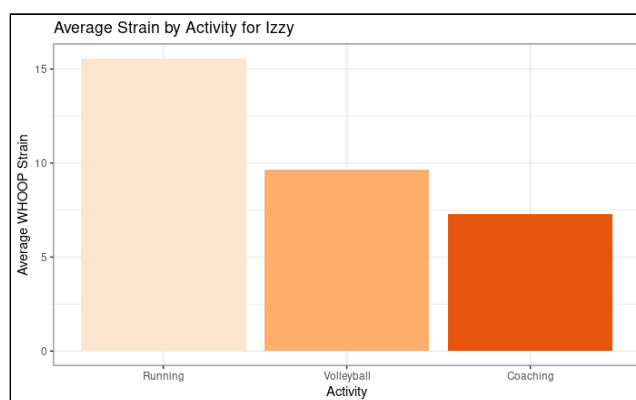


Fig. 4 Activity Strain for Isabel Sommers

### A. Recovery

The recovery score measures how ready the body is to take on strain. This metric is calculated from four major components: resting heart rate (RHR), heart rate variability (HRV), sleep, and respiratory rate. Perhaps the most important of these factors is heart rate variability, or the “variance in time between the beats of your heart [6].” The higher this number is, the more ready the body is to perform physical activity. WHOOP generates a recovery score every morning based on these four factors, which have been found to indicate how recovered the body is.

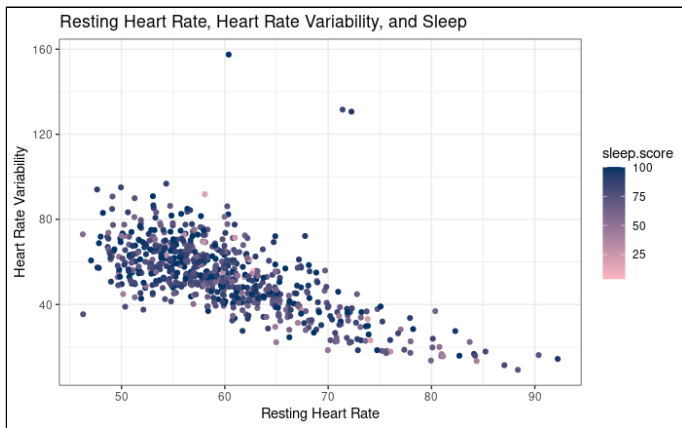


Fig. 5 The Relationship between Heart Rate and Sleep (T.J. Liggett)

An important thing to note is that these metrics are highly personal. A variety of factors can influence a person’s RHR, HRV, and respiratory rate. What is important to look for is the *differences* day-to-day in these metrics for an individual. These differences can tell a story of how the body is doing. Figure 5 shows the relationship between RHR and HRV on the axes, and we can see a negative correlation between these two variables. Typically, a low RHR and high HRV indicate the body is well recovered, and the inverse is true as well.

## V. THE IMPORTANCE OF SLEEP

In today’s world, humans have developed an interesting, and sometimes unhealthy, relationship with sleep. Sleep is critical for both mental and physical performance, but is often one of the first things that is sacrificed when pressed for time. Many populations live

in intense and competitive environments where it is perceived as an advantage to work more and sleep less. Perhaps one of the most famously sleep-deprived populations is the armed forces. The military is well-known for training soldiers in sleep-deprived conditions. Many members of the military are adamant that sleep is more of a luxury than a need, but the research suggests otherwise. A study published in 2013 had the following findings:

*Poor sleepers (5-6) were significantly ( $P<.001$ ) more likely than good sleepers (0-1) to consider themselves in fair or poor health, be overweight or obese, and score in the lowest quartile of the emotional, social, family, and spiritual fitness dimensions. Additionally, poor sleepers were significantly ( $P<.001$ ) less likely to have a healthy body mass index and waist circumference, eat breakfast 6 or more times a week, meet aerobic exercise and resistance training recommendations, and pass their Army Physical Fitness Test in the top quartile [7].*

Despite cultural pressures that suggest sleep is unnecessary, science and research consistently point to sleep as a key pillar of mental and physical performance. College students are another glaring example of a population lacking adequate sleep. According to a study published in 2018 using the Pittsburgh Sleep Quality Index (PSQI), somewhere between 40 and 65 percent of college students in the United States are classified as having poor sleep [8]. Students spend many late nights finishing assignments and studying for exams. Many must also get up early for class, required workouts (for student-athletes), or work. Their busy schedules often force them to sacrifice sleep to fit everything in. Young adults in America are developing poor relationships with sleep at a young age.

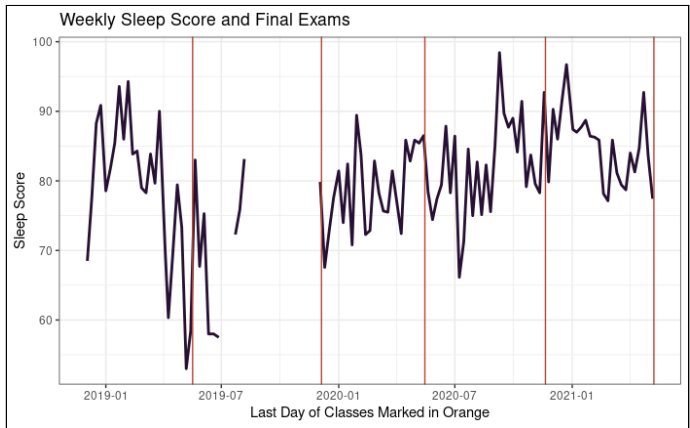


Fig. 6 Weekly Mean Sleep Score and Final Exam Impact (T.J. Liggett)

As a student athlete at Augustana, I have not been immune to the impacts that the collegiate calendar has on sleep. Final exams are one of the biggest opponents of sleep for college students. The graph below shows my sleep performance over the course of my time on WHOOP. The vertical lines represent the last day of classes for a semester. While my sleep performance has improved gradually over time, there is a clear dropoff in sleep performance around each final exam period. Despite my consistent efforts to get good sleep, a bevy of final projects, assignments, and exams typically takes a toll on my sleep performance around the end of the semester.

### VI. PERSONAL SLEEP FINDINGS

This project provided me with the opportunity to dive deeper into my personal data. WHOOP provides members with weekly, monthly, and yearly reports, but it was interesting to take a more summarized approach to this data for this project. Overall, my sleep performance has improved since I began using WHOOP. This is not just a result of the device but also the active steps I have taken to become a better sleeper. While it helps to have a device that measures sleep performance, it is a change in sleep habits that will unlock a better version of ourselves.

#### Trends Throughout the Week

Figures 7 through 9 display sleep statistics by day of the week. It is of note that I — like most people — tend to try to “catch up” on sleep a little bit on the weekends. While this is common in the American lifestyle, it is

much more beneficial to get a steady amount of sleep each night. In the future, I plan to focus on improving the amount of sleep I get during the week to try and counteract this cycle.

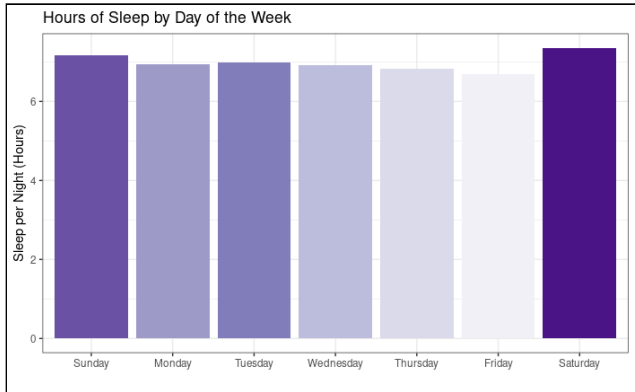


Fig. 7 Mean Hours of Sleep by Day of the Week (T.J. Liggett)

The negative side effect of this type of sleep pattern is displayed in Figure 9. Katherine Dudley [9] talks at length about this issue on the Harvard Health Blog. She talks about how our average amount of sleep might hide some of the issues with sleep debt. When people don’t get enough sleep at night, a sleep debt is incurred. Dudley states that “our sleep is not very forgiving of being moved around to more convenient times.” Sleep deficit can cause negative effects on our health, even if “made up” during the weekends. In the end, it is important to get an adequate amount of sleep every night, and to resolve sleep debt as soon as possible.

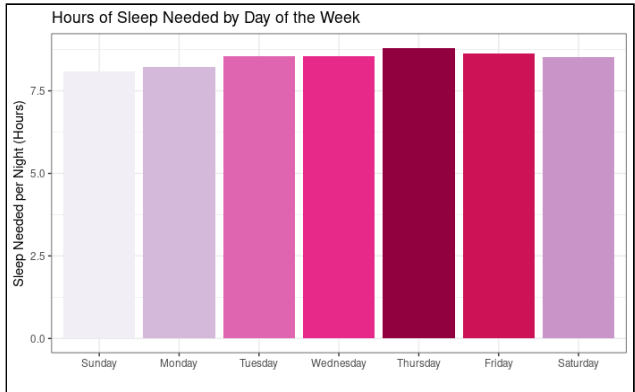


Fig. 8 Mean Sleep Needed by Day of the Week (T.J. Liggett)

The pattern of sleep debt during the week can be seen in my body’s recovery as well. Figure 10 shows that I am by far the most recovered on Mondays, with a gradual decline through the rest of the work week.

WHOOP has never shown me any trends like this by weekday, so it was interesting to see how varied my statistics were by the day of the week.

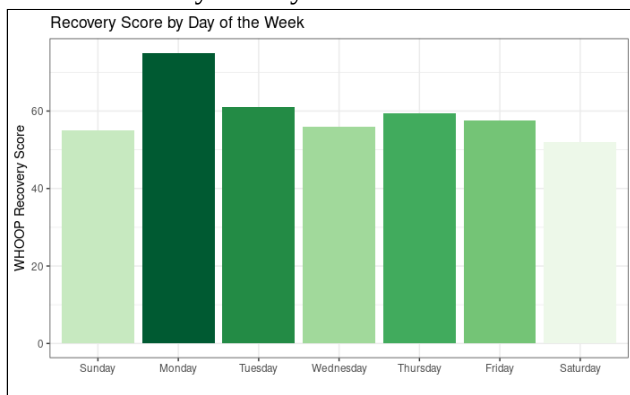


Fig. 9 Median Recovery Score by Day of the Week (T.J. Liggett)

#### Sleep Statistics over the Years

Figure 10 shows my average sleep duration, consistency, and efficiency over my time on WHOOP. Sleep consistency was introduced in early 2019, so there is no data for this statistic before that time. The large gap in the middle of the graph was a period of time in 2019 where I did not wear my WHOOP strap, so there is no data from this time.

Sleep duration, consistency, and efficiency are all important metrics in sleep. Sleep consistency is essential in setting the body's circadian rhythm [3], and it is also the metric that I tend to struggle the most with. I imagine this is true of most college students who often wake up at different times throughout the week due to classes and how late they were up the night before.

From the graphs to the right, it appears that I am making slight improvements in both sleep duration and consistency over time. While my sleep efficiency is declining slightly, this might be partially due to the increase in sleep duration. The body tends to sleep more efficiently in debt, but this sleep debt is in general problematic. There is certainly work to do, as I should strive to avoid the dips in these graphs that occur periodically.

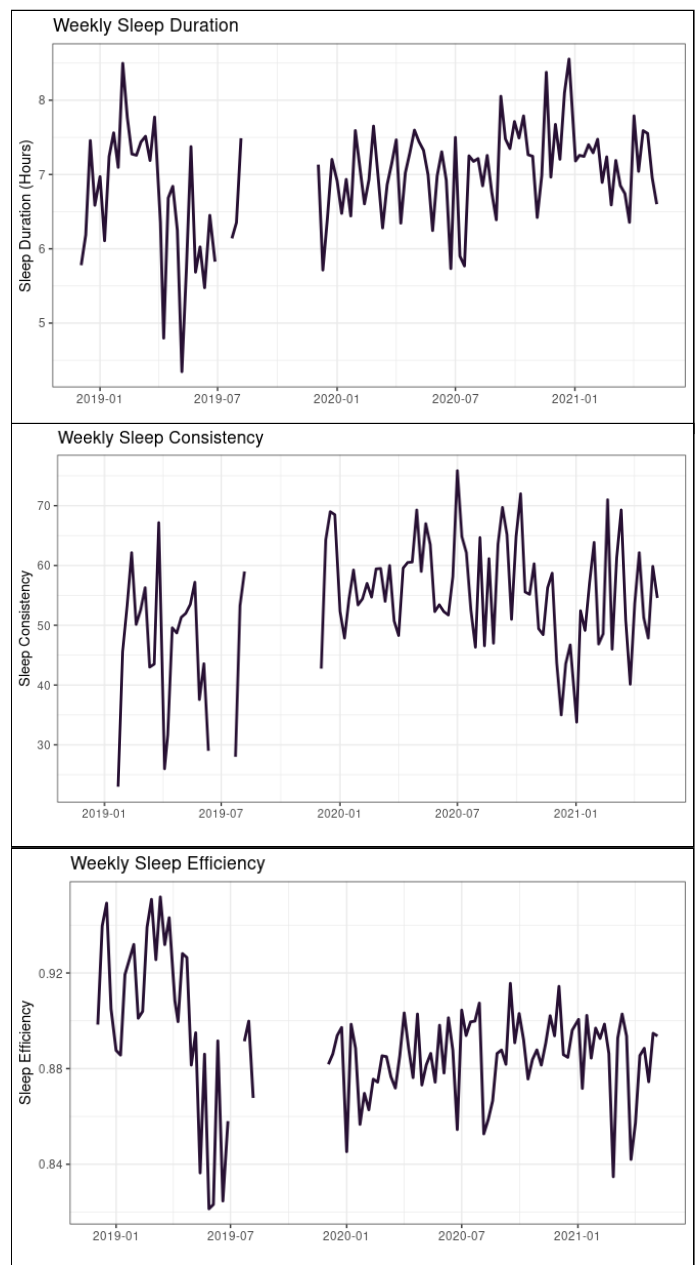


Fig. 10 Average Weekly Sleep Statistics Over Time (T.J. Liggett)



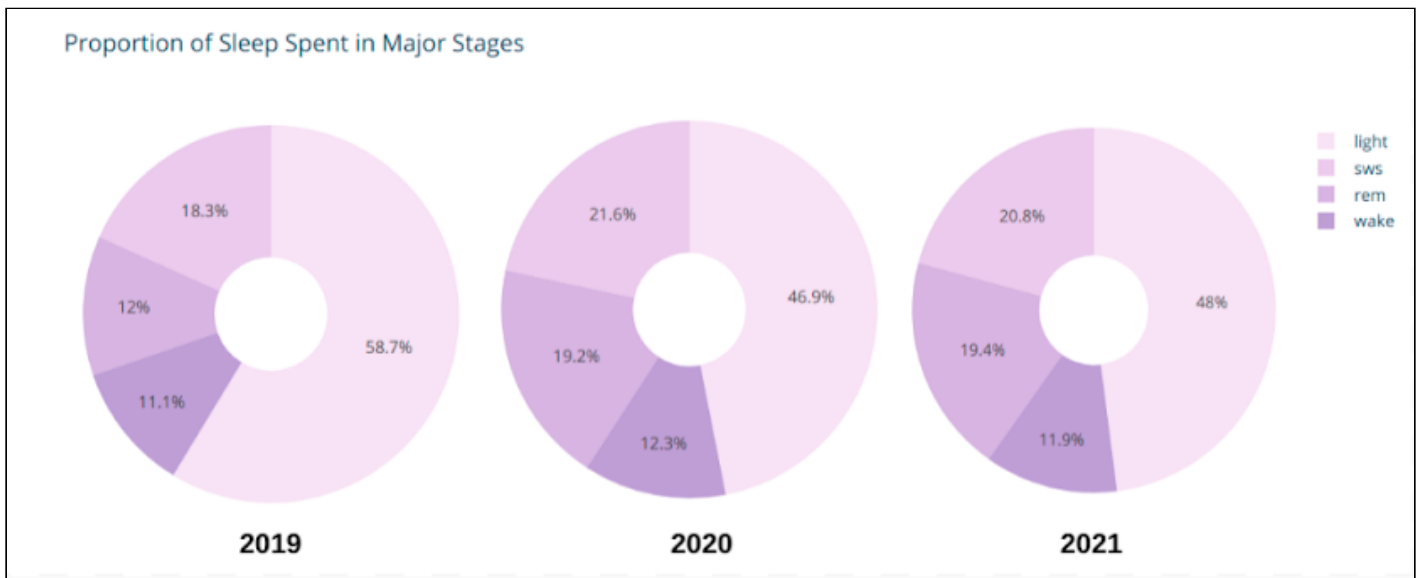


Fig. 11 Proportion of Sleep Spent in Major Stages Over The Years (T.J. Liggett)

Figure 11 shows the proportion of sleep I spent in each major stage by year. The proportion of sleep spent in both SWS and REM sleep drastically improved from 2019 to 2020. Getting more sleep in the deeper stages is very beneficial for health, so I was excited to see these numbers. In the future, my focus will be to lower the proportion of time spent in bed awake. This period is clearly a waste of time, and sleeping more efficiently grants more time to be active and enjoy life.

#### VII. SLEEP DASHBOARD

To help supplement the WHOOP app in the future, I created a sleep dashboard to provide an overview of how my sleep is going. This dashboard displays recent sleep need versus sleep duration, sleep efficiency, sleep consistency, and the proportion of sleep spent in the different sleep stages. The date range for this is flexible, allowing the user to observe different time frames and gain insight.

For the dashboard, I utilized the Dash framework for Python, which is produced by Plotly. Dash's graphics out of the box seemed similar in quality to those of Shiny Flexdashboard. It was relatively simple to generate Plotly graphics in this dashboard. For the data manipulation side of things, Dash felt easier than Flexdashboard. It was easier to manipulate the Pandas dataframes than the reactive data frames used for

Flexdashboard. A screenshot of this dashboard can be found in appendix D.

#### VIII. CONCLUSION

One of the most challenging things about sleep research is how personal the process of sleep is. Sleep statistics vary drastically from person to person, so what works for one person may not work for another. This data provided me with invaluable information about my own habits, and I would recommend WHOOP to anyone looking to improve their sleep habits. Many of the things I found confirmed larger patterns that have been observed in people in America and around the world. Sleep is an essential part of human life, and anyone looking to be their best self is advised not to overlook sleep. Sleep is a natural superpower of the body that promotes healing and growth. Sleep is strength.

## APPENDIX A: RESPIRATORY RATE AND COVID-19 DETECTION

One of the silver linings of the COVID-19 pandemic is the impressive display of technology that has saved lives and improved quality of life during this time. Modern technology has both improved efficiency during the pandemic and limited the impact of the pandemic. Conferencing technologies like Zoom and the wide accessibility of the internet have allowed companies and people to work remotely from the safety of their home, reducing their risk of infection. Multiple COVID vaccines were developed and began distribution by the later months of 2020, with much of the U.S. population vaccinated by mid 2021. The efforts of STEM professionals impacted the world tremendously.

On a smaller — but nonetheless important — scale, the WHOOP wearable displayed the power of big data and wearable technology. A study produced by Miller et al. [10] showed that advanced wearable devices like WHOOP could detect COVID-19 risk in both symptomatic and asymptomatic individuals. They found that a spike in respiratory rate can be an early indicator of COVID-19. After publishing their findings, WHOOP enabled members to track their respiratory rates, and alerted them if a sudden spike occurred.

This detection would prove impactful in the form of PGA tour golfer Nick Watney [11]. When Watney woke up on the Friday morning of the PGA tour's RBC Heritage tournament in 2020, he noticed this spike in his respiratory rate. Watney felt fine, but went to the tournament physician and talked himself into a COVID-19 test. The doctor was skeptical as Watney was asymptomatic, but the golfer's test came back positive. Watney was able to quarantine, when he otherwise potentially would have spread the disease to other golfers.

This story is a crazy example of the impact that data from wearable technology can have on the future. Using data from these devices could be the next step in preventative healthcare. These devices do not just make us healthier, but potentially safer as well. Watney is one of the many WHOOP members who detected COVID-19 with their device. Another example is me.

On September 8th, 2020, I woke up with symptoms of a mild cold. When I checked my WHOOP recovery from the previous night, I discovered that my respiratory rate had spiked to over 17 for the first time

ever, which can be seen in Figure 12 as the first spike above the black line. After hearing the many stories from WHOOP members, I decided to self-quarantine and get tested. Sure enough, my test came back positive. Without my recovery data, I likely wouldn't have gotten tested until the next day when my symptoms worsened. Another interesting observation from Figure 12 is the second spike above the black line on May 14th, 2021. This was the day I got my Johnson & Johnson COVID-19 Vaccination.

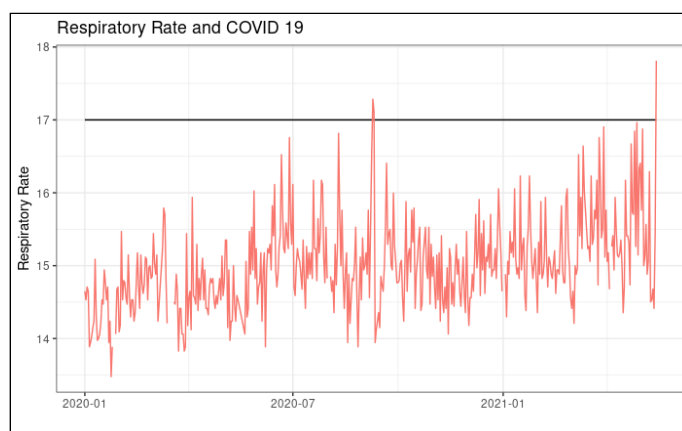


Fig. 12 How WHOOP Detected my COVID-19 Case (T.J. Liggett)



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