Visualizing data collected from Fitbit Wearables & Smart scales

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14th April 2021

Abstract

National Cancer Institute states that Head and Neck Cancer (HNC) accounts for about 4% of all cancers in the United States. Besides several respiratory and oral problems, HNC patients also suffer from unexplained weight loss and muscular atrophy. These two symptoms are identified as Cachexia (loss of body weight) and Sarcopenia (loss of lean muscle mass). The difference between cachexia and other types of weight loss is that it's involuntary. People who develop it don't lose weight because they're trying to trim down with diet or exercise. At the same time, their metabolism changes, which causes their body to break down too much muscle. Both inflammation and substances created by tumors can affect appetite and cause the body to burn calories more quickly than usual. Up to 80 percent of people with late-stage cancer have cachexia and close to one-third of people with cancer die from this condition. It is extremely valuable to the patient's life if this situation can be identified earlier. This project specifically aims to help Oncology Clinicians to analyze and detect early stages of Cachexia and Sarcopenia in HNC patients undergoing therapy.

Our platform uses Fitbit's Web API to retrieve time-series data points related to physical activity, food and water intake, sleep cycles, heart rate, body weight, and fat metrics of HNC patients. In their daily usage, whenever these smart devices sync with Fitbit servers, our backend server receives update notifications for each patient. For each notification received, a background task is scheduled by the backend server. Since these data processing tasks can be long-running and often take more than a few seconds, we are using a job scheduler to simplify the data collection process. Once these tasks complete successfully, this new information is stored in a relational database.

We also present a frontend interface with various interactive charts and visualizations, that allows clinicians to easily browse through the activity history of these patients. To prevent unauthorized access to patient data, our frontend is secured behind a password-protected login screen. By providing the activity data of patients directly in a transparent manner, this

platform enables clinicians to remotely monitor all the traits pointing towards cachexia and sarcopenia well in advance.

This project was developed following *Kitsiou et al.*'s iCardia, a mobile health platform developed to support remote monitoring of cardiac rehabilitation patients, using Fitbit Web API through their smartphones. The difference in our project is that it is specifically targeted at monitoring body weight during oncological treatment of head and neck cancer patients, and the timely prevention of aforementioned symptoms.

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1. Introduction

To solve the problem of remotely monitoring the physical activity of head and neck cancer patients, we provide an analytics dashboard protected by a password-based login to clinicians. Patient credentials are plugged into our server for the first time and our platform begins tracking updates from the Fitbit cloud.

Fitbit provides a Web API for accessing data from Fitbit activity trackers, Aria and Aria 2 smart scales, and manually entered logs from the Fitbit mobile application. Every time patients walk by their wireless base station (Bluetooth dongle and computer), data from their Fitbit device is silently uploaded in the background to Fitbit cloud.

We then process this obtained data into meaningful outputs as graphs in the dashboard for each user. The dashboard also allows comparing patient's data with the national average obtained from various sources like health studies, dietary guidelines, and Fitbit global activity index.

1.1. Instrumentation

For the confines of this project, the data was collected using the following Fitbit devices:

Fitbit Smart Weighing Scale:
Fitbit's smart weighing scales measure a person's body weight, body mass index (BMI), and body fat percentage and syncs the data periodically to Fitbit Cloud servers through the Fitbit smartphone app. We used a "Fitbit Aria Air" smart scale for the development of the platform. However, our platform supports other Fitbit smart scales too since they all use the same API.

Note: Aria Air cannot measure body fat percentage but tracks the body weight and BMI.

Fitbit SmartWatch:
The smartwatch keeps track of a person's all-day physical activity, heart rate variability, and sleep cycles. We used a "Fitbit Versa 2" smartwatch during the development of the platform. Our platform does work well with any smartwatch from Fitbit.

2. Fitbit Web API - Types of data collected

2.1. Activity Summary

Activity data is computed based on the activity recorded by the Fitbit smartwatch and manual user input of activity logs from the Fitbit app.

Sample data collected from Fitbit: Activity Summary

Data processed from the summary provided:

- Duration of each activity cycle
- Calories burned in each activity cycle
- Name and description of the activity cycle
- Total step count per day
- Total distance traveled per day
- Total calories burned per day
- Total floors climbed per day
- Total no. of minutes spent in each activity zone
    - Sedentary
    - Lightly active
    - Fairly active
    - Very active
- Physical Activity Level

2.2. Food & Water logs

Food and water logs are submitted by the user from the Fitbit app on their smartphone. No smartwatches or smart scales can determine these logs.

Sample data collected from Fitbit:

- Food Summary
- Water Summary

Data which could be processed from the summary provided:

- Type and quantity of each food item consumed
- Amount of calories present in each food item
- Total number of calories consumed per day
- Amount of fat consumed per day
- Amount of fiber consumed per day
- Amount of protein consumed per day
- Amount of Sodium consumed per day
- Amount of water consumed per day
- Basal metabolic rate
- Optimal calorie requirement of patient per day

2.3. Sleep summary

Sleep summary is recorded by the Fitbit smartwatch (provided the patient wears it while sleeping) and manual user input from within the Fitbit app on their smartphone.

Sample data collected from Fitbit: Sleep Summary

Data which could be processed from the summary provided:

- Duration of each sleep cycle
- Duration of each sleep condition (awake, asleep, or restless)
- Total number of sleep cycles
- The total duration of sleep time

2.4. Body Weight & Fat logs

Body Weight, Body Mass Index, and Fat percentage are sent by Fitbit smart weighing scale and manual user input from the Fitbit app.

Sample data collected from Fitbit:

- Weight logs
- Fat logs

Data which could be processed from the summary provided:

- Body Fat percentage (Aria Air - the smart scale provided for the project purpose cannot compute this)
- Body weight (Aria Air)
- BMI (Aria Air)
- Source of data (manual user input / smart scale input)

2.5. Heart Rate

Heart Rate data provided by Fitbit Web API and is sourced from the smartwatch only.

Sample data collected from Fitbit: Heart Rate

Data which could be processed from the summary provided:

- Resting heart rate (averaged on daily basis)
- Maximum and minimum heart rate per zone (fat burn / cardio / peak)
- Time spent in each heart rate zone (fat burn / cardio / peak)

3. Platform Components & Architecture

As shown in Figure 1 below, the data monitoring platform currently consists of the following components.

a) Fitbit smart devices (wearable smartwatch, smart weighing scale)
b) Smartphones with Android / iOS operating system
c) Fitbit mobile app and Fitbit Cloud server
d) An application server, a database, and a background job scheduler

e) Clinician dashboard

We chose Fitbit because of its popularity, accuracy, availability, and ease of use compared to its competitors. Fitbit currently holds the largest market share in the United States and is an established leader in the connected health and fitness market.

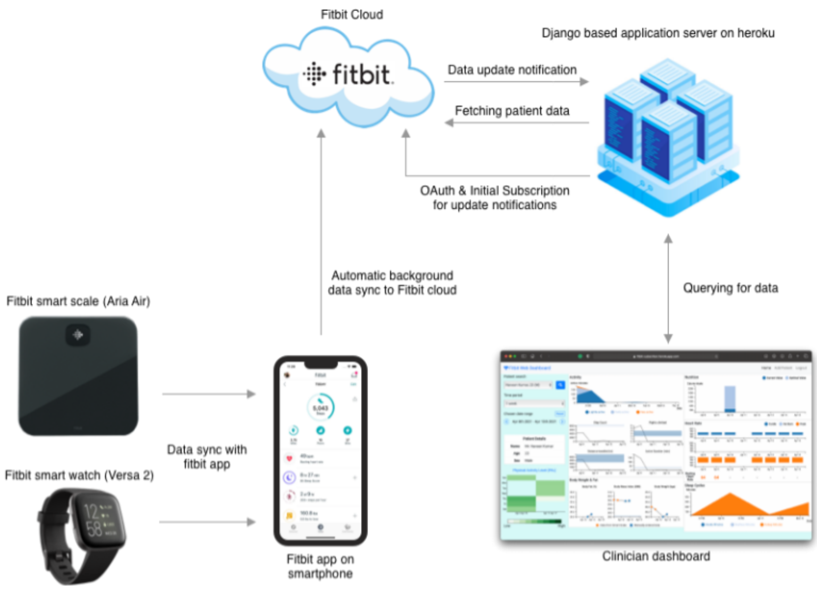


Figure 1: Platform Components & Architecture

3.1. Fitbit Companion App on smartphones

Fitbit smart devices pair with a companion iOS (version 12.0 or later) / Android (version 7.0 or later) smartphone app via Bluetooth Low Energy (Bluetooth 4.0 or later) network technology to wirelessly upload data to Fitbit cloud to provide users with easy to understand visualizations of their daily activities. The Fitbit mobile app incorporates a host of behavior change techniques and tools, including goal setting, self-monitoring of activity behavior and goals (e.g. physical activity, exercise, and sedentary time), feedback on performance, prompts/cues, social support, gamification in the form of "challenges", rewards (e.g. badges), and general encouragement among others.

3.2. Web Server Configuration

Our application server is written in Python 3 using the Django web application framework along with the Django-rest-framework module. The user-facing dashboard uses jQuery, Bootstrap, and D3.js to display content.

We are using PostgreSQL to store relational data for each user that has authenticated with our server. We have specifically chosen PostgreSQL as it has the option to store arbitrary JSON data in its JSON field type.

We also have a distributed task scheduler based on Celery to process incoming Fitbit subscription notifications. We'll arrive at the details later about this.

Heroku is a platform as a service (PaaS) that enables developers to build, run, and operate applications entirely in the cloud. Our application server uses the Heroku Docker container runtime to deploy a containerized web application.

3.2.1. Authorization

Any private information is not readily available from an API to be consumed directly. It requires user consent. Fitbit enforces this consent by letting users manually choose what data they would like to expose to third-party servers behind an OAuth 2.0 consent screen. Fitbit supports “Authorization Code Grant” and “Implicit Grant” flows. For the confines of this project, we have used Authorization Code Grant OAuth flow since our application server runs like a service (persistent process).

Once a user logs in with OAuth 2.0 authorization (Login with Fitbit) on our application server, we receive an access token and a refresh token from Fitbit Cloud. The access token has a default expiry of 86400 seconds (1 day), beyond which we can no longer use it to query information from Fitbit Cloud. We can, however, use the refresh token to fetch a new pair of access and refresh tokens again. These tokens are then updated in our database for all further uses. This refresh cycle repeats every time the access token expires.

These access tokens can be used to fetch any information from Fitbit that falls into the list of scopes given below.

Scope	Usage
`activity`	Querying physical activity summary daily
`heartrate`	Querying heart rate summary daily
`nutrition`	Querying food and water consumption logs daily
`sleep`	Querying sleep summary logs daily
`weight`	Querying BMI, body fat percentage, bodyweight daily
`profile`	Querying basic user info (age, gender, full name, Fitbit username) and configuring subscriptions for further updates from Fitbit Cloud
`settings`	Configuring subscriptions for further updates from Fitbit Cloud

3.2.2. Fitbit Subscription Notifications

Data synced to the smartphone is automatically sent to Fitbit cloud servers once every 10-15 minutes or every time the user manually accesses the app. When the app sends the synced data to Fitbit cloud servers, our Heroku-based application server is notified through the Fitbit Subscriptions API. This prompts our server to implement a background job scheduling system to pull the latest data every time it is notified. Upon receipt of a notification, the worker processes perform the appropriate API calls based on the scope of the notification.

3.2.2.1. Security

These notifications also referred to as webhooks, are HTTP POST requests attached with a body and a signature to verify the authenticity. To prevent arbitrary data from being injected into our database, this signature which can only be verified by our OAuth Client key and Secret keys combined is used as a security measure.

3.2.2.2. Sample notification data


```
[
  {
    "collectionType": "foods",
    "date": "2020-06-01",
    "ownerId": "228S74",
    "ownerType": "user",
    "subscriptionId": "1234"
  },
  {
    "collectionType": "foods",
    "date": "2020-06-02",
    "ownerId": "228S74",
    "ownerType": "user",
    "subscriptionId": "1234"
  },
  {
    "collectionType": "activities",
    "date": "2020-06-01",
    "ownerId": "184X36",
    "ownerType": "user",
    "subscriptionId": "2345"
  }
]
```


3.2.2.3. Distributed task queue

Once the webhook arrives, Fitbit expects an approximate response time of 5 seconds for each request. Now, considering that we need to fetch an entire day's worth of data from Fitbit API for each notification, we cannot afford to wait that long. If we delay the response, Fitbit assumes that the webhook timed out and disables our subscription stopping all further updates. So, we instead schedule the data fetching task to be performed asynchronously while immediately sending an **HTTP Response 204** (No Content) to the Fitbit cloud.

[Celery is a simple, flexible, and reliable distributed system](https://docs.celeryproject.org/) to process vast amounts of messages while providing operations with the tools required to maintain such a system. It's a task queue with a focus on real-time processing, while also supporting task scheduling.

3.3. Web Dashboard

Our web dashboard is a password-protected web application that is currently deployed on Heroku and is accessible [here](). It is a user-friendly environment that allows clinicians to view each participant's activity data in the form of graphs and charts. The dashboard also shows the optimal average values and their ranges for each type of metric.

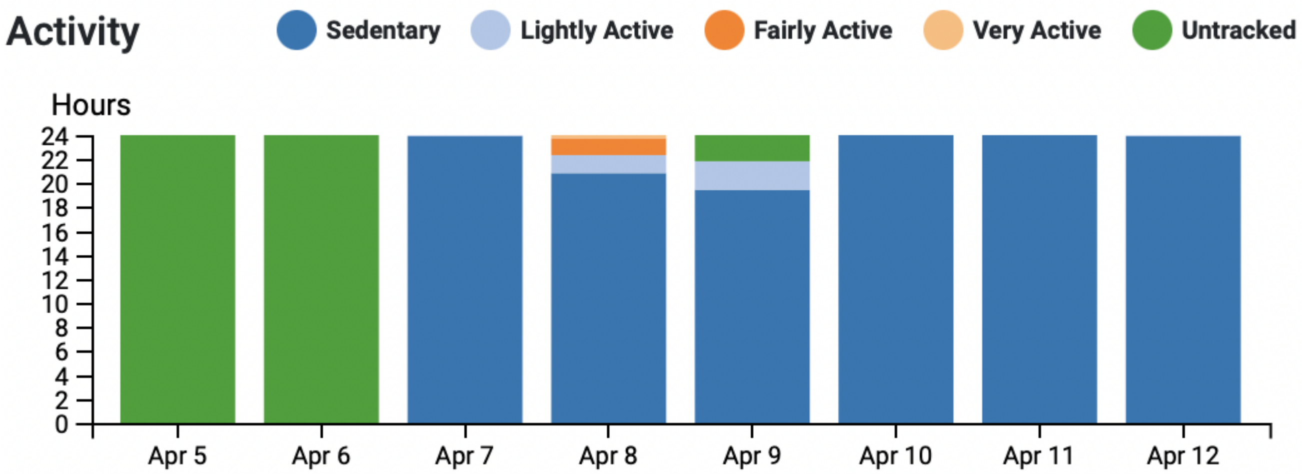
It is divided into 5 sections to enhance the visibility of all metrics as follows.

a) Activity
b) Nutrition
c) Body Weight & Fat
d) Heart Rate
e) Sleep Cycles

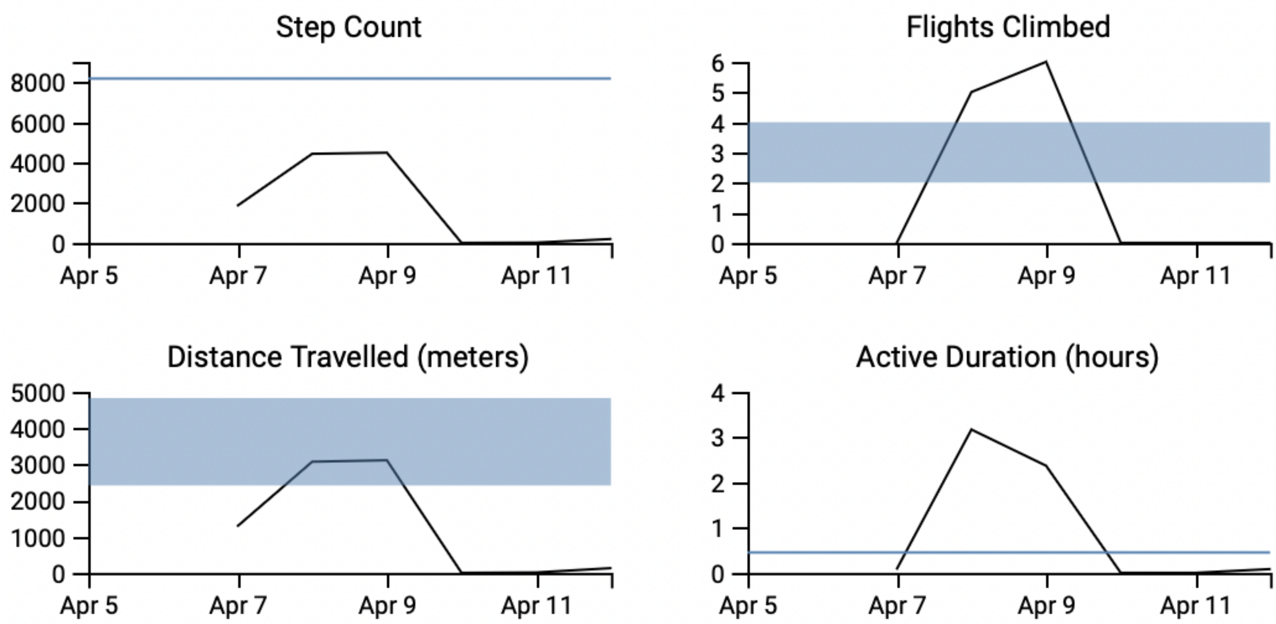
The left side of the dashboard has input controls to search for a particular patient and choose a time range for the metrics to be displayed.

3.3.1. Activity

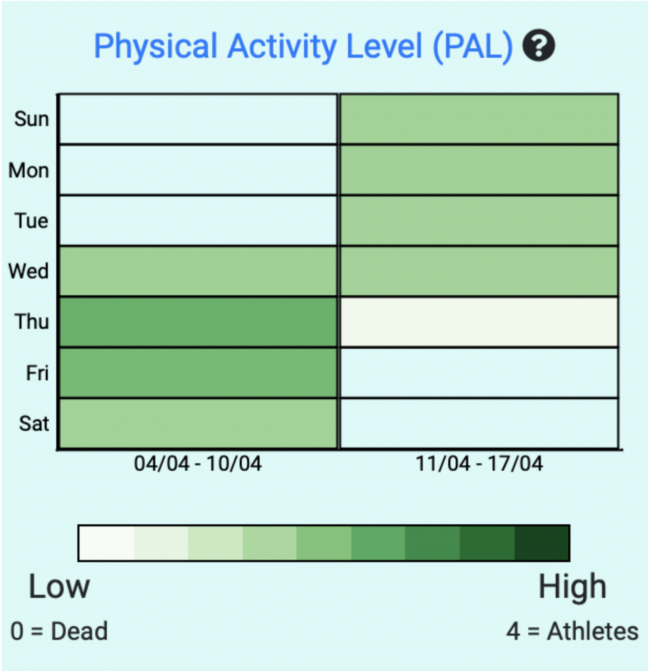
The activity (a) section comprises an activity zone chart that shows how active the patient was each day. We used a stacked 100% bar chart to show the amount of time the patient spends in a day in each zone. Looking at the chart below, for example, shows that the patient spends most of the day sedentary.



This section also consists of 3 additional metrics (as shown below) -- the total number of steps, the total number of flights of stairs climbed, total distance traveled during the day alongside the total amount of duration the patient was physically active. All of these values are displayed as line charts. These charts also highlight how the patient's activity differs from the U.S. National averages as collected by Fitbit Global Activity Index. This information provides us with a general overview of how the activity summary recorded from the patient's smartwatch is categorized.

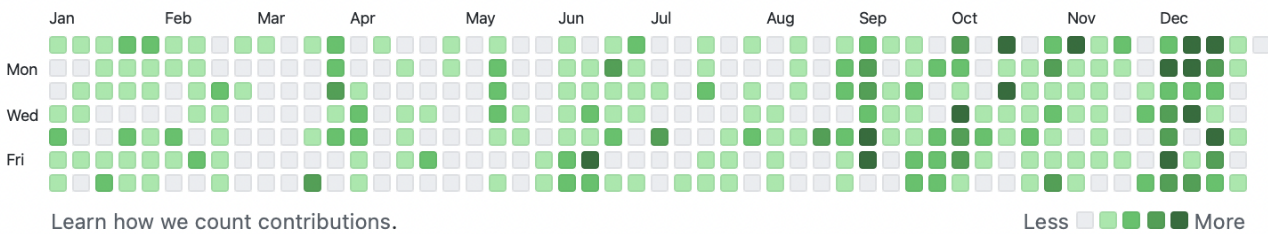


We also present the clinicians with a heatmap of the Physical Activity Level (PAL) during a chosen period. PAL is a measure of the ratio between total energy expenditure and resting energy expenditure for a particular day. It is a dimensionless quantity. This value ranges between 0 for a dead person to 4 which is observed in athletes undergoing heavy strength training sessions.



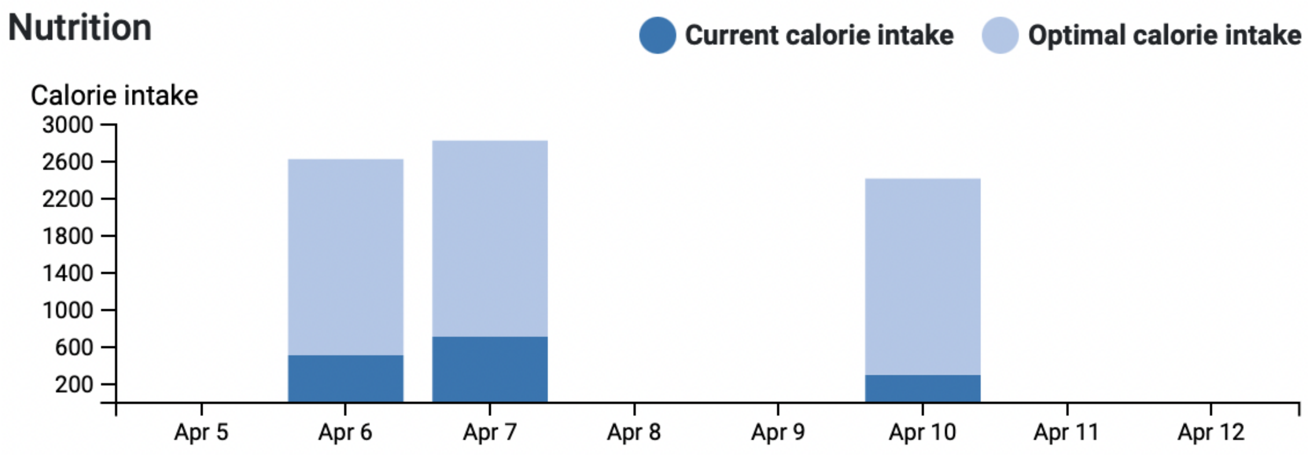
Looking at the figure above, we can see that the patient maintains a steady PAL value that is close to the average.

This heatmap was inspired by the contribution heatmap on GitHub's user profile page. It highlights how the number of contributions per day varied throughout the last year. The figure below shows what the contribution heatmap looks like.



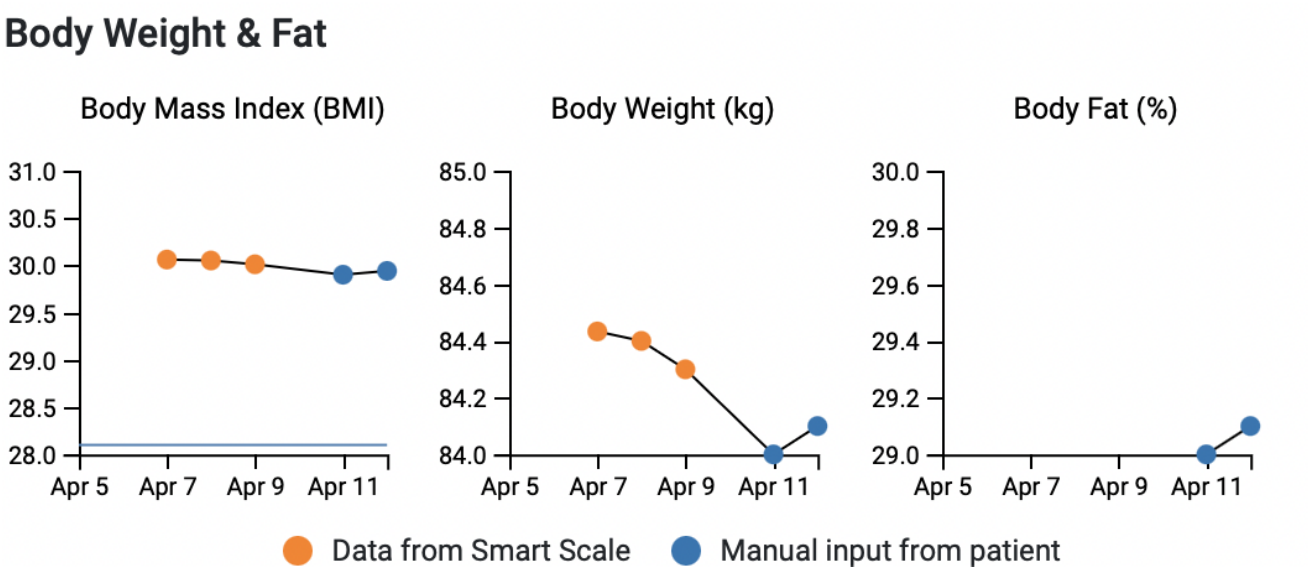
3.3.2. Nutrition

The nutrition (b) section differentiates between a patient's current calorie intake and approximate required calorie intake measurement on a stacked bar chart as shown below. For example, from the figure shown below, we can understand that the patient has been consuming very less amount of calories than required and is on the path to losing weight soon.



Note: Patients are expected to keep track of their everyday calorie consumption and record them through the Fitbit smartphone app. The required calorie intake is then calculated as the product of the Basal Metabolic Rate (BMR) and the Activity Factor (AF) of the patient. This value depends on the patient's current age, height, weight, and gender. Section 4.3 of this document explains these calculations in detail.

3.3.3. Body Weight & Fat



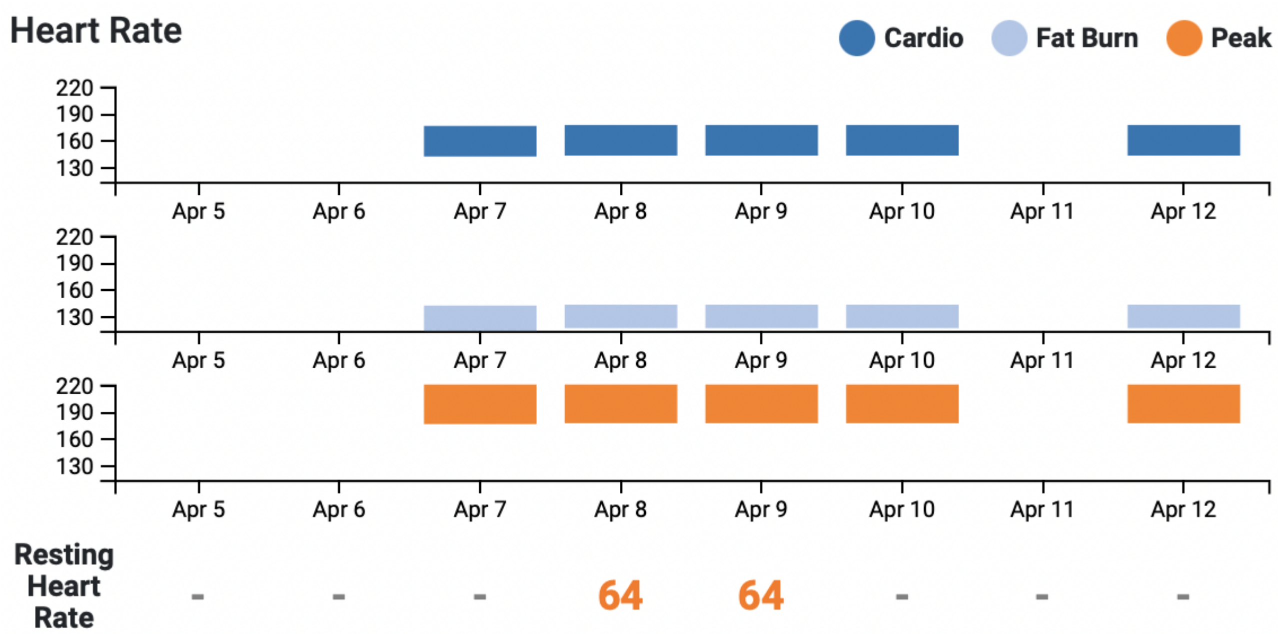
The Body weight and Fat section (c) highlights how the patient's weight, BMI, and Fat percentage vary over time as a line chart. The BMI chart also differentiates how the patient's BMI compares to the U.S. National averages from [Fitbit Global Activity Index](). This data can be either recorded from the smart weighing scales or manually updated by the user from the

Fitbit smartphone app and so the chart differentiates these data points by using different colors as shown above in the chart's legend.

For example, if we look at the chart above, it is noticeable that the patient is experiencing a steady weight loss from April 7th to April 11th albeit in small quantities. We can also see that the data reported from April 11th is manually added by the patient. Having information like this at hand can be helpful to clinicians in identifying if a patient is suffering from Cachexia.

3.3.4. Heart Rate

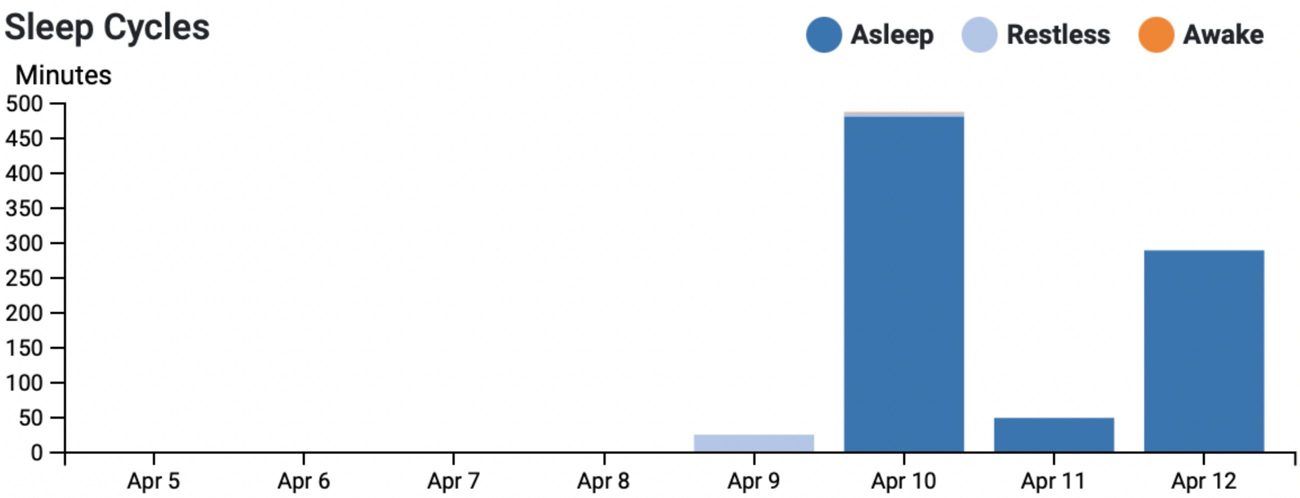
Heart rate section (d) compares the minimum and maximum heart rate shown by the patient in different heart rate zones, namely, cardio, fat burn, and peak. It also shows the average resting heart rate of the person during the day.



Taking a look at the figure above, it is noticeable that the patient is showing a normal heart rate in each zone with a fairly healthy resting heart rate of 64 bpm.

3.3.5. Sleep Cycles

The sleep cycles section (e) compares the quality of sleep the patient experienced during a particular day using the average amount of time spent in each sleep zone (awake, restless, or asleep) in a stacked bar chart.



4. Data used for comparison (Optimal avg. values)

4.1. Fitbit Global Activity Index

Fitbit provides a global activity index which provides the general average of Fitbit users worldwide updated annually.

The following metrics are captured from the global activity index for the United States:

- **Avg. step count:** 8170 steps
- **Avg. physically active duration:** 27 min
- **Avg. time spent sleeping:** 7hr 16min
- **Avg. resting heart rate:** 68 bpm
- **Avg. body mass index:** 28.1

4.2. Harvard Health Studies

The number of stairs/flights climbed per day by an average healthy American individual is given as 2-4 flights per day by *Juan Pablo Ray-Lopez, Emmanuel Stamatakis, Martin Mackey, Howard D. Sesso, and I-Min Lee in "Associations of self-reported stair climbing with all-cause and cardiovascular mortality: The Harvard Alumni Health Study", 2019* **DOI**

The total distance traveled by an average healthy individual per day is considered as 1.5 to 3 miles as given by a study on Aerobics, walking, and health: A Harvard Health Study. The study specifies it as 30-45 minutes of travel at 3-4 miles per hour which amounts to the calculated average of 1.5 to 3 miles of travel per day.

4.3. Dietary Guidelines from Office of Disease Prevention and Health Promotion

Following the 2015-2020 dietary guidelines, women are likely to need between 1600 to 2400 calories a day and men from 2000 to 3000 calories a day. However, the exact value varies based on age, size, height, overall health, and activity level.

The following calculation shows how to calculate an approximate calorie requirement for a particular individual with his details:

$$\textit{\textbf{Average calorie intake required}} = \textit{\textbf{Basal Metabolic Rate}}\ (BMR) \times \textit{\textbf{Activity Factor}}\ (AF)$$

where Basal Metabolic Rate (BMR) is given as follows:

$$\textit{\textbf{BMR}}\ (male) = \mathbf{10} \times \textit{\textbf{weight}}\ (kg) + \mathbf{6.25} \times \textit{\textbf{height}}\ (cm)\ \mathbf{-\ 5} \times \textit{\textbf{age}}\ (years) + \mathbf{5}$$
$$\textit{\textbf{BMR}}\ (female) = \mathbf{10} \times \textit{\textbf{weight}}\ (kg) + \mathbf{6.25} \times \textit{\textbf{height}}\ (cm)\ \mathbf{-\ 5} \times \textit{\textbf{age}}\ (years)\ \mathbf{-\ 161}$$

and the Activity Factor (AF) is given as follows:

Nature of the Activity	**Activity Factor**
Sedentary	1.2
Slightly Active	1.375
Moderately Active	1.55
Active	1.725
Very Active	1.9

Discussion

During the development of this project, only a small subset of all the data points provided by the Fitbit API was used. This data could further be processed to gain more insights into the patient's activity lifestyle, as follows.

- How active are the patient's days? Does he/she spend a considerable amount of time being sedentary?
- How does this data vary on weekends vs weekdays?
- What factors contribute to the highest calorie burn?
- Is the patient following a steady sleep schedule?
- Training a simple machine learning model to see if there's a better way at achieving better sleep

Insights like these could provide Clinicians with a better understanding of how a patient's health is varying over time and in turn what they can do to improve it.

Conclusion

This report outlines the main components and features of this Clinical dashboard in detail. While this was only tested using the specific Fitbit devices aforementioned in the report, this should in theory support all other Fitbit devices with more data parameters, like the Aria 2 weighing scale for instance, which also records the Body Fat percentage of the user.

The entire source code for this project can be found here. Overall, the learning experience has been quite positive for me. I hope to continue extending this project in due course later. Please feel free to get in touch if you have other questions that aren't answered in this report.