

Helping BellaBeat learn from FitBit

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1 Introduction

This case study, part of the Google Data Analytics Capstone, analyzes Fitbit tracker data to provide actionable insights for Bellabeat's marketing strategy. Bellabeat is a high-tech manufacturer of health-focused smart products for women and was co-founded by Urška Sršen and Sando Mur.

Note: This project will use R and SQL to explore the Fitness Tracker Data available at Kaggle

1.1 Business task

The goal of this analysis is to identify smart device usage trends and determine how these patterns can be applied to Bellabeat's customers to optimize their marketing strategy. It aims to answer the following 3 questions

1. What are some trends in smart device usage?
2. How could these trends apply to Bellabeat customers?
3. How could these trends help influence Bellabeat marketing strategy?

1.2 Key stakeholders

1. Urška Sršen: Bellabeat's cofounder and Chief Creative Officer
2. Sando Mur: Mathematician and Bellabeat's cofounder; key member of the Bellabeat executive team
3. Bellabeat marketing analytics team

1.3 Data Source and Description

Data source

The dataset, hosted on Kaggle, contains personal tracker data from 30 Fitbit users who consented to a distributed survey via Amazon Mechanical Turk. The data can be accessed from the following link:

<https://www.kaggle.com/datasets/arashnic/fitbit>

The original source of the data is the following:

<https://zenodo.org/records/53894#.X9oeh3Uzaao>

It was collected by

- Furberg, Robert
- Brinton, Julia
- Keating, Michael
- Ortiz, Alexa

Data Description (as described by Authors)

As mentioned on Kaggle:

These datasets were generated by respondents to a distributed survey via Amazon Mechanical Turk between 03.12.2016-05.12.2016. Thirty eligible Fitbit users consented to the submission of personal tracker data, including minute-level output for physical activity, heart rate, and sleep monitoring. Individual reports can be parsed by export session ID (column A) or time stamp (column B). Variation between output represents use of different types of Fitbit trackers and individual tracking behaviors / preferences.

This data set has a total of 29 files spanning over two time periods:

1. 3-12-16 to 4-11-16
2. 4-12-16 to 5-12-16

This analysis focuses specifically on the period between April 12, 2016, and May 12, 2016

There are 18 CSV files for the following indicators for the given time period:

- Physical Activities (Daily, Hourly, Minute-level)
- Calories (Daily, Hourly, Minute-level)
- Daily Intensities (Daily, Hourly, Minute-level)
- Daily Steps (Daily, Hourly, Minute-level)
- Heart Rate in Seconds
- Sleep (Daily, Minute)
- Weight

The majority of the data is in a long format. However, minute-level output for intensities, steps, and calories from April to May is also provided in a wide format.

This case study is structured into two parts:

- Part 1 will analyze **Daily** data for the following indicators:
 - Daily Activity
 - Daily Calories
 - Daily Intensities
 - Daily Steps
 - Daily Sleep
 - Weight
- Part 2 will analyze **Hourly** data for the following indicators:
 - Hourly Calories
 - Hourly Intensities
 - Hourly Steps

1.4 Issues with bias or credibility in this data

The dataset has a limited sample size (**33** respondents) and lacks critical demographic information such as age, gender, and occupation. Additionally, the weight dataset is too small (8 respondents) to provide statistically significant insights and will be excluded.

To gain meaningful insight into seasonal distribution, data collection should span at least a full year. Two months is insufficient for drawing definitive conclusions, as it doesn't account for variation across an entire annual cycle.

1.5 Privacy concerns

The kaggle data is open source and all Fitbit users consented to the submission of personal tracker data removing any privacy concerns

1.6 Using R and SQL

This data study uses a combination of *R* and *SQL*. (via SQLite)

SQL will be used for all Data Processing and Cleaning upto and including the Join

R will be used for formatting any SQL data and Data Visualization and Plots (including any analysis and transformations post the join).

Setting Up

The code below loads up the relevant libraries and sets up an SQL connection via SQLite.

```
#Load libraries
library(tidyverse)
library(readxl)
library(readr)
```

```

library(dplyr)
library(ggplot2)
library(ggcorrplot)
library(cowplot)
library(knitr)
library(kableExtra)
library(DBI)
library(RSQLite)

#Set up the SQL connection with a new database created purely in memory.
# I am storing it in memory rather than disk as I do not need these tables
# outside of this Rmd file
con <- dbConnect(RSQLite::SQLite(), dbname = ":memory:")

#General Settings for Code chunks
knitr::opts_chunk$set(connection = con) # Enable the connection for all chunks
knitr::opts_chunk$set(fig.align = "center") # Align output when knitting the document

```

Creating tables from the CSV files

Dedicated CSV data files exist for each of the indicators mentioned above. The code below loads all six of these CSV files as separate tables for analysis using SQL

```

dbWriteTable(con, "dailyactivity_merged",
            read.csv("Fitbit_Data/dailyActivity_merged.csv"))
dbWriteTable(con, "dailyintensities_merged",
            read.csv("Fitbit_Data/dailyIntensities_merged.csv"))
dbWriteTable(con, "dailycalories_merged",
            read.csv("Fitbit_Data/dailyCalories_merged.csv"))
dbWriteTable(con, "dailysteps_merged",
            read.csv("Fitbit_Data/dailySteps_merged.csv"))
dbWriteTable(con, "sleepday_merged",
            read.csv("Fitbit_Data/sleepDay_merged.csv"))
dbWriteTable(con, "weightLogInfo_merged",
            read.csv("Fitbit_Data/weightLogInfo_merged.csv"))
dbWriteTable(con, "hourlyintensities_merged",
            read.csv("Fitbit_Data/hourlyIntensities_merged.csv"))
dbWriteTable(con, "hourlycalories_merged",
            read.csv("Fitbit_Data/hourlyCalories_merged.csv"))
dbWriteTable(con, "hourlysteps_merged",
            read.csv("Fitbit_Data/hourlySteps_merged.csv"))

```

2 Part 1: Daily Level Analysis

2.1 Data Processing and Cleaning

This section details the process for data processing and cleaning in preparation for the daily analysis.

Initially, it will identify the tables required for joining to derive information for meaningful insights. Subsequently, it will select the relevant columns from these tables through in-depth examination, data validation, and checks for duplicate and missing values. The final steps will involve cleaning and transforming the data, followed by joining it into a consolidated data frame.

2.1.1 Shortlisting Tables

As mentioned in the description, individual records in each data file represent an individual at a specific time period. This is significant because it implies that any joins between the tables will necessitate being performed at the individual-datetime level.

We have identified a total of six relevant daily data indicators. We will assess which ones require joining.

- Activity
- Calories
- Intensities
- Steps
- Sleep
- Weight

2.1.1.1 Unique ID's in each table Let's first check the number of Unique ID's in each of the daily tables. This will help determine any tables that do not contain information for all tables

The following SQL query checks the number of unique ID's in all 6 tables.

```
SELECT          -- Activity Table
    'Activity' AS DataIndicator, -- Data indicators representing each table
    COUNT(DISTINCT Id) AS UniqueIds -- Count of Unique IDs
FROM
    dailyactivity_merged
UNION          -- UNION to stack rows for all tables
    SELECT          -- Process Repeated for Weight
        'Weight' AS DataIndicator,
        COUNT(DISTINCT Id) AS UniqueIds
    FROM
        weightlogininfo_merged
UNION
    SELECT          -- Process Repeated for Sleep
        'Sleep' AS DataIndicator,
        COUNT(DISTINCT Id) AS UniqueIds
    FROM
        sleepday_merged
UNION
    SELECT          -- Process Repeated for Steps
        'Steps' AS DataIndicator,
        COUNT(DISTINCT Id) AS UniqueIds
    FROM
        dailysteps_merged
UNION
    SELECT          -- Process Repeated for Intensities
        'Intensities' AS DataIndicator,
```

```

        COUNT(DISTINCT Id) AS UniqueIds
    FROM
        dailyintensities_merged
UNION
    SELECT          -- Process Repeated for Calories
        'Calories' AS DataIndicator,
        COUNT(DISTINCT Id) AS UniqueIds
    FROM
        dailycalories_merged
ORDER BY          -- Sort by Unique ID's
    UniqueIds

```

Table 1: 6 records

DataIndicator	UniqueIds
Weight	8
Sleep	24
Activity	33
Calories	33
Intensities	33
Steps	33

The results above indicate a maximum sample size of 33 respondents.

The weight data set will need to be dropped from this analysis due to insufficient data. Only 8 respondents provided weight information, making the sample size too small for meaningful insights

The sleep data, while limited to only 24 respondents, will be retained. However, it's important to be aware that merging this data with other tables will likely result in missing values for the columns originating from the sleep table.

After dropping weight, we now have a total of 5 data indicators:

- Activity
- Calories
- Intensities
- Steps
- Sleep

2.1.1.2 Checking for Shared Column Names via a Pivot Table Next, we will determine which of the remaining tables require joining. Although each indicator has its own dedicated data file, we need to check if any of these already contain combined data from others.

Our first step is to review the column names in each table to identify shared names.

The following code will generate a pivot table with the following details:

- Rows: Combined a list of unique column names
- Columns: The 5 data indicators (Activity, Calories, Intensities, Steps and Sleep) columns.
- Values: 1 if a column is present in the tables as represented by the Data Indicator. 0 otherwise.

```

-- The Outer Query creates a pivot table from the pivot_data created by the subquery

-- Unique values from the Field column represent the rows of the pivot table
-- This is achieved through group aggregation using the GROUP BY clause in
-- conjunction with the SUM function

```

```

-- GROUP By groups all rows for a given field together
-- The SUM() function for the CASE statement collapses all rows for a field in one

-- Columns for the Pivot Table and the Values in them are created using CASE
-- For each Field/Column Name, CASE checks if it is present in the table
-- represented by the Data Indicator
-- If a given field is present, a Value of 1 is assigned to the relevant Column
-- If a given field is not present, a value of 0 is assigned instead

SELECT
    Field,
    SUM(CASE WHEN DataIndicator = 'Activity' THEN 1 ELSE 0 END) AS Activity,
    SUM(CASE WHEN DataIndicator = 'Intensities' THEN 1 ELSE 0 END) AS Intensities,
    SUM(CASE WHEN DataIndicator = 'Steps' THEN 1 ELSE 0 END) AS Steps,
    SUM(CASE WHEN DataIndicator = 'Calories' THEN 1 ELSE 0 END) AS Calories,
    SUM(CASE WHEN DataIndicator = 'Sleep' THEN 1 ELSE 0 END) AS Sleep,
    Count(*) as Total -- Count total tables the field column is in
FROM
    -- The Inner query below stores column names from each of the 6 tables
    -- in a column named Field

    -- Column names are retrieved using PRAGMA table_info(table-name)
    -- This is a specialized command in SQLite used to retrieve metadata about the
    -- columns within a specific table

    -- A DataIndicator value was also assigned to each table to represent it.
    -- Results from the six tables rows are combined into a single output using the
    -- UNION operation and are aliased as pivot_data
    (SELECT
        name AS Field, 'Sleep' AS DataIndicator
    FROM
        PRAGMA_TABLE_INFO('sleepday_merged')
    UNION
        SELECT
            name AS Field, 'Activity' AS DataIndicator
        FROM
            PRAGMA_TABLE_INFO('dailyactivity_merged')
    UNION
        SELECT
            name AS Field, 'Steps' AS DataIndicator
        FROM
            PRAGMA_TABLE_INFO('dailysteps_merged')
    UNION
        SELECT
            name AS Field, 'Intensities' AS DataIndicator
        FROM
            PRAGMA_TABLE_INFO('dailyintensities_merged')
    UNION
        SELECT
            name AS Field, 'Calories' AS DataIndicator
        FROM
            PRAGMA_TABLE_INFO('dailycalories_merged')) as pivot_data

```

```

Group By
  Field -- Group By Field and then use SUM() in the select statement for unique rows
Order by
  Activity, Total DESC, Field
  -- Order by the Activity column, then by Total
  -- Count (in descending order) and then by Field for easier visualization.

```

The results derived from the SQL query will be color-coded and formatted to facilitate visualization.

- All rows where ‘Activity’ is equal to 0, signifying rows for all columns not present in the ‘Activity’ table, are formatted in bold. Given that the SQL table was ordered by ‘Activity,’ these rows will appear at the top of the pivot table.
- The row corresponding to the ‘ID’ field is highlighted in green, as this column will serve as the key for joining tables.
- The rows for ‘ActivityDay,’ ‘ActivityDate,’ and ‘Sleepday’ are highlighted in salmon red.
- The rows for ‘TotalSteps’ and ‘StepTotal’ are highlighted in *yellow**.

```

pivot_table %>%
  kable(caption = "Presence of a Field in each Table. 1 if Yes, 0 if not",
        booktabs=TRUE) %>% kable_styling("striped") %>% #For striped rows
  row_spec(which(pivot_table$Activity == 0), bold=TRUE) %>%
  row_spec(which(pivot_table$Field == 'Id'), background ='#C1FFC1') %>%
  row_spec(which(pivot_table$Field == 'ActivityDay' |
                  pivot_table$Field == 'ActivityDate' |
                  pivot_table$Field == 'SleepDay'),background ='#FA8072') %>%
  row_spec(which(pivot_table$Field == 'TotalSteps' |
                  pivot_table$Field == 'StepTotal'), background ='#FAFAD2')

```

Table 2: Presence of a Field in each Table. 1 if Yes, 0 if not

Field	Activity	Intensities	Steps	Calories	Sleep	Total
ActivityDay	0	1	1	1	0	3
SleepDay	0	0	0	0	1	1
StepTotal	0	0	1	0	0	1
TotalMinutesAsleep	0	0	0	0	1	1
TotalSleepRecords	0	0	0	0	1	1
TotalTimeInBed	0	0	0	0	1	1
Id	1	1	1	1	1	5
Calories	1	0	0	1	0	2
FairlyActiveMinutes	1	1	0	0	0	2
LightActiveDistance	1	1	0	0	0	2
LightlyActiveMinutes	1	1	0	0	0	2
ModeratelyActiveDistance	1	1	0	0	0	2
SedentaryActiveDistance	1	1	0	0	0	2
SedentaryMinutes	1	1	0	0	0	2
VeryActiveDistance	1	1	0	0	0	2
VeryActiveMinutes	1	1	0	0	0	2
ActivityDate	1	0	0	0	0	1
LoggedActivitiesDistance	1	0	0	0	0	1
TotalDistance	1	0	0	0	0	1
TotalSteps	1	0	0	0	0	1
TrackerDistance	1	0	0	0	0	1

Insights

The following insights were derived from the Pivot Table analysis:

- Most columns are present in the Activity Data set. Six out of a total of 21 rows exhibit a value of 0 for Activity (the top six rows are highlighted in bold).
- The ‘Id’ column is common across all five tables, as indicated in the green row.
- A single, consolidated Date Column is absent. Three potential date fields were identified due to their similar naming conventions: ‘ActivityDate’, ‘ActivityDay’, and ‘SleepDay’. These rows are highlighted in red.
- ‘ActivityDay’ and ‘SleepDay’ are included in the six rows highlighted in bold. ‘ActivityDay’ is found in the Steps, Calories, and Intensities tables, while ‘SleepDay’ is exclusive to the Sleep table. Further investigation is necessary to ascertain if these are equivalent to ‘ActivityDate’ in the Activity table.
- ‘StepTotal’ is another column name not present in the Activity table but found in the Steps table. Scrolling through the pivot table reveals that the Activity table contains ‘TotalSteps’. Additional analysis is required to confirm the equivalence of these two columns. See rows highlighted in Yellow
- The remaining three columns not present in the Activity table, ‘TotalMinutesAsleep’, ‘TotalSleepRecords’, and ‘TotalTimeinBed’, lack similarly named alternatives in the Activity data set and are therefore unique columns from the Sleep table.

2.1.1.3 Resolving Inconsistencies in Column Names and Values Insights from the pivot table show that when compared with the Activity table:

- Steps contains two additional columns; ActivityDay and StepTotal
- Calories contains one additional column; ActivityDay
- Intensities contains one additional column; ActivityDay
- Sleep contains 4 additional columns; SleepDay, TotalMinutesAsleep’, ‘TotalSleepRecords’, and ’TotalTimeinBed. *Any analysis for the last 3 columns with the data from any other table warrants a join*

The SQL query below will check:

- The number of records when TotalSteps is not the same as StepTotal
- The number of records when ActivityDate is not the same as ActivityDay in each of Calories, Steps and Intensities tables
- The number of records when ActivityDate is not the same as SleepDay

```
WITH step_diff AS (    -- Create a temporary table when TotalSteps != StepTotal
SELECT
    Count(*) AS StepsDiff, -- Count for total Rows
    1 AS UniId           -- 1 set as a uniqueid which will be used for the Join
FROM
    (SELECT
        TotalSteps
    FROM
        dailyactivity_merged
    EXCEPT          -- EXCEPT operator is a set operation that returns distinct
    -- rows from the result set of the first SELECT query that are not present
    -- in the result set of the second
        SELECT
            StepTotal
    FROM
        dailysteps_merged) AS tab1
),           -- Repeat for ActivityDate != ActivityDay in Steps
date_diff_step AS (
SELECT
    Count(*) AS DatesDiffSteps,
```

```

    1 as UniId
FROM
  (SELECT
    ActivityDate
  FROM
    dailyactivity_merged
EXCEPT
  SELECT
    ActivityDay
  FROM
    dailysteps_merged) as tab2
), -- Repeat for ActivityDate != ActivityDay in Calories
date_diff_cal as (
SELECT
  Count(*) as DatesDiffCal,
  1 as UniId
FROM
  (SELECT
    ActivityDate
  FROM
    dailyactivity_merged
EXCEPT
  SELECT
    ActivityDay
  FROM
    dailycalories_merged) as tab3
), -- -- Repeat for ActivityDate != ActivityDay in Intensities
date_diff_inten as (
SELECT
  Count(*) as DatesDiffInten,
  1 as UniId
FROM
  (SELECT
    ActivityDate
  FROM
    dailyactivity_merged
EXCEPT
  SELECT
    ActivityDay
  FROM
    dailyintensities_merged) as tab4
), -- Repeat for ActivityDate != SleepDay
date_diff_sleep as (
SELECT
  Count(*) as DatesDiffSleep,
  1 as UniId
FROM
  (SELECT
    ActivityDate
  FROM
    dailyactivity_merged
EXCEPT
  SELECT

```

```

SleepDay
FROM
    sleepday_merged) as tab5
)
-- Join rows from all 5 temporary tables in 1 using UniId as the key
SELECT
    A.StepsDiff,
    B.DatesDiffSteps,
    C.DatesDiffCal,
    D.DatesDiffInten,
    E.DatesDiffSleep
FROM
    step_diff as A
JOIN
    date_diff_step as B ON A.UniId=B.UniId
JOIN
    date_diff_cal as C ON A.UniId=C.UniId
JOIN
    date_diff_inten as D ON A.UniId=D.UniId
JOIN
    date_diff_sleep as E ON A.UniId=E.UniId

```

Table 3: 1 records

StepsDiff	DatesDiffSteps	DatesDiffCal	DatesDiffInten	DatesDiffSleep
0	0	0	0	31

- 0 records are returned when TotalSteps in the Activity table is *not* the same as StepTotal in the Steps table.
- 0 records are returned when ActivityDate in the Activity table is *not* the same as ActivityDay in the Steps table.
- 0 records are returned when ActivityDate in the Activity table is *not* the same as ActivityDay in the Calories table.
- 0 records are returned when ActivityDate in the Activity table is *not* the same as ActivityDay in the Intensities table
- 31 records are returned when ActivityDate is *not* the same as SleepDay. This includes all 31 days for the whole time-period. This will need to be explored and cleaned further in the next section.

Subsequently, the Steps, Calories, and Intensities tables were found to be redundant, as their data is already captured within the Daily Activity table. Therefore, only the **Activity** and **Sleep** tables will be merged for this analysis.

2.1.2 Shortlisting Columns to Include in the Join

Having identified that the Activity and Sleep tables require a join, the next steps are to determine the specific columns for the join and to identify any necessary data cleaning or transformations.

2.1.2.1 Cleaning Dates The inconsistency between the ActivityDate and SleepDay values, as previously noted, will be addressed in this section to ensure they are uniform.

Compare SleepDay with ActivityDate

First, let's retrieve the values from both tables for comparison. .

```
With sleep as ( -- Create a temporary table with the first row of the Sleep table
SELECT
    SleepDay as Dates,      -- Rename as Dates
    'Sleep' as Tablename   -- Tablename to distinguish table
FROM
    sleepday_merged
LIMIT
    1      -- 1st row only
),
activity as (      -- Repeat for Activity with a new temporary table
SELECT
    ActivityDate as Dates,
    'Activity' as Tablename
FROM
    dailyactivity_merged
LIMIT
    1
)
SELECT
    *
FROM
    sleep
UNION      -- Union results from both tables
SELECT
    *
FROM
    activity
```

Table 4: 2 records

Dates	Tablename
4/12/2016	Activity
4/12/2016 12:00:00 AM	Sleep

The results show that while the SleepDay column also represents dates, its values are in a completely different format; they contain time stamps as well.

The next step involves creating new columns, labeled RecordedDate, in both tables. These columns will store the date values after they have been cleaned and transformed into a consistent format.

Activity Table

Currently values in ActivityDate are either in the M/DD/YYYY or M/D/YYYY format. These need to be standardized to the YYYY-MM-DD format and stored in a column named RecordedDate

The code below creates a new column for RecordedDate

```
ALTER TABLE dailyactivity_merged -- Create a new column named as RecordedDate
ADD COLUMN RecordedDate TEXT
```

The code below updates the RecordedDate column standardizing corresponding values in the ActivityDate table to the YYYY-MM-DD format

```
UPDATE dailyactivity_merged

-- Update RecordedDate with Cleaned Values from the ActivityDate field
-- Last 4 digits as YYYY
-- Month as MM (All months are currently either 4 or 5, these will be formatted
-- to 04 or 05)
-- Day as DD (Dates when Days are represented in single digits eg 1 will need to
-- be treated separately from Days in double digits eg 10)

SET RecordedDate = (
    SUBSTR(ActivityDate, -4) || '-0' || -- Last 4 digits for YYYY
    SUBSTR(ActivityDate, 1,1) || -- 0 and First digit for MM
    CASE -- 0 and Third, or, Third and Fourth Digits for DD
        WHEN SUBSTR(ActivityDate, 4, 1) = '/'
        THEN '-0' || SUBSTR(ActivityDate, 3, 1)
        ELSE '-' || SUBSTR(ActivityDate, 3, 2)
    END
)
```

The code below checks that RecordedDate stores the correct values from ActivityDate regardless of the format (M/DD/YYYY or M/D/YYYY)

```
With doubleday as ( -- Create a temporary table with rows where the ActivityDate
SELECT          --format is M/DD/YYYY
    ActivityDate, RecordedDate
FROM
    dailyactivity_merged
WHERE
    LENGTH(ActivityDate) = 9
LIMIT
    1      -- 1st row only
),
singleday as ( -- Create a temporary table with rows where the ActivityDate
SELECT          --format is M/D/YYYY
    ActivityDate, RecordedDate
FROM
    dailyactivity_merged
WHERE
    LENGTH(ActivityDate) = 8
LIMIT
    1      -- 1st row only
)
SELECT
    *
FROM
    doubleday
UNION      -- Union results from both tables
SELECT
```

```

*
FROM
singleday

```

Table 5: 2 records

ActivityDate	RecordedDate
4/12/2016	2016-04-12
5/1/2016	2016-05-01

Sleep Table

Currently values in SleepDay are either in the M/DD/YYYY hh:mm:s or M/D/YYYY hh:mm:s format. These need to be standardized to the YYYY-MM-DD format and stored in a column named RecordedDate

The code below creates a new column for RecordedDate

```

ALTER TABLE sleepday_merged -- Create a new column named as RecordedDate
ADD COLUMN RecordedDate TEXT

```

The code below updates the RecordedDate column standardizing corresponding values in the SleepDay table to the YYYY-MM-DD format

```

-- Update RecordedDate with Cleaned Values from the SleepyDay field

-- When Day are in Single Digits:
-- Digits 5-9 as YYYY
-- 0 and First digit for MM
-- 0 and Third Digit, or , Third and Fourth Digit DDD
-- Day as DD (Dates when Days are represented in single digits eg 1 will need to
-- be treated separately from Days in double digits eg 10)

```

```

UPDATE sleepday_merged
SET RecordedDate =
CASE
    WHEN SUBSTR(SleepDay, 4, 1) = '/'
    THEN SUBSTR(SleepDay, 5,4) || '-0' || SUBSTR(SleepDay, 1,1) ||
        '-0' || SUBSTR(SleepDay, 3, 1)
    ELSE SUBSTR(SleepDay, 6,4) || '-0' || SUBSTR(SleepDay, 1,1) ||
        '-' || SUBSTR(SleepDay, 3, 2)
END
)

```

The code below checks that RecordedDate stores the correct values from SleepDay regardless of the format (M/DD/YYYY or M/D/YYYY)

```

With doubleday as ( -- Create a temporary table with rows where the SleepDay
SELECT           --format is M/DD/YYYY hh:mm:ss
    SleepDay, RecordedDate
FROM
    SleepDay_merged
WHERE
    LENGTH(SleepDay) = 21
LIMIT

```

```

1      -- 1st row only
),
singleday as (    -- Create a temporary table with rows where the ActivityDate
SELECT          --format is M/D/YYYY hh:mm:ss
    SleepDay, RecordedDate
FROM
    sleepday_merged
WHERE
    LENGTH(SleepDay) = 20
LIMIT
    1      -- 1st row only
)
SELECT
    *
FROM
    doubleday
UNION      -- Union results from both tables
SELECT
    *
FROM
    singleday

```

Table 6: 2 records

SleepDay	RecordedDate
4/12/2016 12:00:00 AM	2016-04-12
5/1/2016 12:00:00 AM	2016-05-01

The fields `ActivityDate` and `SleepDay` will now be excluded from the Join and any subsequent relevant code, as we have successfully created new date fields with cleaned data

2.1.2.2 Finalize and Validate Remaining Columns Next, we will assess if any other columns in the two tables require dropping or transformation. To begin, let's obtain a brief description of the columns within both tables.

```
PRAGMA table_info(dailyactivity_merged)
```

Table 7: 16 records

cid	name	type	notnull	dflt_value	pk
0	Id	REAL	0	NA	0
1	ActivityDate	TEXT	0	NA	0
2	TotalSteps	INTEGER	0	NA	0
3	TotalDistance	REAL	0	NA	0
4	TrackerDistance	REAL	0	NA	0
5	LoggedActivitiesDistance	REAL	0	NA	0
6	VeryActiveDistance	REAL	0	NA	0
7	ModeratelyActiveDistance	REAL	0	NA	0
8	LightActiveDistance	REAL	0	NA	0
9	SedentaryActiveDistance	REAL	0	NA	0
10	VeryActiveMinutes	INTEGER	0	NA	0
11	FairlyActiveMinutes	INTEGER	0	NA	0

cid	name	type	notnull	dflt_value	pk
12	LightlyActiveMinutes	INTEGER	0	NA	0
13	SedentaryMinutes	INTEGER	0	NA	0
14	Calories	INTEGER	0	NA	0
15	RecordedDate	TEXT	0	NA	0

```
PRAGMA table_info(sleepday_merged)
```

Table 8: 6 records

cid	name	type	notnull	dflt_value	pk
0	Id	REAL	0	NA	0
1	SleepDay	TEXT	0	NA	0
2	TotalSleepRecords	INTEGER	0	NA	0
3	TotalMinutesAsleep	INTEGER	0	NA	0
4	TotalTimeInBed	INTEGER	0	NA	0
5	RecordedDate	TEXT	0	NA	0

Let's also review their descriptions. The table below lists descriptions for the relevant columns from the Fitabase data dictionary avaialble at this link:

<https://www.fitabase.com/media/2126/fitabase-fitbit-data-dictionary-as-of-05162025.pdf>

```
datadescription <- read_excel("datadescription.xlsx", sheet='Daily')
kable(datadescription, booktabs=TRUE) %>% kable_styling("striped") %>%
  column_spec(2, width = "12cm")
```

Data Header	Data Description
ActivityDate	Date value in mm/dd/yyyy format.
TotalSteps	Total number of steps taken.
TotalDistance	Total kilometers tracked.
TrackerDistance	Total kilometers tracked by Fitbit device.
LoggedActivitiesDistance	Total kilometers from logged activities.
VeryActiveDistance	Kilometers travelled during very active activity.
ModeratelyActiveDistance	Kilometers travelled during moderate activity.
LightActiveDistance	Kilometers travelled during light activity.
SedentaryActiveDistance	Kilometers travelled during sedentary activity.
VeryActiveMinutes	Total minutes spent in very active activity.
FairlyActiveMinutes	Total minutes spent in moderate activity.
LightlyActiveMinutes	Total minutes spent in light activity.
SedentaryMinutes	Total minutes spent in sedentary activity.
Calories	Total estimated energy expenditure (in kilocalories).
SleepDay	Date on which the sleep event started. (in mm/dd/yyyy hh:mm:ss format)
TotalSleepRecords	Number of recorded sleep periods for that day. Includes naps > 60min
TotalMinutesAsleep	Total number of minutes classified as being “asleep”.
TotalTimeInBed	Total minutes spent in bed, including asleep, restless, and awake, that occurred during a defined sleep record.

Finalize and Validate Columns from the Activity table

Let's examine the distance and minutes columns from the Activity table to finalize which ones to keep.

Note: Variables name are renamed below for easier analysis and visualization. This renaming will be repeatedly used in other codes as well including the Join**

Validate Distance Columns

The code below list first 5 observations for the distance columns

```
SELECT
    LoggedActivitiesDistance as LogActDist,
    TotalDistance as TotalDist,
    TrackerDistance as TrackDist,
    SedentaryActiveDistance as SedActDist,
    LightActiveDistance as LightActDist,
    VeryActiveDistance as VeryActDist,
    ModeratelyActiveDistance as ModActDist
FROM
    dailyactivity_merged
LIMIT
    5
```

Table 10: 5 records

LogActDist	TotalDist	TrackDist	SedActDist	LightActDist	VeryActDist	ModActDist
0	8.50	8.50	0	6.06	1.88	0.55
0	6.97	6.97	0	4.71	1.57	0.69
0	6.74	6.74	0	3.91	2.44	0.40
0	6.28	6.28	0	2.83	2.14	1.26
0	8.16	8.16	0	5.04	2.71	0.41

It appears that Tracker Distance and Total Distance are largely equivalent. To confirm this, we can calculate the difference between these two variables and then compute summary statistics to check if the difference is zero.

Additionally, LoggedActivitiesDistance and Sedentary Active Distance appear to be mostly zero. We can calculate summary statistics to verify this observation.

The following query calculates the average difference between Tracker Distance and Total Distance and determines the percentage of rows where the difference is zero. It also computes the average values for LoggedActivitiesDistance and Sedentary Active Distance and counts the percentage of rows where these values are zero

```
SELECT
    avg(DistDiff) as AvgDistDiff, -- Mean of the difference
    COUNT(CASE WHEN DistDiff=0 THEN 1 END)*100/940 as PerDistDiffZero, -- % when 0
    avg(LogActDist) as AvgLogActDist, -- Mean of LoggedActivitiesDistance
    COUNT(CASE WHEN LogActDist=0 THEN 1 END)*100/940 as PerLogActDistZero, -- % when 0
    avg(SedActDist) as AvgSedActDist, -- Mean of SedentaryActiveDistance
    COUNT(CASE WHEN SedActDist=0 THEN 1 END)*100/940 as PedActDistZero -- % when 0
FROM -- Inner query to select relevant columns
(SELECT
    TrackerDistance,
    TotalDistance,
    LoggedActivitiesDistance as LogActDist,
    SedentaryActiveDistance as SedActDist,
```

```

    TrackerDistance - TotalDistance as DistDiff -- Difference the two
FROM
    dailyactivity_merged) as table1

```

Table 11: 1 records

AvgDistDiff	PerDistDiffZero	AvgLogActDist	PerLogActDistZero	AvgSedActDist	PedActDistZero
-0.0143511	98	0.1081709	96	0.0016064	91

The mean difference between ‘Tracker distance’ and ‘total distance’ is negligible, averaging approximately -0.01. The difference is precisely zero in 98.4% of instances.

Similarly, the mean of ‘LoggedActivitiesDistance’ is close to zero, registering as zero in 96.6% of cases. The Sedentary Active Distance is consistently zero (0) across all observations. This anomaly may be attributed to an import error; however, it has been confirmed that the actual values were so minuscule—only negligibly above zero—that the data import process rounded them down to zero.

Given the preceding analysis, Tracker Distance, LoggedActivitiesDistance, and SedentaryActiveDistance can be excluded from the scope of our analysis.

It is also apparent that the Total Distance is the sum of VeryActiveDistance, ModeratelyActiveDistance, and LightActiveDistance (disregarding Sedentary Active Distance, as its value is uniformly zero). We can confirm this by summing the values for VeryActiveDistance, ModeratelyActiveDistance, and LightActiveDistance and subsequently calculating the difference of the sum from the Total Distance.

The subsequent query calculates the difference between the sum, of VeryActiveDistance, ModeratelyActiveDistance, and LightActiveDistance, and TotalDistance. It then computes the minimum, maximum, and average values for this difference.

```

SELECT
    'TotalDistanceDifference' as Field,
    min((TotalDistance_Diff)) as Minimum,
    avg(TotalDistance_Diff) as Average,
    max((TotalDistance_Diff)) as Maximum
FROM
    (SELECT
        VeryActiveDistance + ModeratelyActiveDistance +
        LightActiveDistance - TotalDistance as TotalDistance_Diff
    FROM
        dailyactivity_merged) as table1

```

Table 12: 1 records

Field	Minimum	Average	Maximum
TotalDistanceDifference	-9.37	-0.0786596	0.0100006

The “Total distance” metric is not precisely equivalent to the sum of “VeryActiveDistance,” “ModeratelyActiveDistance,” and “LightActiveDistance”; however, it is highly comparable. **Consequently, the “TotalDistance” column will be excluded, and a new, comprehensive total will be calculated by aggregating the three active distance categories.**

Validate Minutes Columns

The code below list first 5 observations for the minutes columns

```

SELECT
    VeryActiveMinutes as VeryActMin,
    FairlyActiveMinutes as FairlyActMin,
    LightlyActiveMinutes as LightlyActMin,
    SedentaryMinutes as SedMin
FROM
    dailyactivity_merged
LIMIT
    5

```

Table 13: 5 records

VeryActMin	FairlyActMin	LightlyActMin	SedMin
25	13	328	728
21	19	217	776
30	11	181	1218
29	34	209	726
36	10	221	773

It would be beneficial to introduce columns for “Total Active Minutes” The creation of an aggregate value for Total Active Minutes will be advantageous for analyzing activity as a whole. We will keep this in mind while constructing the SQL query for the join

Finalize and Validate Columns from the Sleep table

Now let's explore the first few rows from the Sleep table.

The code below list first 5 observations for the minutes columns

```

SELECT
    *
FROM
    sleepday_merged
LIMIT 5

```

Table 14: 5 records

Id	SleepDay	TotalSleepRecords	TotalMinutesAsleep	TotalTimeInBed	RecordedDate
1503960366	4/12/2016 12:00:00 AM	1	327	346	2016-04-12
1503960366	4/13/2016 12:00:00 AM	2	384	407	2016-04-13
1503960366	4/15/2016 12:00:00 AM	1	412	442	2016-04-15
1503960366	4/16/2016 12:00:00 AM	2	340	367	2016-04-16
1503960366	4/17/2016 12:00:00 AM	1	700	712	2016-04-17

The Sleep table just contains 5 columns. As discussed earlier, the SleepDay variable would need to be cleaned to make it consistent with the ActivityDate column in the Activity table.

Lets explore the TotalSleepRecords column with some summary statistics.

```

SELECT
    'TotalSleepRecords' as Field,
    min(TotalSleepRecords) as Minimum,
    avg(TotalSleepRecords) as Average,
    max(TotalSleepRecords) as Maximum,
    COUNT(CASE WHEN TotalSleepRecords = 1 THEN 1 END)*100/413 as PerEqualOne
FROM
(SELECT
    TotalSleepRecords
FROM
    sleepday_merged) as table1

```

Table 15: 1 records

Field	Minimum	Average	Maximum	PerEqualOne
TotalSleepRecords	1	1.118644	3	88

The **TotalSleepRecords** variable ranges from 1 to 3, with a value of 1 occurring approximately 89% of the time. As defined in the Data Description this is the “Number of recorded sleep periods for that day. Includes naps > 60min”. The data suggests that most people only sleep once in a day (presumably at night)

As this variable does not appear to provide meaningful variation in data, it will be excluded from the analysis.

Next, we will verify whether “minutes asleep” is consistently less than “time in bed.”

```

SELECT
    count(*) as AsleepMoreThanInBed
FROM
    sleepday_merged
WHERE
    TotalMinutesAsleep > TotalTimeInBed

```

Table 16: 1 records

AsleepMoreThanInBed
0

Yes, we can confirm that time spent asleep is always less than the time spent in bed

2.1.2.3 Checking for Duplicates and Missing Values Next we will check for any duplicates and missing values that exist for our finalized column lists for both activities and sleep,

```

WITH dup_act as (      -- Create a temporary table to calculate Duplicates
SELECT
    1 as UniId,      -- Define UniId in each temporary table to facilitate the join
    COUNT(*) -       -- Calculate the difference between the count of total rows
(SELECT                  -- and distinct rows. This difference will be the # of duplicates
    count(*)
FROM
(SELECT DISTINCT      -- This inner query counts distinct rows
    RecordedDate,
    Id,

```

```

Calories,
TotalSteps,
LightlyActiveMinutes,
FairlyActiveMinutes,
VeryActiveMinutes,
SedentaryMinutes,
LightActiveDistance,
ModeratelyActiveDistance,
VeryActiveDistance
FROM
    dailyactivity_merged) as t1) as DuplicatesActivity
FROM
    dailyactivity_merged
),
miss_act as ( -- Create a temporary table to calculate Missing Values
SELECT
    COUNT(*) AS MissingValuesActivity, -- Count values when any one of the columns
    1 as UniId                         -- specified is null. See where
FROM
    dailyactivity_merged
WHERE
    RecordedDate IS NULL OR
    Id IS NULL OR
    Calories IS NULL OR
    TotalSteps IS NULL OR
    LightlyActiveMinutes IS NULL OR
    FairlyActiveMinutes IS NULL OR
    VeryActiveMinutes IS NULL OR
    SedentaryMinutes IS NULL OR
    LightActiveDistance IS NULL OR
    ModeratelyActiveDistance IS NULL OR
    VeryActiveDistance IS NULL
),
dup_sleep as (      -- Repeat the process for the sleep table
SELECT
    1 as UniId,
    COUNT(*) -
(SELECT
    count(*)
FROM
(SELECT DISTINCT
    Id,
    RecordedDate,
    TotalMinutesAsleep,
    TotalTimeInBed
FROM
    sleepday_merged) as t2) as DuplicatesSleep
FROM
    sleepday_merged
),
miss_sleep as (
SELECT
    COUNT(*) AS MissingValuesSleep,

```

```

    1 as UniId
FROM
    sleepday_merged
WHERE
    Id IS NULL OR
    RecordedDate IS NULL OR
    TotalMinutesAsleep IS NULL OR
    TotalTimeInBed IS NULL
)
SELECT          -- Join results from all tables into one
    A.DuplicatesActivity,
    B.MissingValuesActivity,
    C.DuplicatesSleep,
    D.MissingValuesSleep
FROM
    dup_act as A
JOIN
    miss_act as B on A.UniId=B.UniId
JOIN
    dup_sleep as C on A.UniId=C.UniId
JOIN
    miss_sleep as D on A.UniId=D.UniId

```

Table 17: 1 records

DuplicatesActivity	MissingValuesActivity	DuplicatesSleep	MissingValuesSleep
0	0	3	0

Both tables are clean, with zero missing values. While the activity table also has no duplicate rows, the Sleep Data set contains three duplicate rows. These three duplicates will be excluded when the SQL query for the join is constructed.

2.1.3 Joining the Daily tables

Now that the columns are finalized, the Activity and Sleep tables can be joined. This joining process will exclude the previously identified columns and incorporate any newly discussed ones.

- A column for Total Active Minutes (LightlyActiveMinutes + FairlyActiveMinutes + VeryActiveMinutes) will be created.
- A column for Total Distance (LightActiveDistance + ModeratelyActiveDistance + VeryActiveDistance) will be created.
- A column for DayType is created (Weekend or Weekday)
- The cleaned date columns for both datasets are used
- We will exclude rows when Steps are less than 1 (equal to 0) as these are likely to be days when the watch wasn't worn or it didn't record anything
- A left join will be utilized to combine the two tables.
- Unique rows will be selected from the Right i.e. Sleep table in order to account for the duplicate rows in this table.

As discussed earlier, variables name are renamed for easier analysis and visualization.

The subsequent SQL query employs a left join (with the Activity as the Left and Sleep as the right tables) using the Id and RecordedDate columns. It also generates the new columns mentioned above and cleans the date columns. This code chunk will produce a data frame named **daily_activity_sleep**, containing the results of the query.

```
-- This SQL Query will output a data frame named as named as daily_activity_sleep
-- with the results of the query.
```

```
SELECT
    A.Id,
    A.RecordedDate,          -- Cleaned Date variable
    CASE CAST(STRFTIME('%w', A.RecordedDate) AS INTEGER)
        WHEN 0 THEN 'Weekend'
        WHEN 6 THEN 'Weekend'
        ELSE 'Weekday' -- DayType; Weekday or Weekend
    END AS DayType,
    A.Calories,
    A.TotalSteps as Steps,
    A.LightlyActiveMinutes as LightlyActMin,
    A.FairlyActiveMinutes as FairlyActMin,
    A.VeryActiveMinutes VeryActMin,
    A.LightlyActiveMinutes + A.FairlyActiveMinutes +
    A.VeryActiveMinutes as TotalActMin,   -- Add all active minutes
    A.SedentaryMinutes as SedMin,
    A.LightActiveDistance as LightActDist,
    A.ModeratelyActiveDistance as ModActDist,
    A.VeryActiveDistance as VeryActDist,
    A.LightActiveDistance + A.ModeratelyActiveDistance +
    A.VeryActiveDistance as TotalDist,   -- Add all distance
    B.TotalMinutesAsleep as MinAsleep,
    B.TotalTimeInBed as TimeInBed
FROM
    dailyactivity_merged as A
LEFT JOIN
    (SELECT DISTINCT           -- Select Distinct rows to drop duplicates
        Id,
        TotalMinutesAsleep,
```

```

    TotalTimeInBed,
    RecordedDate -- Cleaned Date variable
  FROM
    sleepday_merged) as B
ON
  A.Id = B.Id -- Join on ID and Date
  AND
  A.RecordedDate = B.RecordedDate
WHERE
  A.TotalSteps > 0 -- drop rows where Total Steps = 0

```

2.1.4 Review Joined Data

Lets now the first few rows of the joined dataframe for some quick validation. We will split the view for easier visualization

```

kable(head(daily_activity_sleep,5)[,1:5]) %>%
  kable_styling("striped")

```

	Id	RecordedDate	DayType	Calories	Steps
	1503960366	2016-04-12	Weekday	1985	13162
	1503960366	2016-04-13	Weekday	1797	10735
	1503960366	2016-04-14	Weekday	1776	10460
	1503960366	2016-04-15	Weekday	1745	9762
	1503960366	2016-04-16	Weekend	1863	12669

```

kable(head(daily_activity_sleep,5)[,6:10]) %>%
  kable_styling("striped")

```

	LightlyActMin	FairlyActMin	VeryActMin	TotalActMin	SedMin
	328	13	25	366	728
	217	19	21	257	776
	181	11	30	222	1218
	209	34	29	272	726
	221	10	36	267	773

```

kable(head(daily_activity_sleep,5)[,11:16]) %>%
  kable_styling("striped")

```

	LightActDist	ModActDist	VeryActDist	TotalDist	MinAsleep	TimeInBed
	6.06	0.55	1.88	8.49	327	346
	4.71	0.69	1.57	6.97	384	407
	3.91	0.40	2.44	6.75	NA	NA
	2.83	1.26	2.14	6.23	412	442
	5.04	0.41	2.71	8.16	340	367

The data has been successfully and correctly joined. We will now proceed to the Data Visualization phase.

2.2 Data Visualizations and Plots

Now that we have our data cleaned and consolidated, we can move forward with the Data Visualization phase. This Phase will first focus on understanding the individual distributions and composition of variables and then proceed to identifying any key relationships between them

2.2.1 Distributions and Compositions

This section will concentrate on generating summary statistics, distribution charts, and time trends to facilitate an understanding of distributions and compositions.

2.2.1.1 Summary Statistics The initial step involves generating summary statistics to facilitate a more comprehensive understanding of the dataset. We will split the view easier visualization

```
kable(daily_activity_sleep[,1:5] %>% summary(digits=2)) %>%
  kable_styling("striped")
```

Id	RecordedDate	DayType	Calories	Steps
Min. :1.5e+09	Length:863	Length:863	Min. : 52	Min. : 4
1st Qu.:2.3e+09	Class :character	Class :character	1st Qu.:1856	1st Qu.: 4923
Median :4.4e+09	Mode :character	Mode :character	Median :2220	Median : 8053
Mean :4.9e+09	NA	NA	Mean :2361	Mean : 8319
3rd Qu.:7.0e+09	NA	NA	3rd Qu.:2832	3rd Qu.:11092
Max. :8.9e+09	NA	NA	Max. :4900	Max. :36019

```
kable(daily_activity_sleep[,6:10] %>% summary(digits=2)) %>%
  kable_styling("striped")
```

LightlyActMin	FairlyActMin	VeryActMin	TotalActMin	SedMin
Min. : 0	Min. : 0	Min. : 0	Min. : 0	Min. : 0
1st Qu.:146	1st Qu.: 0	1st Qu.: 0	1st Qu.:182	1st Qu.: 722
Median :208	Median : 8	Median : 7	Median :258	Median :1021
Mean :210	Mean : 15	Mean : 23	Mean :248	Mean : 956
3rd Qu.:272	3rd Qu.: 21	3rd Qu.: 35	3rd Qu.:323	3rd Qu.:1189
Max. :518	Max. :143	Max. :210	Max. :552	Max. :1440

```
kable(daily_activity_sleep[,11:16] %>% summary(digits=2)) %>%
  kable_styling("striped")
```

LightActDist	ModActDist	VeryActDist	TotalDist	MinAsleep	TimeInBed
Min. : 0.0	Min. :0.00	Min. : 0.00	Min. : 0.0	Min. : 58	Min. : 61
1st Qu.: 2.3	1st Qu.:0.00	1st Qu.: 0.00	1st Qu.: 3.3	1st Qu.:361	1st Qu.:404
Median : 3.6	Median :0.31	Median : 0.41	Median : 5.5	Median :432	Median :463
Mean : 3.6	Mean :0.62	Mean : 1.64	Mean : 5.9	Mean :419	Mean :458
3rd Qu.: 4.9	3rd Qu.:0.86	3rd Qu.: 2.27	3rd Qu.: 7.9	3rd Qu.:490	3rd Qu.:526
Max. :10.7	Max. :6.48	Max. :21.92	Max. :28.0	Max. :796	Max. :961
NA	NA	NA	NA	NA's :453	NA's :453

Some quick insights:

- Daily average for calories burned, 2,361, aligns with standard dietary guidelines.
- Interestingly, the average step count, 8319 is well within the typical 5,000–7,000 step range, suggesting an active user base. Source: <https://www.health.harvard.edu/heart-health/just-7000-daily-steps-reduces-heart-disease-risk>
- Lightly Active Minutes are significantly higher than both Fairly Active and Very Active Minutes. The mean for lightly active minutes, at approximately 210, is about 14 times greater than Fairly Active Minutes and 9 times greater than Very Active Minutes.
- Sedentary Minutes are considerably higher than the Total Active Minutes, with the mean for sedentary minutes being roughly four times that of total active minutes.
- The differences in the means of the Distance columns are not that glaring. However, the mean for Light Active Distance is 6 times that of Moderately Active Distance and around twice that of Very Active Distance.
- The means for time in bed and minutes asleep are very close to each other as expected.
- The mean for Minutes Asleep is 419 minutes, which is approximately 7 hours and aligns with the standard recommended value.
- Missing values are only observed for columns from the Sleep table
- The data set sourced from the Sleep table exhibits 453 missing values. This discrepancy is logical, given that our initial analysis identified that the sleep table only included data from 24 respondents, while the other tables contained data from 33 respondents. Consequently, columns derived from the sleep table will contain missing values.

We will now proceed to delve deeper into these statistics using pie charts, histograms, and time-trend analysis.

2.2.1.2 Analyzing Calories First lets analyze calories with a histogram using a custom function to visualize the distribution.

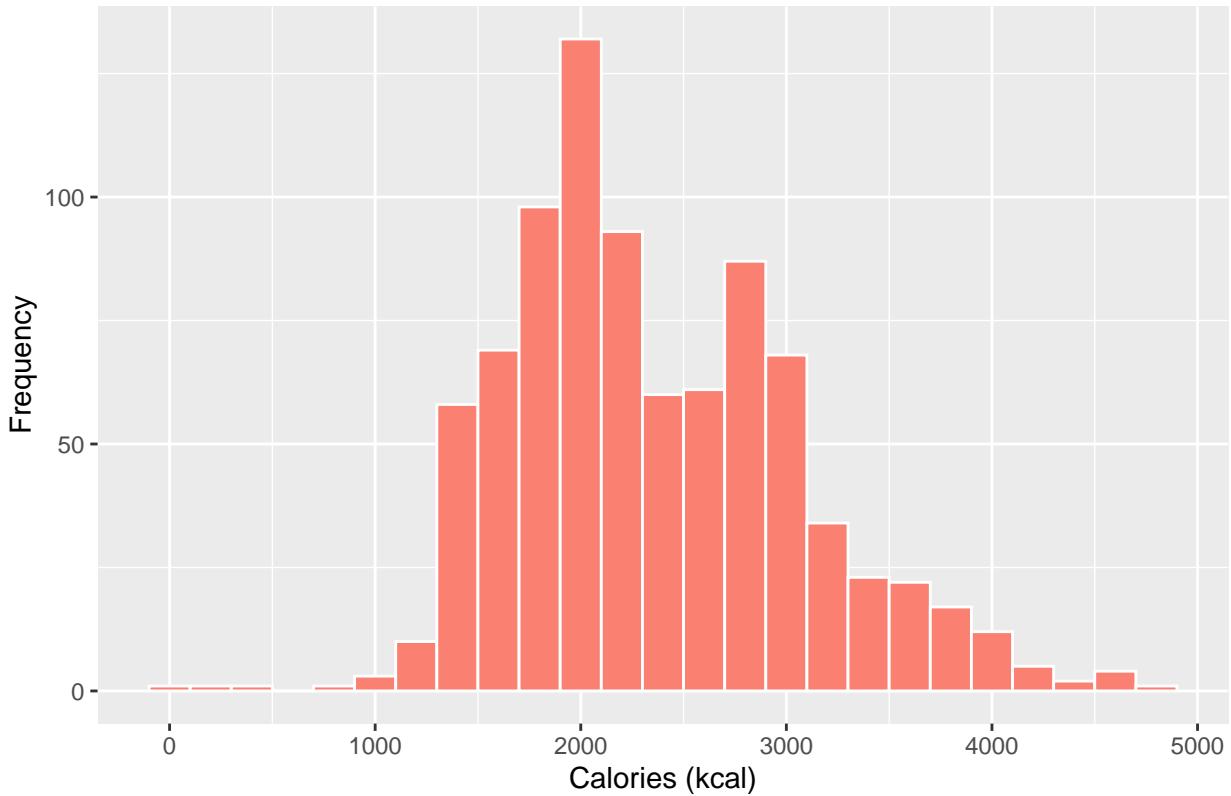
Distribution of Total Calories

```
hist_func <- function(column, indicator, divisor, fillcol, bw) {
  # column for relevant column name
  # indicator for descriptive name for titles and labels
  # divisor to convert any values eg minutes to hours
  # fillcol for color of histogram
  # bw for binwidth

  # This function:
  # Plots a histogram for the specified column after dividing it by a divisor
  ggplot(daily_activity_sleep, aes(.data[[column]]/divisor)) +
    geom_histogram(fill = fillcol, color = 'white', binwidth=bw) +
    labs(title = paste0("Histogram of " ,indicator),
         x = indicator,
         y = "Frequency")
}

hist_func("Calories", "Calories (kcal)", 1, 'salmon', 200)
```

Histogram of Calories (kcal)



The data shows a peak calorie distribution around 2000 kcal, which is at the lower end of the 2,000–3,000+ Daily Calorie Intake Guidelines for Active Individuals maintaining their weight. This suggests that many participants are not highly active, indicating a potential target audience for Bellabeat.

Average Daily Calories Burned Trend

We will now examine the time-based trend of the average daily calories burned using a custom function.

```
daily_trend_func <- function(column, indicator, divisor) {

  # column for relevant column name
  # indicator for descriptive name for titles and labels
  # divisor to convert any values eg minutes to hours

  # The function:
  # Groups the daily_activity_sleep dataframe by Date and Id.
  # Calculates the daily mean of the specified column and divides it by the divisor
  # Plots the daily means against dates

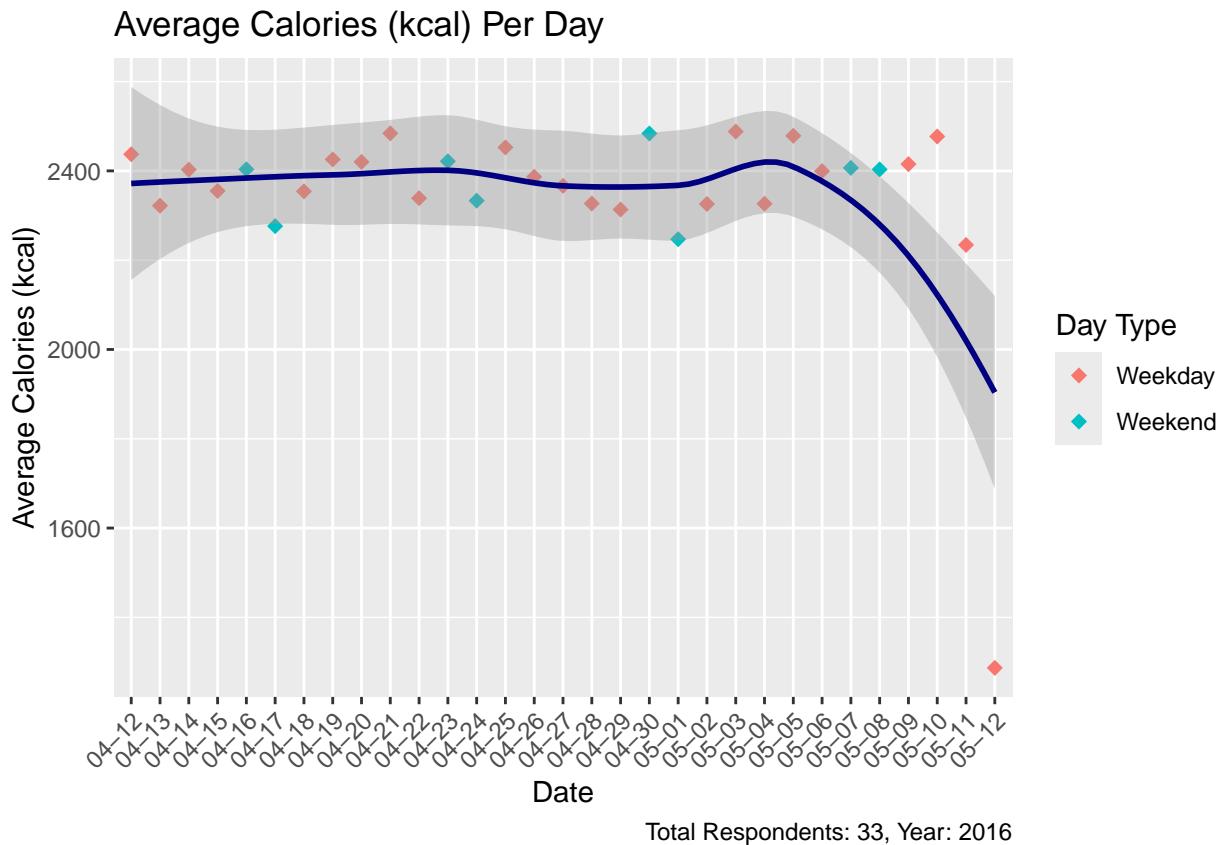
  daily_activity_sleep %>% group_by(RecordedDate, DayType) %>%
    summarise(daily_avg= mean(.data[[column]]/divisor), .groups = 'drop') %>% # Calculate mean per day
    ggplot(aes(x=format(as.Date(RecordedDate), format = "%m-%d"), # Remove Year
               y=daily_avg, group = 1, color=DayType)) +
    geom_point(shape=18, size=2.5) +
    geom_smooth(color = "navyblue") +
    theme(axis.text.x = element_text(angle = 45, hjust = 1, vjust = 1)) +
    labs(
      x = "Date", # New x-axis title
```

```

y = paste0("Average ", indicator), # New y-axis title
title = paste0("Average ", indicator, " Per Day"), # New title
color="Day Type", # New legend title
caption = "Total Respondents: 33, Year: 2016"
)
}

daily_trend_func("Calories","Calories (kcal)",1)

```



The average calories burned level remains relatively stable throughout April but shows a decline in May. There is also no observed variation based on day type (weekends compared to weekdays).

The drop in calories burned could be attributed to two main factors:

- Rising Summer Temperatures:** As summer progresses, people may be less inclined to participate in outdoor activities due to increased heat. Bellabeat could address this by promoting and recommending indoor workouts and activity options during the summer months.
- Possible Attrition of High Performers:** The decrease in average could also result from the attrition of users who were previously high performers in the final days of the period, thereby lowering the overall average.

We can check whether general attrition took place through the code below:

```

# Group by Recorded Date and count observations
# Arrange with lowest values of observations at the top
daily_activity_sleep %>%
  group_by(RecordedDate, DayType) %>%
  summarize(Observations = n(), .groups = 'drop') %>% arrange(Observations) %>%
  head(6) %>% kable(booktabs = TRUE) %>% kable_styling("striped")

```

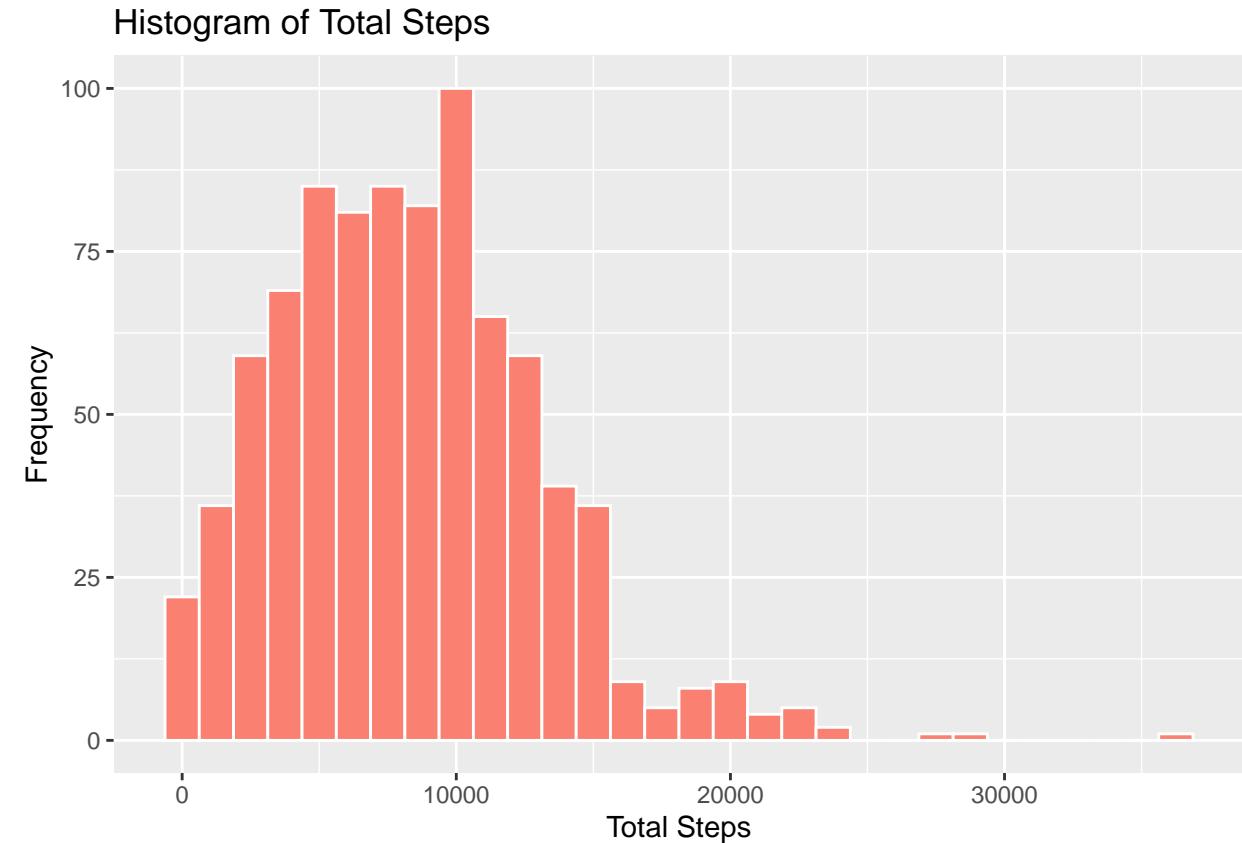
RecordedDate	DayType	Observations
2016-05-12	Weekday	17
2016-05-10	Weekday	22
2016-05-11	Weekday	22
2016-05-08	Weekend	23
2016-05-09	Weekday	24
2016-05-07	Weekend	25

The code analysis above does confirm the decline, as the lowest observations are from the last 5 days in May. However, it does not confirm that the missing data is exclusively from high performers, which would verify this as the reason for the lower overall average.

2.2.1.3 Analyzing Steps Lets next analyze Total Steps beginning with a histogram to visualize the distribution. Note: We filter out observations when steps are less than 1 or 0 as this is likely to be a case when either the watch's battery was 0 or it wasn't worn at all.

Distribution of Total Steps

```
hist_func("Steps", "Total Steps", 1, 'salmon', 1250)
```



The Total Steps data exhibits a right-skewed (positively skewed) distribution, meaning most data points are concentrated on the left side of the graph. A few extremely high values (outliers) influence the mean, pulling it above the median, as evidenced by the summary statistics.

Additionally the distribution for Total Steps suggests that the participant group includes individuals who are both significantly high and significantly low performers as:

1. High Performers (Enthusiasts): The peak of the distribution is observed at 10,000 steps. There is also notable number of observations recording well over its. These high-value observations raise the average step count to approximately 8319 (refer to summary statistics), placing it within the 5,000–7,000 range. Bellabeat can target these enthusiasts by recommending workout plans and fitness goals
2. Low Performers : Conversely, good portion of the distribution is also concentrated on the left of 10,000. This suggests a substantial number of users are not meeting the recommended daily goal of 5,000–7,000 steps. Bellabeat could consider targeting these users with daily reminders.

It would be beneficial to determine the percentage of all individuals whose average daily steps fall below 6,000 (the midpoint of 5000-7000).

This code calculates the percentage of respondents whose Average Daily Step count is below 6000

```
daily_activity_sleep %>% group_by(Id) %>% ##
  summarize(meanStep=mean(Steps)) %>% ## Calculate avg steps for each Id
  filter(meanStep < 6000) %>% ## Filter for less than 500
  nrow()*100 /length(unique(daily_activity_sleep$Id))

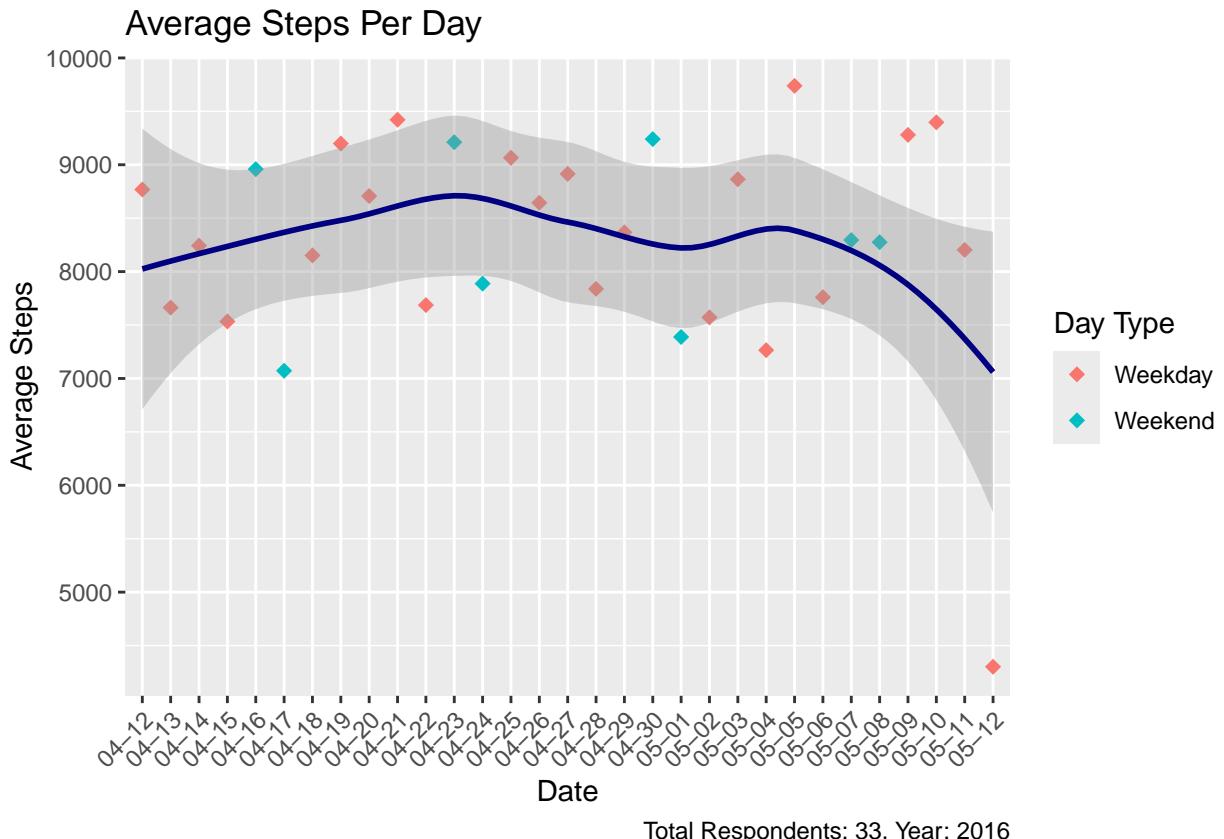
## [1] 30.30303
# Calculate %age by dividing by no. of unique Ids
```

Approximately **30%** of participants have a daily average step count of **less than 6000**. This is a very high percentage and Bellabeat should work towards targeting this

Average Daily Steps Trend

We will now examine the time-based trend of the average total steps covered.

```
daily_trend_func("Steps","Steps",1)
```



Similar to Calories, the average of daily steps remains relatively stable throughout April. However, it shows a slight rise in April followed by a slight decline in May. There is also no observed variation based on day type (weekends compared to weekdays).

The rise and then drop in activity level could be attributed to the same two factors discussed earlier (Rising Summer Temperatures or Possible Attrition of High Performers)

2.2.1.4 Analyzing Total Active Minutes and Sedentary Minutes

Lets next analyze the Minutes variables

Recall that in the Join statement Total Active Minutes was created as the sum of Fairly Active Minutes, Lightly Active Minutes and Very Active Minutes

Composition of Total Active Min

Lets first review the composition of Total Active Minutes using a custom function.

```
pie_plot_func <- function(cols_plot, indicator) {

  # cols plot to identify list of columns
  # indicator for descriptive name for titles and labels

  # The function:
  # Calculates the sum of the specified columns and their percentages as a portion of the whole.
  # Creates A pie chart is to visualize the proportions.
  # Means for respective categories are also calculated and displayed shown.

  # Use the apply function to sum all rows in each of the columns
  # Calculate percentage by dividing each sum value with the sum
  # Update Category to include means by dividing each sum values with total rows
  # in the joined data set

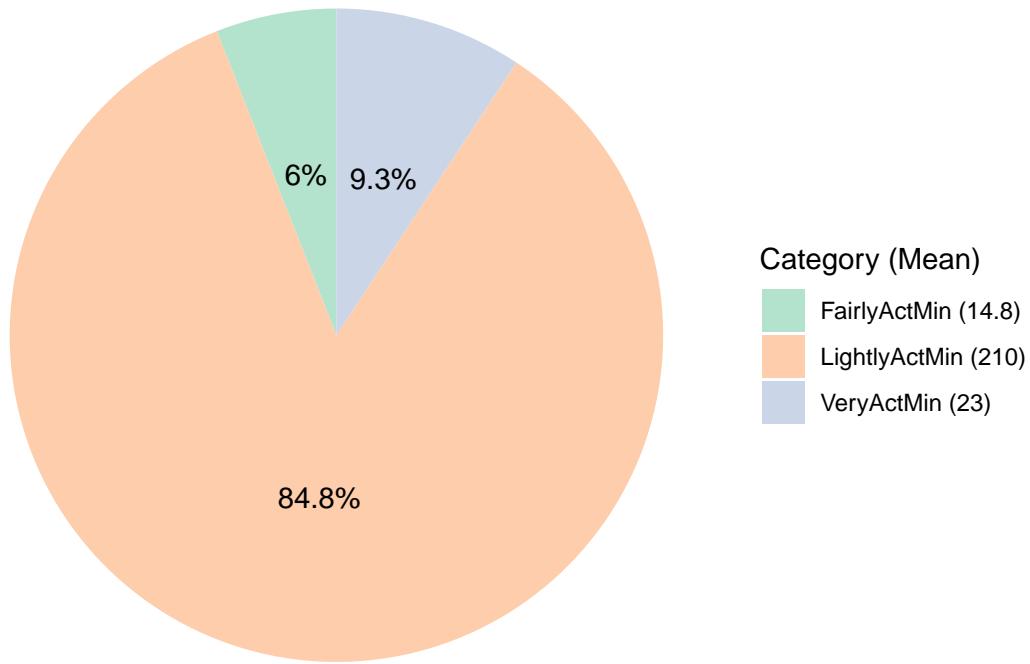
  pie <- daily_activity_sleep[,cols_plot] %>%
    apply(2,sum) %>% as.data.frame() %>% setNames("value") %>%
    rownames_to_column("category") %>%
    mutate(percentage = value / sum(value) * 100,
      means=value/nrow(daily_activity_sleep),
      category = paste0(category, " (", round(means, 1), ")"))
  %>%
  arrange(value) %>%
  ggplot(aes(x = "", y = value, fill = category)) + #Plot the data using geom_bar
  geom_bar(stat = "identity", width = 1) + #stacked bar chart
  coord_polar(theta = "y") + #To convert the chart into a pie-chart
  theme_void() + # Removes background grid and axes
  labs(title = paste0("Composition of ", indicator),
    fill='Category (Mean)') + #Add title and legend
  geom_text(aes(label = paste0(round(percentage, 1), "%")),
    position = position_stack(vjust = 0.5)) + #Add labels for %age
  scale_fill_brewer(palette = "Pastel2")

  return(pie)
}

# Select FairlyActMin, LightlyActMin, VeryActMin

pie_plot_func(c("FairlyActMin", "LightlyActMin", "VeryActMin"), "Total Active Minutes")
```

Composition of Total Active Minutes



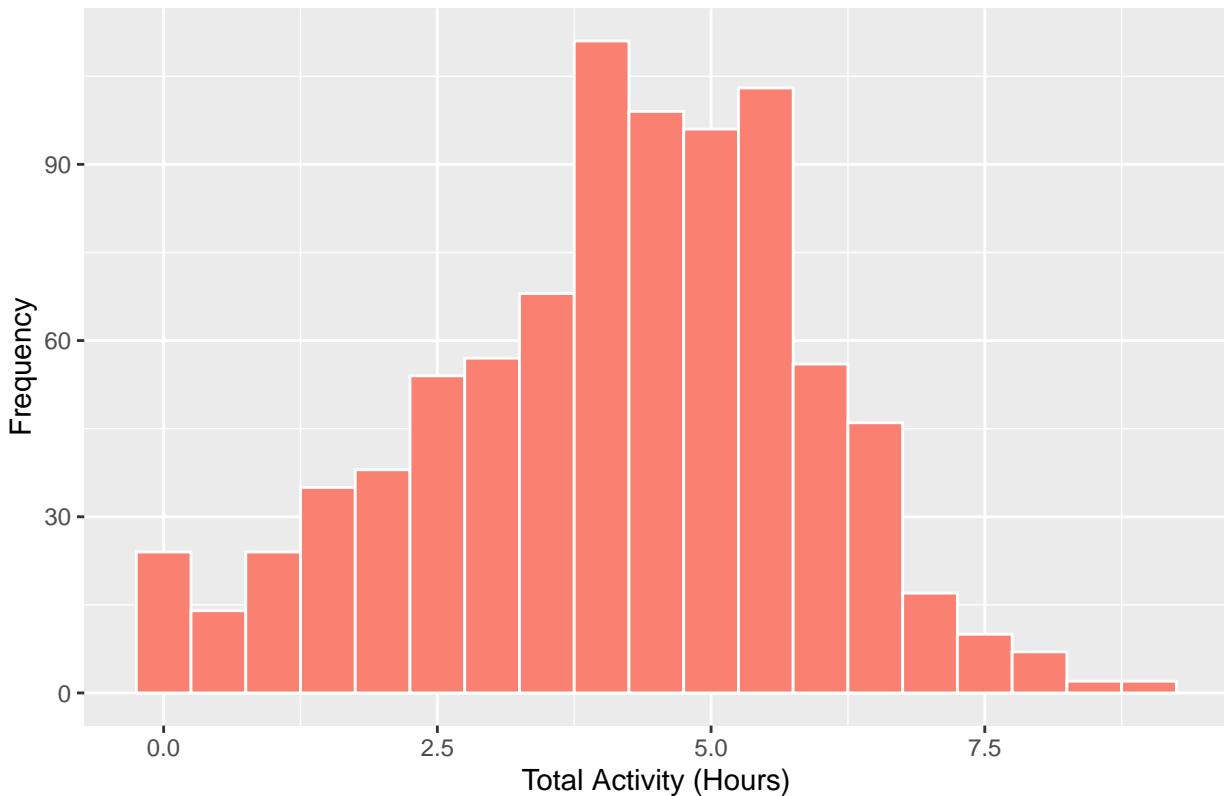
Lightly Active Minutes account for approximately 85% of the total activity. This significant proportion explains why the average for Lightly Active Minutes (210 minutes or 3.5 hours) is notably higher than the averages for Fairly Active Minutes (~ 15 minutes) and Very Active Minutes (23 minutes). Overall, the data indicates that most respondents are primarily lightly active

Distribution of Total Active Hours

Next, let's use a histogram to visualize the distribution of Total Active Hours. Minutes are converted to hours for easier readability

```
hist_func("TotalActMin", "Total Activity (Hours)", 60, 'salmon', 0.5)
```

Histogram of Total Activity (Hours)



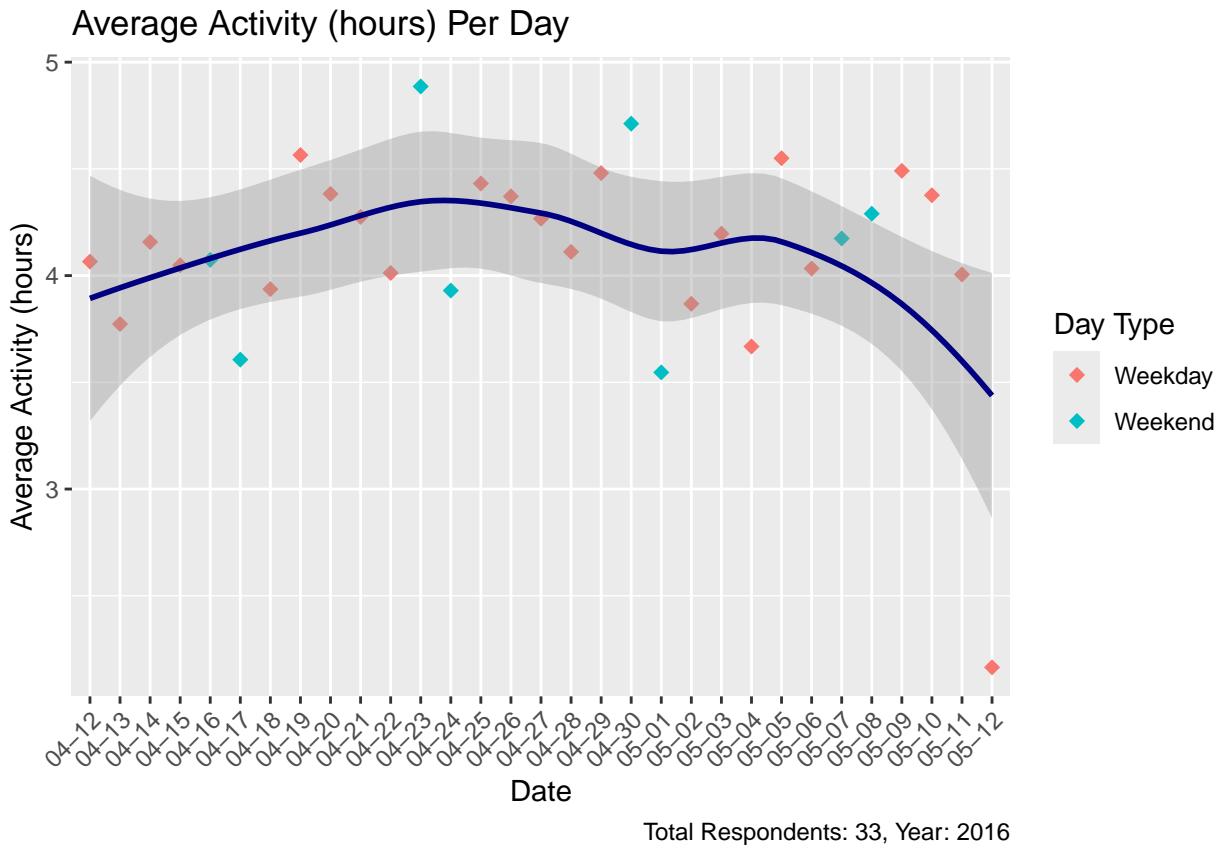
The distribution of Total Activity exhibits a peak around 3.75, which suggests the presence of a generally active user base. This group represents a key target audience for Bellabeat, offering an opportunity to increase engagement by recommending tailored workout plans and specific fitness goals.

As shown in the pie-chart earlier, Total Active hours compose mainly of Lightly Active Hours and Bellabeat can encourage

Average of Daily Activity Trend

We will now examine the time-based trend of the average daily activity.

```
daily_trend_func("TotalActMin","Activity (hours)",60)
```



Similar to Steps, the average of activity level remains relatively stable throughout April but shows a slight rise in April followed by a slight decline in May. There is also no observed variation based on day type (weekends compared to weekdays).

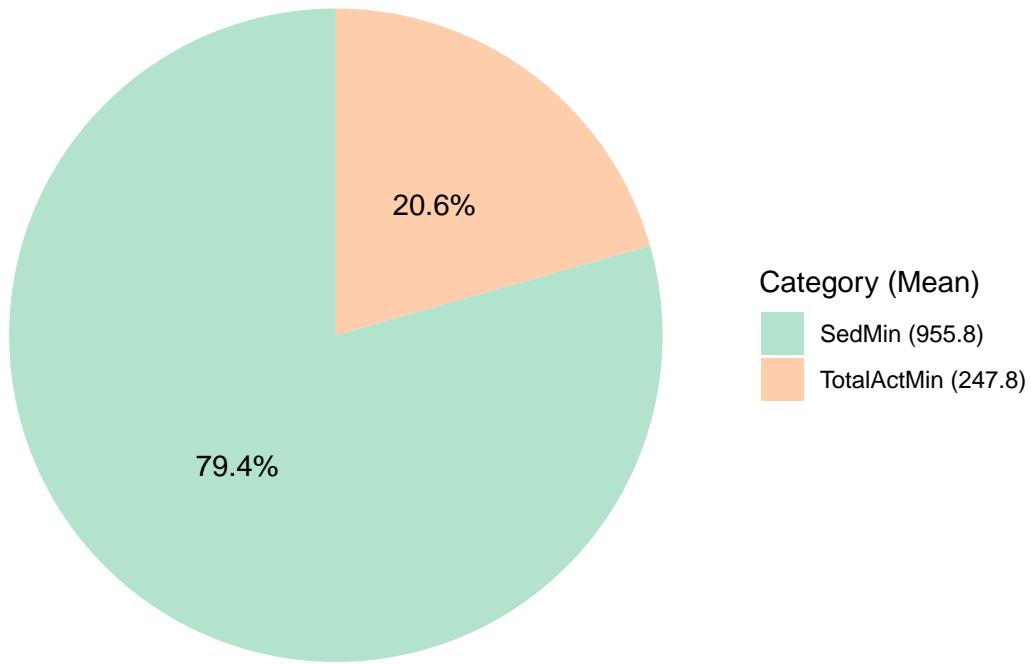
The rise and then drop in activity level could be attributed to the same two factors discussed earlier (Rising Summer Temperatures or Possible Attrition of High Performers)

Composition of Active + Sedentary Minutes

Lets next review the composition of Active + Sedentary Minutes as a sum of Total Active Minutes and Sedentary Minutes.

```
# Select TotalActiveMinutes and SedentaryMinutes
pie_plot_func(c("TotalActMin", "SedMin"), "Active + Sedentary Minutes")
```

Composition of Active + Sedentary Minutes



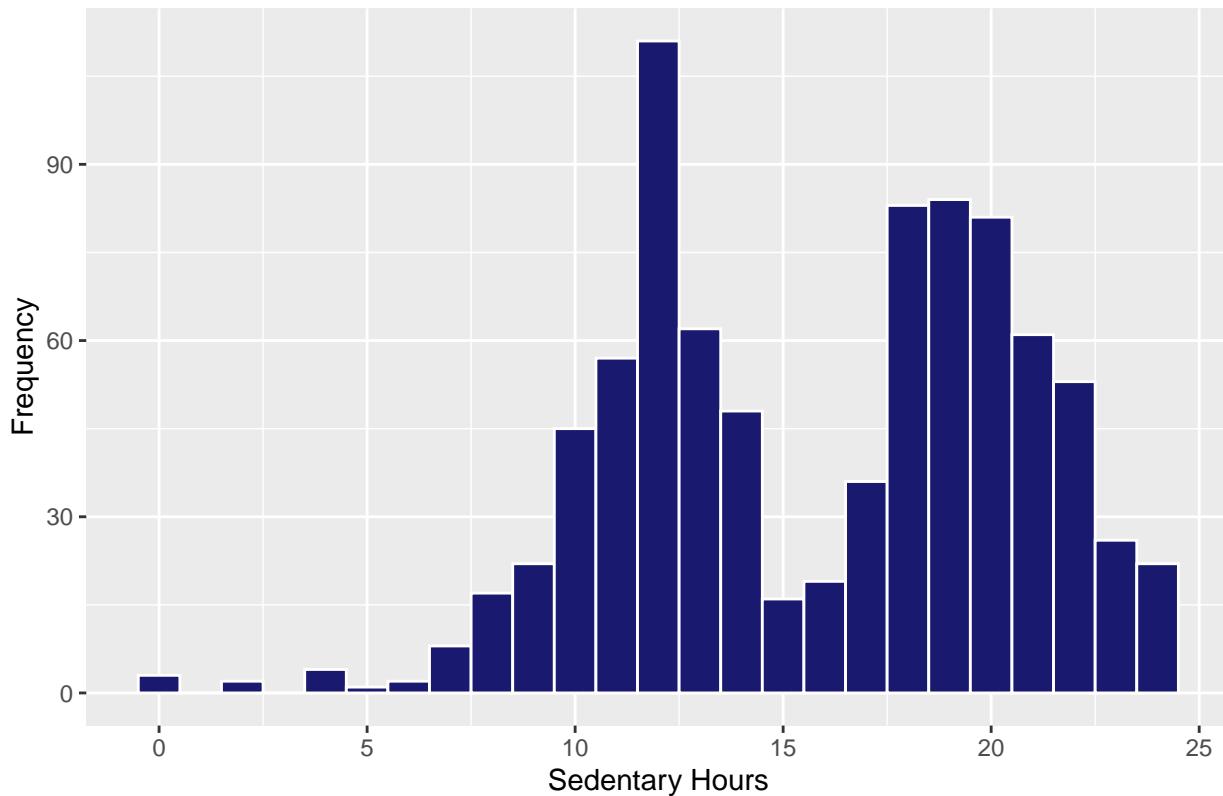
Sedentary Minutes constitute a striking 79.4% of the total time. This high proportion directly leads to a very high average of around 956 minutes (or 16 hours) for Sedentary Minutes, significantly overshadowing the average of around 248 minutes (or 3.8 hours) for Total Active Minutes. The data strongly suggests a considerably sedentary lifestyle among the users, which is a key area Bellabeat should target for intervention to promote lower sedentary behavior.

Distribution of Sedentary Hours

Next, let's use a histogram to visualize the distribution of Sedentary hours. Minutes are converted to hours for easier readability

```
hist_func("SedMin","Sedentary Hours",60,'midnightblue',1)
```

Histogram of Sedentary Hours



The data shows a Peak for Sedentary Hours at 12 hours which represents a very high level as compared to the recommended time limit of 300 minutes or 6 hours*. This highlights that a significant portion of users spend more than half of their day in a sedentary lifestyle. Bellabeat should target this group with reminders to engage in activity when sedentary hours surpass a specific threshold. Suggestions such as “Time to take a walk” or “Time for some stretches”, “Time to Stand” could be beneficial to convert sedentary users into active ones.

*<https://pmc.ncbi.nlm.nih.gov/articles/PMC12186656/#:~:text=Sedentary%20behavior%20is%20closely%20linked,evidence%20for%20the%20recommendations>

2.2.1.5 Analyzing Distance Lets next analyze the Distance Variables.

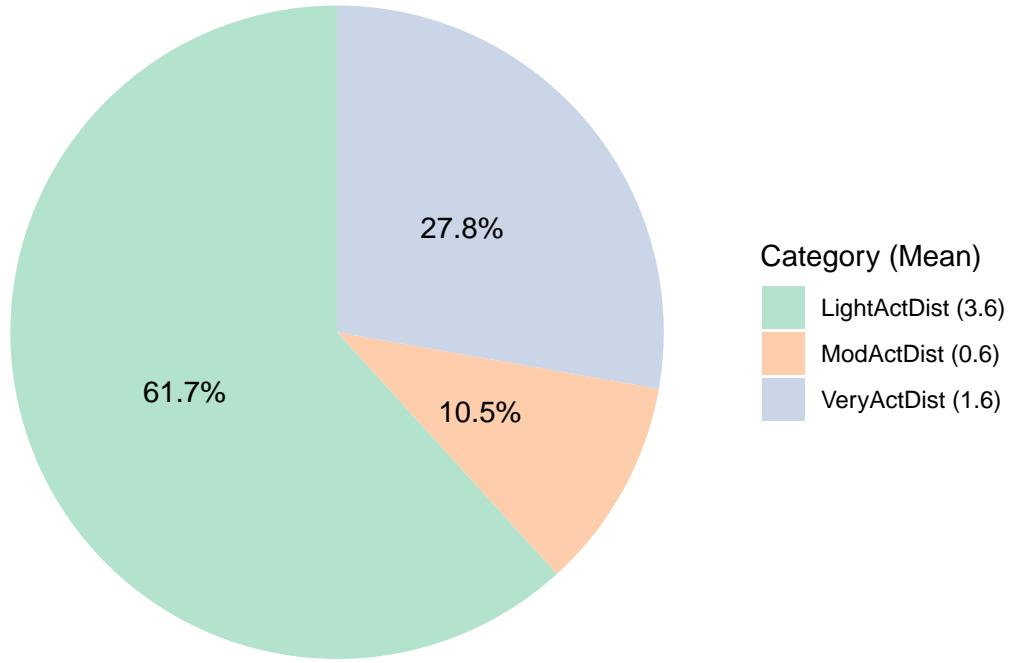
Recall that, in the Join statement, Total Distance was created as the sum of Light Active Distance, Moderately Active Distance and Very Active Distance

Composition of Total Distance

Lets first review the composition of Total Distance.

```
# Select LightActDist, ModActDist, VeryActDist
pie_plot_func(c("LightActDist","ModActDist","VeryActDist"),"Total Distance (km)")
```

Composition of Total Distance (km)



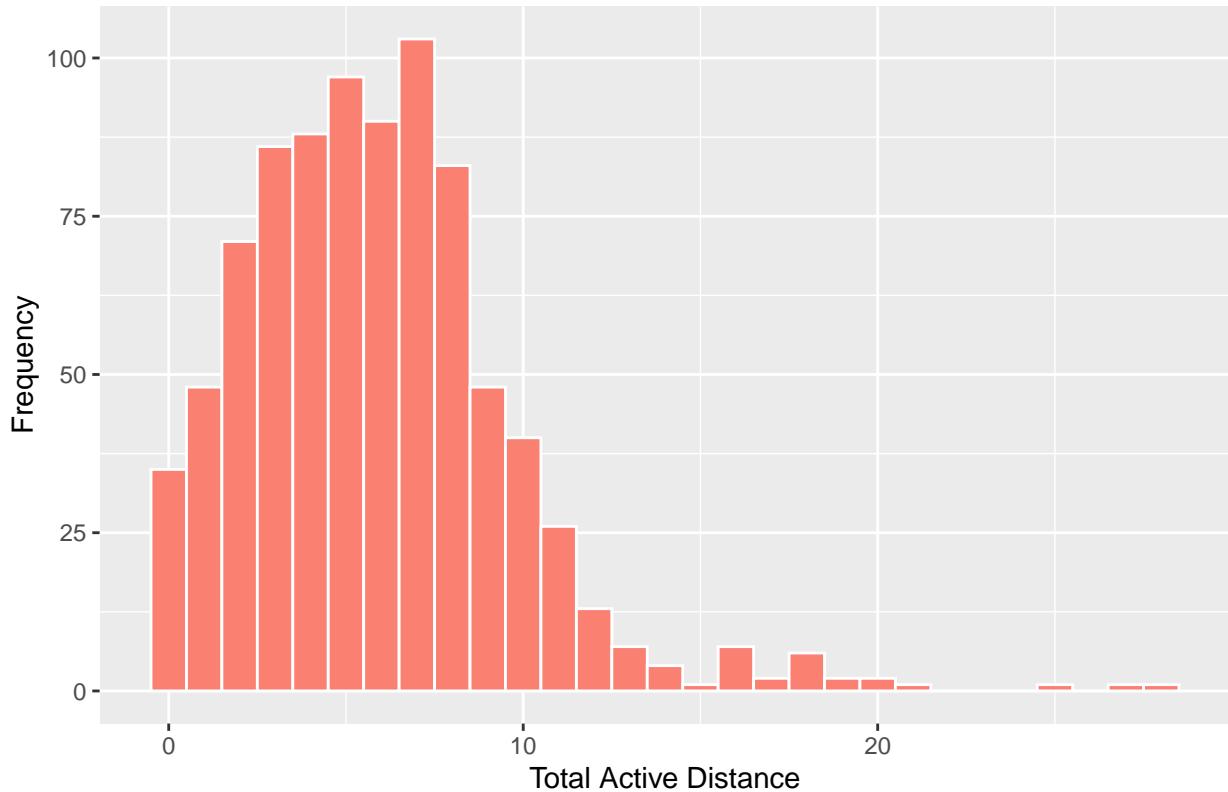
The analysis of activity distance reveals a significant variation in participant performance levels, underscoring the necessity for personalized recommendations. Specifically, LightlyActiveDistance accounts for the largest proportion of the data, comprising about 62% with an average of 3.6 km. This is followed by VeryActiveDistance at approximately 28% (mean of 1.6 km) and ModeratelyActiveDistance at 10% (mean of 0.6 km). These disparate distribution patterns strongly indicate that a one-size-fits-all approach is ineffective, necessitating the development of user-targeted plans.

Distribution of Total Distance

Next, let's use a histogram to visualize the distribution of TotalDistance

```
hist_func("TotalDist", "Total Active Distance", 1, 'salmon', 1)
```

Histogram of Total Active Distance



The distribution of Total Active Distance data, similar to Total Steps, is right-skewed (positively skewed), indicating a concentration of data points on the left side of the graph. A small number of extremely high values (outliers) skew the mean, resulting in a value greater than the median, as demonstrated by the summary statistics.

Furthermore, the distribution for Total Steps suggests that the participant group includes individuals who are both significantly high and significantly low performers as:

1. High Performers (Enthusiasts): The data exhibits a second peak around 7 km (4 miles). These relatively high observations elevate the average daily distance to approximately 6 km (as indicated in the summary statistics). Bellabeat has the opportunity to target these enthusiasts by recommending personalized workout plans and fitness goals to facilitate further improvement.
2. Low Performers (Low Outliers): A substantial portion of the distribution is concentrated below 4 km (2.5 miles), which is the recommended threshold for classifying an individual as “active”*. Bellabeat may consider engaging these users with daily reminders.

It would be beneficial to ascertain the percentage of 33 participants whose average daily active distance is less than 4 km (2.5 miles). The code below calculates this

```
daily_activity_sleep %>% group_by(Id) %>%
  summarize(meanStep=mean(TotalDist)) %>% ## Calculate avg steps for each Id
  filter(meanStep < 4) %>% ## Filter for less than 500
  nrow() * 100 / length(unique(daily_activity_sleep$Id))

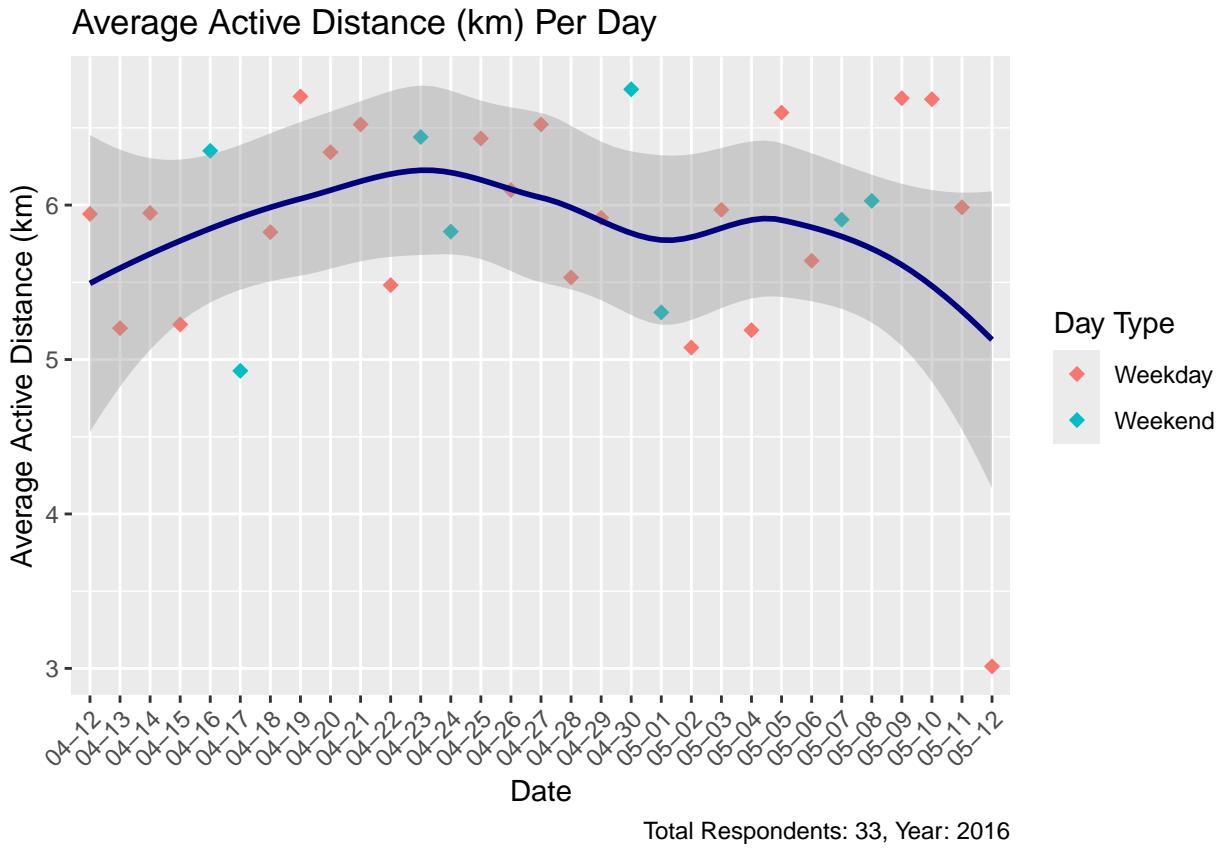
## [1] 30.30303
# Calculate %age by dividing by no. of unique Ids
```

Approximately **30%** of participants exhibit a daily Active Distance of **less than 4 km**. This constitutes a substantial percentage that Bellabeat should prioritize in its targeting strategy.

Average of Daily Total Distance Trend

We will now examine the time-based trend of the average total distance covered.

```
daily_trend_func("TotalDist","Active Distance (km)",1)
```



Similar to Steps and Activities, the average of Total Active Distance remains relatively stable throughout April but shows a slight rise in April followed by a slight decline in May. There is also no observed variation based on day type (weekends compared to weekdays).

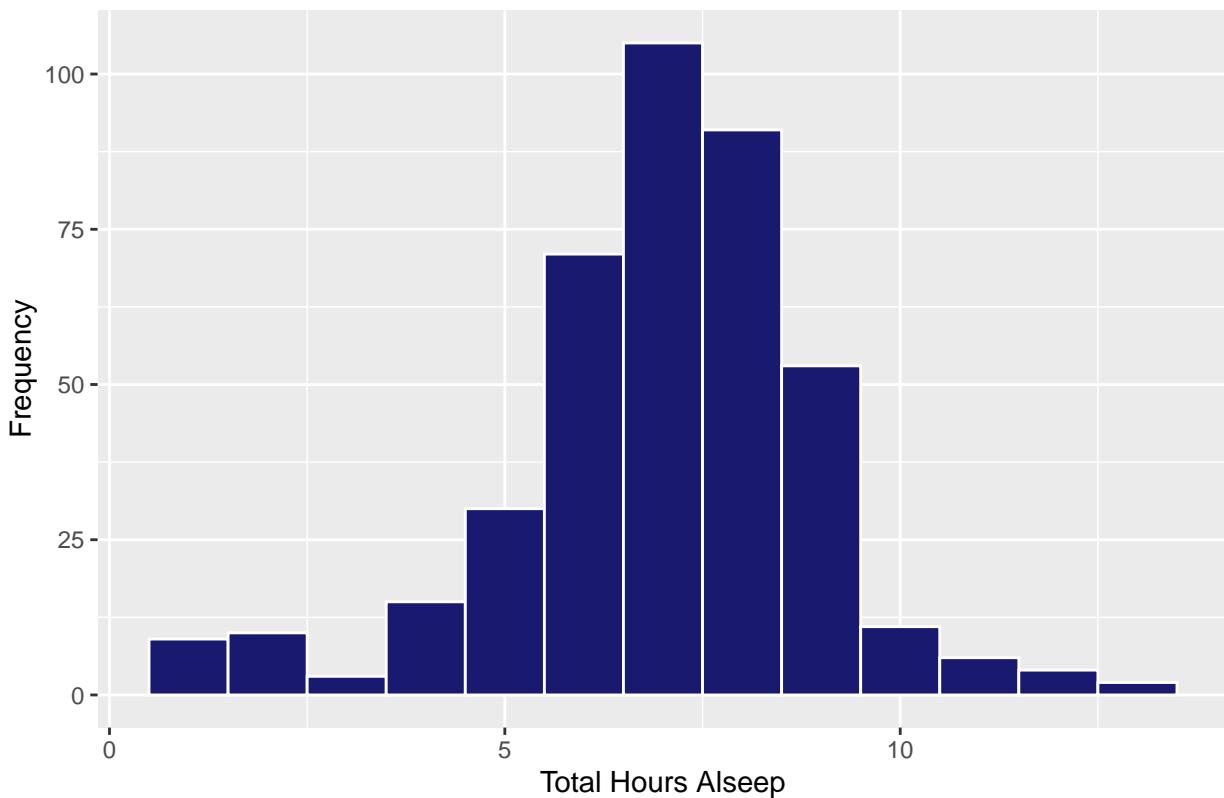
The rise and then drop in activity level could be attributed to the same two factors discussed earlier (Rising Summer Temperatures or Possible Attrition of High Performers)

2.2.1.6 Analyzing Hours Asleep Composition of Total Hours Asleep

Next, let's use a histogram to visualize the distribution of Total Hours Asleep. Minutes are converted to hours for easier readability

```
hist_func("MinAsleep","Total Hours Asleep",60,'midnightblue',1)
```

Histogram of Total Hours Alseep



The majority of users report approximately 7 of sleep per day, which aligns with general recommendations for adults*. As noted in the Data Processing and Cleaning section, most individuals sleep only once per day, with the TotalSleepRecords variable indicating a value of 1 for 88% of observations.

*<https://www.sleepfoundation.org/how-sleep-works/how-much-sleep-do-we-really-need>

For users at the extremes of the distribution (those sleeping less than 5 hours or more than 9 hours), Bellabeat may implement reminders or alarms to promote adherence to the recommended guidelines. Bellabeat can also help users set up sleep schedules.

2.2.2 Identifying Relationships

Having established a clear understanding of the individual distributions and composition of the variables, we shall now proceed to identify their interrelationships. This section will focus on generating a correlation matrix heatmap and scatter plots to discern key relationships. We will also evaluate any impact of the type of the day (Weekend vs Weekday) on fitness trends.

Key Data Handling Decisions:

- Focus on Totals: The analysis will prioritize overall trends in activity and fitness. Therefore, individual component variables such as Lightly/Fairly/Very Active Minutes and Light/Moderately/Very Active Distance will be excluded in favor of their respective totals.
- Redundant Variables: To streamline the analysis, variables that are expected to be highly correlated or equivalent will be reduced:
 - Total Distance vs. Total Steps: We anticipate Total Distance to be equivalent to Total Steps, so only Total Steps will be retained.
 - Time In Bed vs. Minutes Asleep: We anticipate Total Time in Bed to be equivalent to Total Minutes Asleep, so only Minutes Asleep will be retained

To confirm the equivalence of the last two points (Distance/Steps and Time In Bed/Minutes Asleep), correlation coefficients will be calculated. The code following this section will display these coefficients.

```
# For each pair:  
# Calculate te 2X2 correlation matrix and obtain the second elemnt in the first row  
# (or first element in the second row)  
  
cat(paste0("Correlation between Total Distance and Total Steps: ",  
          cor(daily_activity_sleep[,c("TotalDist", "Steps")],  
               use="pairwise.complete.obs")[1,2] %>% round(2),  
          "\nCorrelation between Time In Bed and Minutes Asleep: ",  
          cor(daily_activity_sleep[,c("TimeInBed", "MinAsleep")],  
               use="pairwise.complete.obs")[1,2] %>% round(2)))  
  
## Correlation between Total Distance and Total Steps: 0.97  
## Correlation between Time In Bed and Minutes Asleep: 0.93
```

The results derived from the preceding code confirm the redundancy of the variables “Total Distance” and “Time in Bed” for subsequent analysis.

This leaves the following 5 numeric variables for our analysis:

- Calories
- Steps
- Total Active Minutes
- Sedentary Minutes
- Minutes Asleep

We will use DayType to evaluate any differences in their relationships due to the type of the day.

2.2.2.1 Correlation Matrix Heat Map A heatmap serves as an effective method for identifying strong linear relationships. While a low correlation coefficient does not preclude the existence of a relationship (as a non-linear one may be present), a high correlation coefficient unequivocally provides evidence for the presence of one.

Therefore, the initial step will be to generate a heat map to quickly visualize the correlations. The code below creates a correlation matrix and visualizes that using a heat map

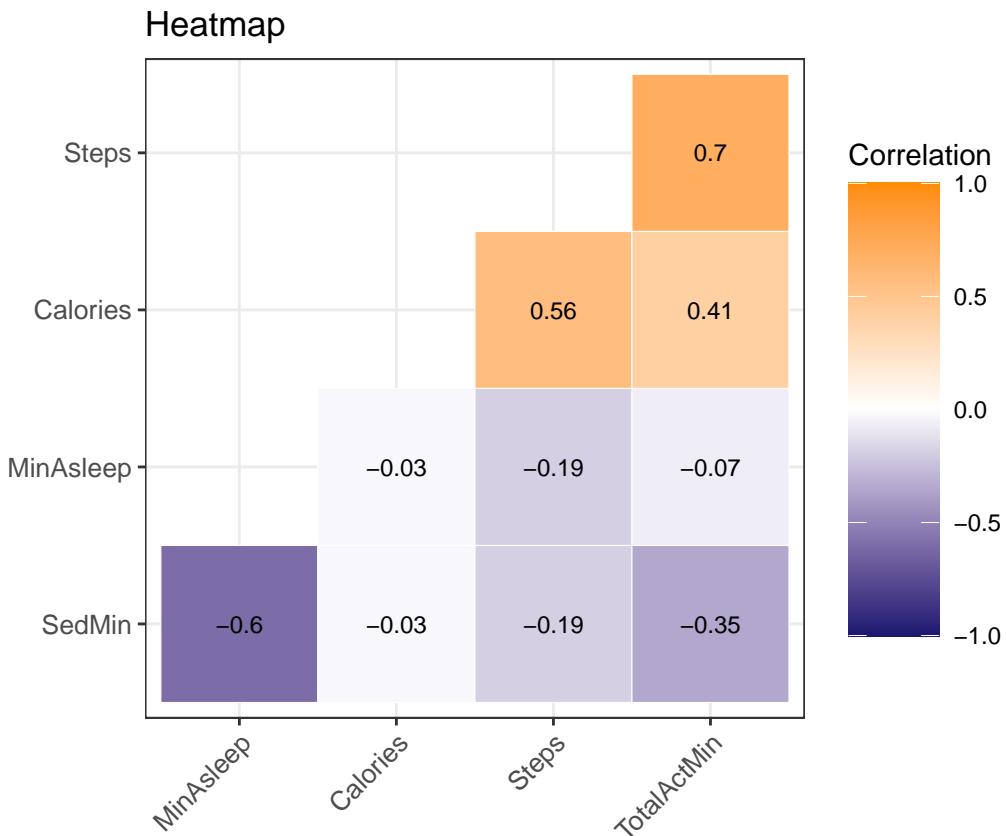
```

hmap_cols <- c("Calories", "Steps", "TotalActMin", "SedMin", "MinAsleep")

# Create correlation matrix
corr_matrix <- cor(daily_activity_sleep[, hmap_cols], # Only select numeric data
                     use="pairwise.complete.obs") %>%
  round(2) #round correlation matrix

ggcorrplot(corr_matrix,
            method='square',
            type='lower',
            hc.order = TRUE, # Automatic hierarchical clustering
            colors = c("midnightblue", "white", "darkorange"),
            lab = TRUE, # Add correlation coefficients
            outline.color='white', #Add outline color
            lab_size = 3.2, # Adjust label size
            tl.cex = 10, # Adjust text label size
            legend.title='Correlation', #Add legend title
            ggtheme = ggplot2::theme_bw(), # Set theme
            title= 'Heatmap') +
  theme(legend.key.size = unit(1.2, "cm")) #Set legend size

```



Key Findings and Potential Opportunities for Bellabeat:

The analysis reveals several important relationships within the fitness data:

- Negative Correlations: The variables “Sedentary Minutes” and “Minutes Asleep” demonstrate negative correlations with all other variables (indicated by purple values). However, it is worth noting that the correlations for “Minutes Asleep,” as well as the correlation between “Sedentary Minutes” and

“Calories,” are all very close to zero.

- Sedentary Behavior Impact: Sedentary Minutes are strongly linked to Minutes Asleep and, moderately, to Total Active Minutes. This suggests that a **higher amount of sedentary behavior is associated with lower sleep quality and decreased activity levels**. This represents a potential area for Bellabeat to focus its product features and messaging. Our upcoming section will delve deeper into the connection between Sedentary Behavior and its effects on both Sleep Quality and Activity.
- Near Zero Correlations: **Minutes Asleep shows surprisingly low, or near-zero, correlations with both Calories and Activity**. Given that correlation only measures linear relationships, further investigation is necessary to determine if any other type of relationship exists between these variables.
- Positive Correlations (Activity and Calorie Burning): Total Active Minutes, Steps, and Calories have moderate or strong positive relationships with each other (indicated by orange values). While it is expected that more steps lead to higher activity, the data also demonstrates that **higher activity levels and step counts have a moderately strong effect on calorie burning**. This connection is another opportunity for Bellabeat to leverage in its advertising campaigns, as it provides a strong incentive for users to increase their physical activity. The next section will explore these key relationships further.

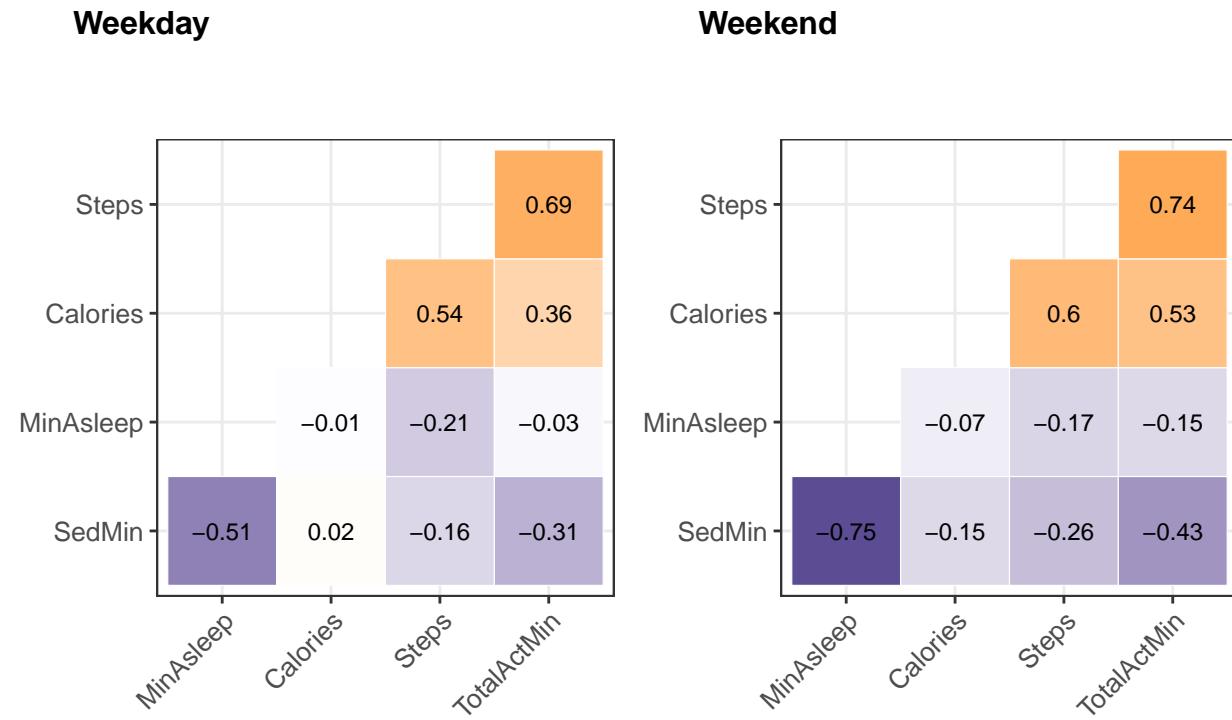
Weekdays Vs Weekend

Next we will see if there is any difference in the intensity of the key relationships identified above on Weekends vs Weekdays.

The code below uses a custom function to repeat the same analysis as above but generates different heat maps for Weekdays and Weekends

```
corrplot_funtion <- function(daytype) {  
  
  # daytype to identify the filter  
  
  # The function:  
  # Filters daily_activity_sleep by the defined filter  
  # Creates a correlation Matrix with it's values rounded to 2 sig figures  
  # Visualizes the matrix using a heatmap  
  
  data <- daily_activity_sleep %>% filter(DayType == daytype)  
  
  corr_mat <- cor(data %>% .[,hmap_cols],  
                  use="pairwise.complete.obs") %>% round(2)  
  
  p <- ggcorrplot(corr_mat,  
                  method='square',  
                  type='lower',  
                  hc.order = TRUE,  
                  colors = c("midnightblue", "white", "darkorange"),  
                  lab = TRUE,  
                  outline.color='white',  
                  lab_size = 3.2,  
                  tl.cex = 10,  
                  ggtheme = ggplot2::theme_bw,  
                  show.legend=FALSE)  
  
  return(p)  
}  
  
plot_grid()
```

```
corrplot_funtion('Weekday'), corrplot_funtion('Weekend'), ncol = 2,
labels = c('Weekday', 'Weekend'), label_size = 12)
```



Key Observations from Correlation Heatmaps:

- Sedentary Behavior and Sleep: All correlations related to sedentary minutes are stronger on weekends than weekdays. Notably, the **negative correlation between Minutes Asleep and sedentary minutes is significantly stronger on weekends**. This suggests that Bellabeat could benefit from promoting increased activity on weekends to help reduce sedentary behavior.
- Calories and Activity: All correlations related to calories are also stronger on weekends than weekdays. The **correlation between Calories and Total Active Minutes is much stronger on Weekends**. This observation prompts the suggestion that Bellabeat should follow a more active policy on weekends to encourage users to boost calorie burn via higher activity.

Research Questions for Further Exploration:

The analysis of all three heatmaps leads to several important research questions, which are summarized below:

- How does sedentary behavior impact sleep quality and overall activity? Is there a difference in the impact on sleep quality between weekdays and weekends?
- Does increased activity result in a compromise on sleep quality or duration?
- What are the primary factors that influence calorie expenditure? Is there a difference in the impact of Activity on Calories between weekdays and weekends?

We will now proceed to answering these questions

2.2.2.2 Impact of Sedentary Behavior on Sleep Quality and Activity We will first try to answer, how does sedentary behavior impact sleep quality and overall activity? We will also see if there's a difference in the impact on sleep quality between weekdays and weekends.

Total Minutes Asleep and Sedentary Minutes

Sedentary Minutes and Minutes Asleep had an overall correlation of co-efficient of -0.6. When disintegrated into weekends and weekdays, it was -0.51 for weekdays and -0.75 for weekends. This means that on weekends

0.75^2 or 56% of the variation in Minutes Asleep is explained by Sedentary Minutes. On weekdays it is 0.51^2 or 26%.

Let's plot the two variables together and see this further

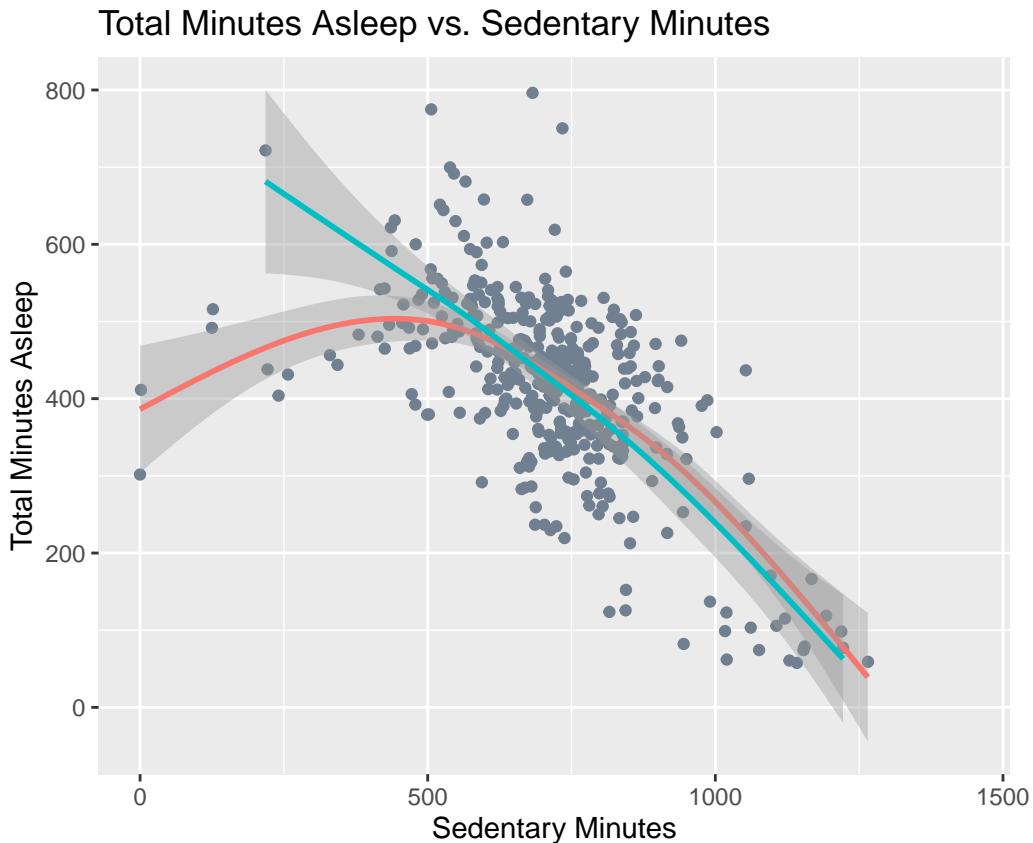
```
daytype_plot <- function(x_col,y_col,x_indicator,y_indicator) {

  # x_col as the x variable
  # y_col as the y variable
  # x_indicator as the descriptive name for the x variable
  # y_indicator as the descriptive name for the y variable

  # This function plots the x variable and the y variable using a scatter plot
  # and two smooth lines (one for Weekend and one for Weekdays)

  ggplot(daily_activity_sleep) +
  geom_jitter(aes(x=.data[[x_col]],y=.data[[y_col]]),color='slategray') +
  geom_smooth(aes(x=.data[[x_col]],y=.data[[y_col]]),color=DayType,method='gam') +
  labs(
    x = x_indicator, # New x-axis title
    y = y_indicator, # New y-axis title
    color = "Day Type", # New legend title
    title = paste0(y_indicator," vs. ",x_indicator) # New title
  )
}

daytype_plot("SedMin","MinAsleep","Sedentary Minutes","Total Minutes Asleep")
```



The plots confirms the results of the correlation coefficient. There is definitely a strong inverse relationship between the two variables. As sedentary minutes rise, the time spent sleeping decreases. We also observe a much steeper relationship on weekends vs weekdays.

The Relationship Between Sedentary Behavior and Poor Sleep Quality: Prolonged sedentary behavior significantly contributes to poor sleep quality through several mechanisms:

- Weakened Sleep Drive: Insufficient physical activity reduces the body's natural need for sleep, leading to difficulty initiating and maintaining sleep.
- Circadian Rhythm Disruption: Regular movement is essential for regulating the body's sleep-wake cycle. A lack of activity can weaken this cycle, resulting in fragmented sleep patterns.
- Melatonin Suppression from Screen Time: Many sedentary activities, such as watching TV or using computers, involve exposure to bright, blue light. This light suppresses the production of melatonin, the hormone necessary for falling asleep.
- Mental and Physical Health Factors: Inactivity is linked to higher levels of stress, anxiety, and depression, which are common causes of sleep problems. Furthermore, physical discomfort from extended sitting can disrupt sleep.

Sources:

<https://link.springer.com/article/10.1186/s12889-023-16041-8> <https://pmc.ncbi.nlm.nih.gov/article/s/PMC12186656/>

Potential Impact on Weekends and Suggested Interventions: The negative effects are more pronounced on weekends, possibly due to an increase in late-night sedentary activities like reading, social media use, and watching movies.

Given this pattern, Bellabeat could implement the following:

- Sleep Reminders: Send notifications to users to encourage sleep when late-night sedentary behavior is detected.
- Screen Time Management: Track screen usage and send reminders to take breaks when use is prolonged.

Total Active Minutes and Sedentary Minutes

The heat map also suggested a moderately negative relationship between Sedentary Minutes and Activity. The scatter plot below demonstrates this relationship

```
combined_plot <- function(x_col,y_col,x_indicator,y_indicator) {

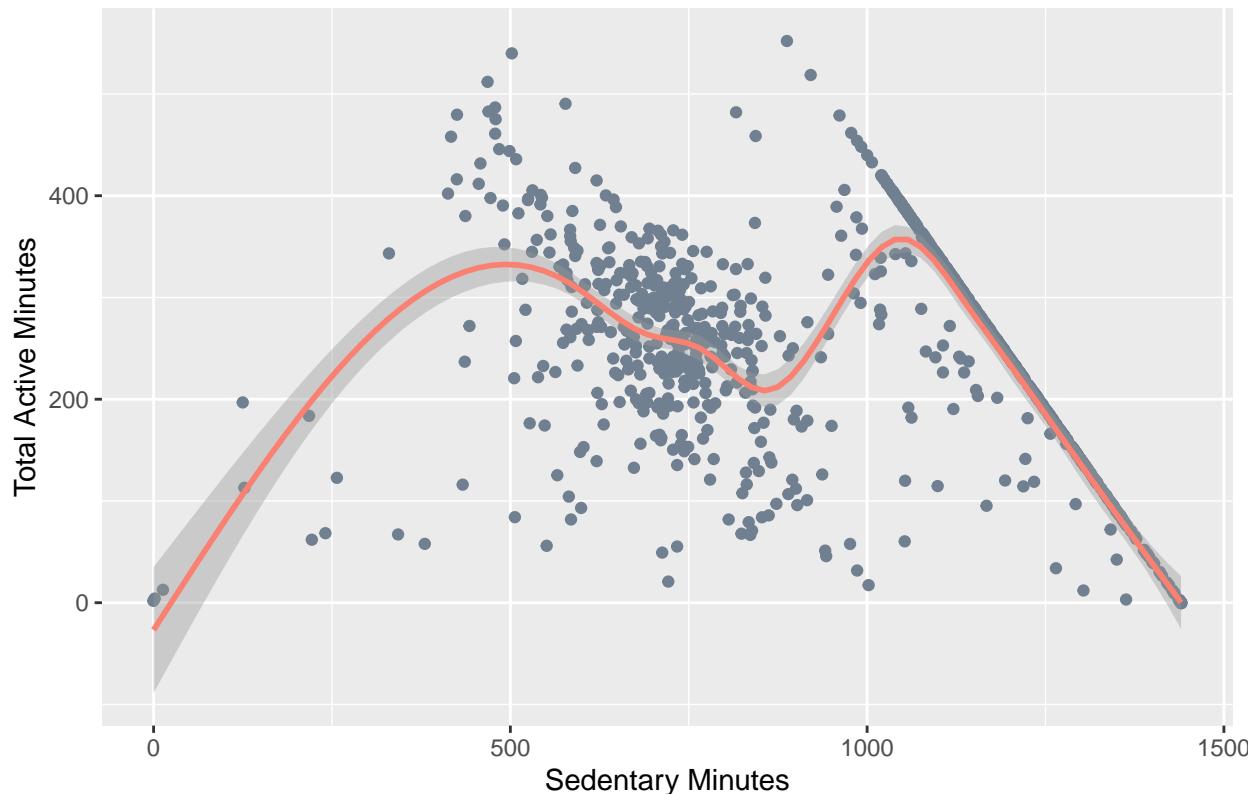
  # x_col as the x variable
  # y_col as the y variable
  # x_indicator as the descriptive name for the x variable
  # y_indicator as the descriptive name for the y variable

  # This function plots the x variable and the y variable using a scatter plot
  # and a smooth lines

  ggplot(daily_activity_sleep) +
  geom_jitter(aes(x=.data[[x_col]],y=.data[[y_col]]),color='slategray') +
  geom_smooth(aes(x=.data[[x_col]],y=.data[[y_col]]),color='salmon',method='gam') +
  labs(
    x = x_indicator, # New x-axis title
    y = y_indicator, # New y-axis title
    title = paste0(y_indicator," vs. ",x_indicator) # New title
  )
}

combined_plot("SedMin","TotalActMin","Sedentary Minutes","Total Active Minutes")
```

Total Active Minutes vs. Sedentary Minutes



The scatter plot data, though split, consistently reveals a negative correlation between total active minutes and sedentary minutes. This logical relationship shows that as sedentary behavior (sitting or inactivity) increases, physical activity decreases.

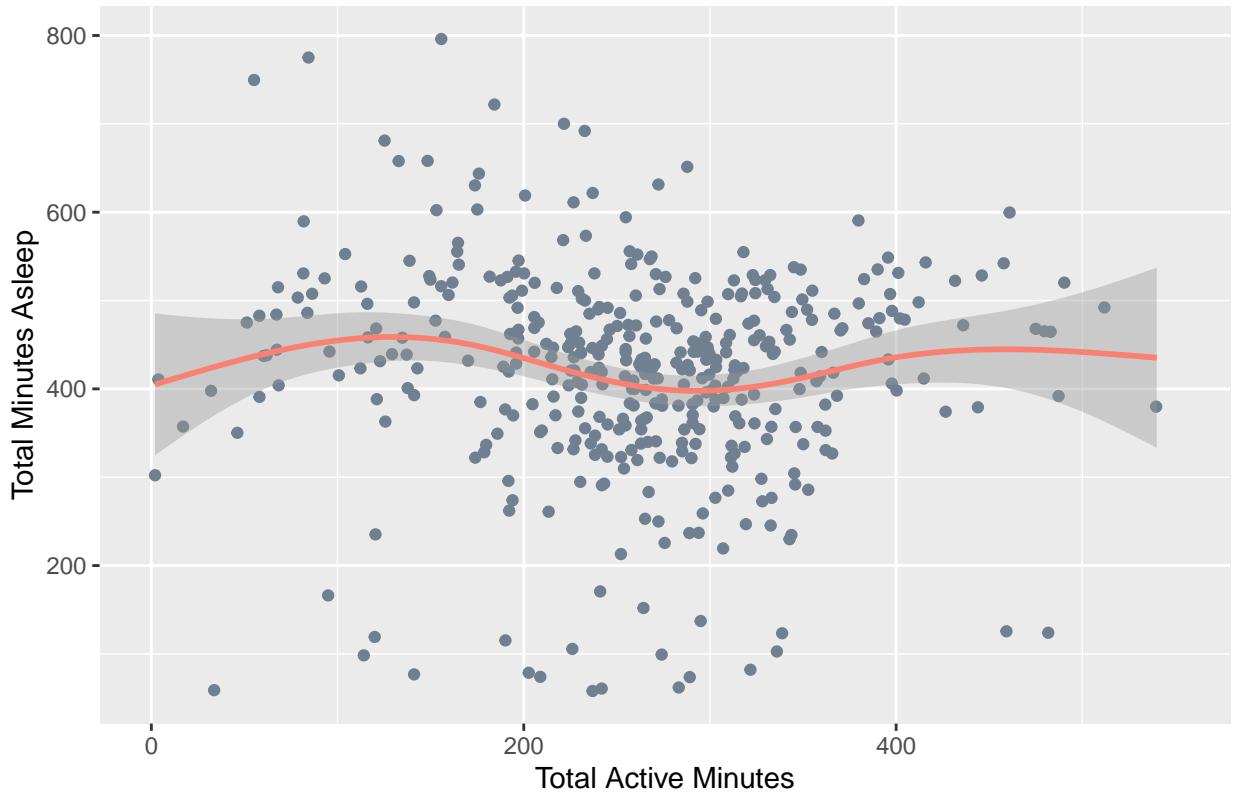
This negative trend is particularly evident when sedentary time exceeds 1000 minutes (approximately 16 hours), which aligns with the calculated mean average.

Based on this strong inverse relationship, it is vital for Bellabeat to integrate actionable activity suggestions into reminders aimed at reducing sedentary time. For instance, messages could include: “You have been sitting for too long, time to take a walk,” or “Trouble having sleep? Time to put the phone down and do some stretches.”

2.2.2.3 Does Increased Activity Mean a Compromise on Sleep? Next, we will try to answer whether increased activity results in a compromise on sleep quality or duration.

```
combined_plot("TotalActMin", "MinAsleep", "Total Active Minutes", "Total Minutes Asleep")
```

Total Minutes Asleep vs. Total Active Minutes



Higher activity levels do not appear to negatively impact sleep quality. Instead, the scatter plots indicate that decreasing sedentary behavior can free up time, leading to both increased activity and improved sleep.

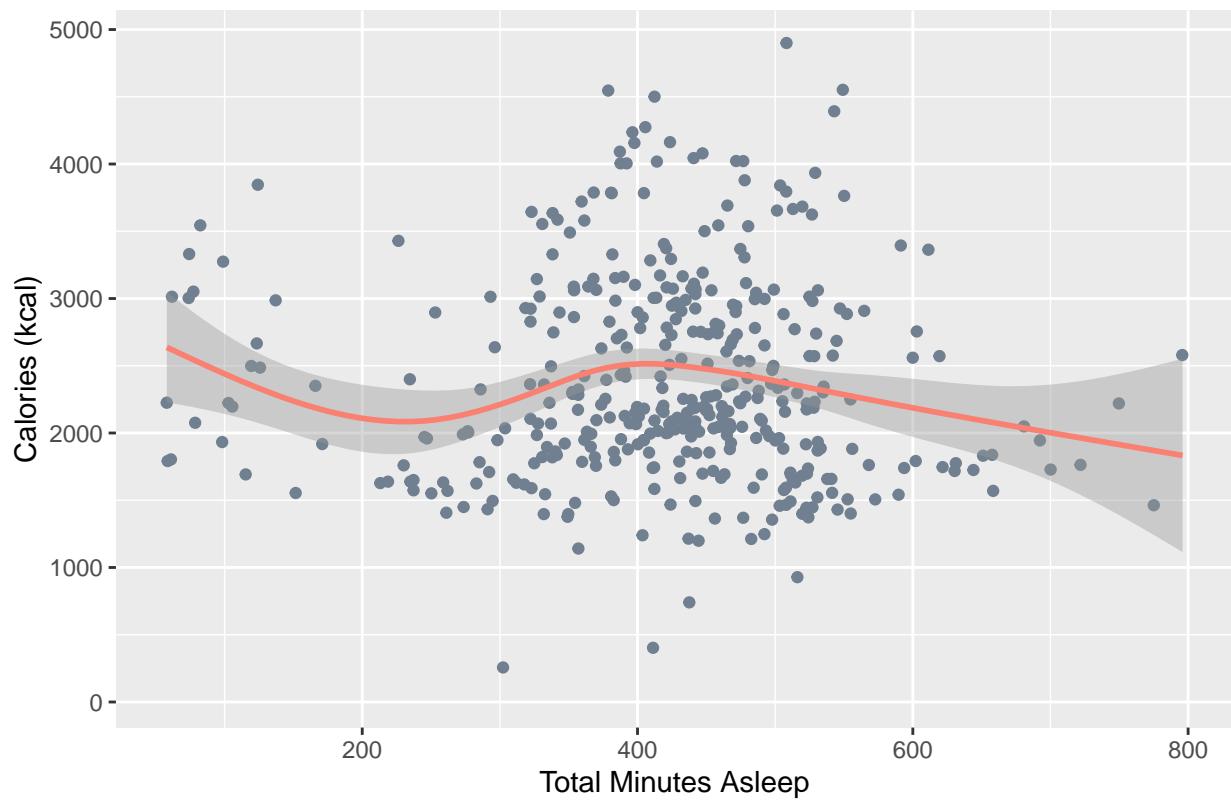
2.2.2.4 What Influences Calorie Expenditure Next, we will try to identify the primary factors that influence calorie expenditure? Is there a difference in the impact of Activity on Calories between weekdays and weekends

Calories and Minutes Asleep

Let's first see if higher sleep quality leads to an increase or reduction in Calorie Expenditure.

```
combined_plot("MinAsleep","Calories","Total Minutes Asleep","Calories (kcal)")
```

Calories (kcal) vs. Total Minutes Asleep

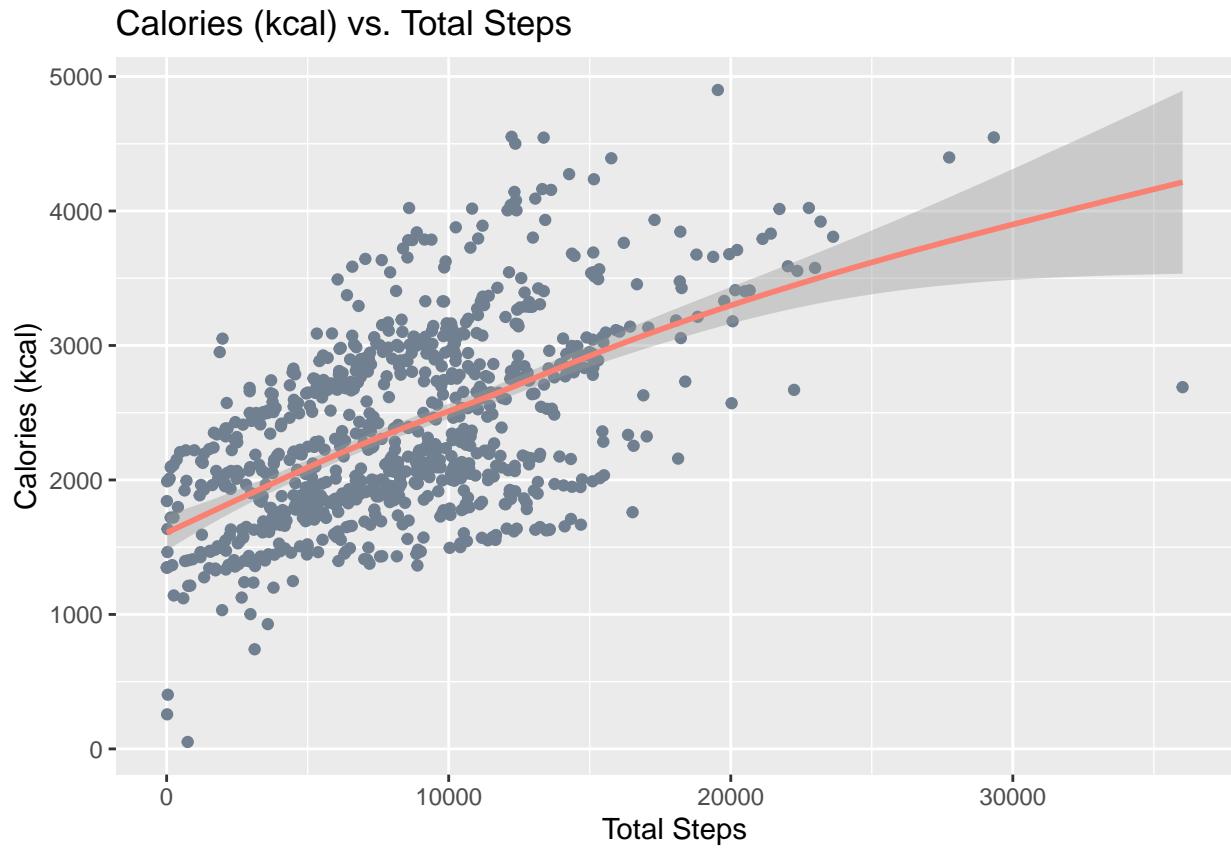


Interestingly, higher sleep duration has no impact on Calorie Expenditure

Calories and Total Steps

Let's now see if a higher step count leads to an increase in Calorie Expenditure.

```
combined_plot("Steps", "Calories", "Total Steps", "Calories (kcal)")
```

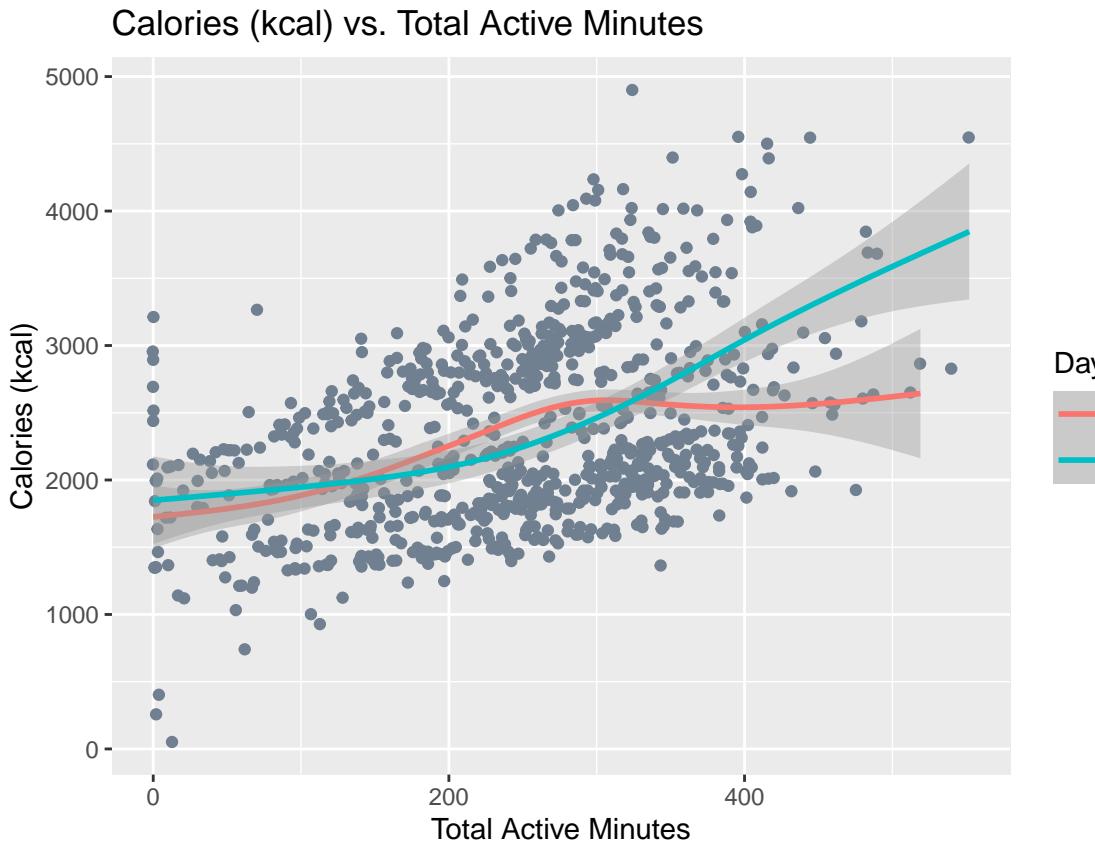


The data shows a strong correlation between a higher step count and a significant increase in calorie expenditure. Bellabeat can leverage this insight in its advertising or user notifications. For instance, encouraging activities like running, walking, or using a treadmill can serve as a direct incentive for users aiming to get more fit and/or achieving a calorie deficit.

Calories and Activity

Let's now see if higher activity leads to an increase in Calorie Expenditure and if there is a more pronounced effect on Weekends.

```
daytype_plot("TotalActMin", "Calories", "Total Active Minutes", "Calories (kcal)")
```



The relationship between activity and calorie expenditure differs significantly between weekdays and weekends. While a positive correlation exists on both, the line representing the relationship is notably steeper on weekends than on weekdays, meaning that each additional minute of activity results in a higher caloric burn on weekends.

This difference may be due to the nature of the activity. Weekend activity is often deliberate and sustained (e.g., long walks, gym sessions, sports), which leads to a predictable, linear, and higher calorie cost. Conversely, weekday calorie burn is more influenced by less intense “background noise” such as stress, fidgeting, work schedules, or incidental steps. These activities are less likely to register fully as “Active Minutes,” resulting in a weaker relationship between logged active time and calories burned.

Ultimately, this finding does not change Bellabeat’s core strategy; the company can continue to use messaging similar to what they use for steps to encourage users to improve their fitness and achieve a calorie deficit. This messaging is likely to have a stronger effect on weekends, as people are often participating in planned fitness activities. On weekdays, the message functions as a helpful prompt for users to engage in more physical activity.

3 Part 2: Hourly Level Analysis

Moving forward, we will now extend our analysis to a higher level of granularity. We will also evaluate any impact of the type of the day (Weekend vs Weekday) on fitness trends.

The subsequent analysis will focus on the hourly level data for Intensities, Calories and Steps. Since a thorough analysis has already been conducted at the daily level, we will bypass repeating this process for the hourly analysis. Our primary goal for the hourly data will be to review how the distributions of these indicators change throughout the hours of the day.

3.1 Data Processing and Cleaning

This section details the process for data processing and cleaning in preparation for the hourly analysis

3.1.1 Shortlisting Tables and Columns

We have identified a total of three relevant hourly data indicators. We will assess which ones require joining.

- Intensities
- Steps
- Calories

3.1.1.1 Unique ID's in each table Just like before, let's first check the number of Unique ID's in each of the hourly tables. This will help determine any tablet that do not contain information for all tables

The following SQL query checks the number of unique ID's in all 3 tables.

```
SELECT      -- Intensities Table
    'HourlyIntensities' AS DataIndicator, -- Data indicators representing each table
    COUNT(DISTINCT Id) AS UniqueIds   -- Count of Unique IDs
FROM
    hourlyintensities_merged
UNION
SELECT      -- Process Repeated for Steps
    'HourlySteps' AS DataIndicator,
    COUNT(DISTINCT Id) AS UniqueIds
FROM
    hourysteps_merged
UNION
SELECT      -- Process Repeated for Calories
    'Calories' AS DataIndicator,
    COUNT(DISTINCT Id) AS UniqueIds
FROM
    hourlycalories_merged
ORDER BY      -- Sort by Unique ID's
    UniqueIds
```

Table 25: 3 records

DataIndicator	UniqueIds
Calories	33
HourlyIntensities	33
HourlySteps	33

All 3 tables contain information on all 33 respondents, therefore none need to be dropped

3.1.1.2 Finalize and Validate Remaining Columns Next, we will assess if any columns in the three tables require dropping or transformation. To begin, let's obtain a brief description of the columns within all tables.

```
PRAGMA table_info(hourlyintensities_merged)
```

Table 26: 4 records

cid	name	type	notnull	dflt_value	pk
0	Id	REAL	0	NA	0
1	ActivityHour	TEXT	0	NA	0
2	TotalIntensity	INTEGER	0	NA	0
3	AverageIntensity	REAL	0	NA	0

```
PRAGMA table_info(hourlysteps_merged)
```

Table 27: 3 records

cid	name	type	notnull	dflt_value	pk
0	Id	REAL	0	NA	0
1	ActivityHour	TEXT	0	NA	0
2	StepTotal	INTEGER	0	NA	0

```
PRAGMA table_info(hourlycalories_merged)
```

Table 28: 3 records

cid	name	type	notnull	dflt_value	pk
0	Id	REAL	0	NA	0
1	ActivityHour	TEXT	0	NA	0
2	Calories	INTEGER	0	NA	0

We can see that Id and ActivityHour are in all 3 tables which can be used to join the tables

All 3 of the remaining columns, TotalIntensity, AverageIntensity, Calories and Steps only exist on one of the tables each. Let's also review their descriptions to see if we should exclude any amongst them. The table below lists descriptions for the relevant columns from the Fitabase data dictionary available at this link:

<https://www.fitabase.com/media/2126/fitabase-fitbit-data-dictionary-as-of-05162025.pdf>

```
datadescription <- read_excel("datadescription.xlsx", sheet='Hourly')
kable(datadescription) %>%
  kable_styling("striped") %>% column_spec(2, width = "12cm")
```

Data Header	Data Description
ActivityHour	Date and hour value in mm/dd/yyyy hh:mm:ss format.
TotalIntensity	Value calculated by adding all the minute-level intensity values that occurred within the hour
AverageIntensity	Average intensity state exhibited during that hour (TotalIntensity for that ActivityHour divided by 60).
StepTotal	Total number of steps taken.

Calories	Total number of estimated calories burned.
----------	--

Since AverageIntensity is just a transformation of TotalIntensity, we will drop it from our analysis

3.1.1.3 Checking for Duplicates and Missing Values Next we will check for any duplicates and missing values that exist for our finalized column lists for all 3 tables

```
WITH dup_inten AS (      -- Create a temporary table to calculate Duplicates
SELECT
    1 AS UniId,          -- Define UniId in each temporary table to facilitate the join
    COUNT(*) -           -- Calculate the difference between the count of total rows
(SELECT              -- and distinct rows. This difference will be the # of duplicates
    count(*)
FROM
(SELECT DISTINCT      -- This inner query counts distinct rows
    Id,
    ActivityHour,
    TotalIntensity
FROM
    hourlyintensities_merged) AS t1) AS DuplicatesIntensities
FROM
    hourlyintensities_merged
),
miss_inten AS ( -- Create a temporary table to calculate Missing Values
SELECT
    COUNT(*) AS MissingIntensities,   -- Count values when any one of the columns
    1 AS UniId                         -- specified is null.
FROM
    hourlyintensities_merged
WHERE
    Id IS NULL OR
    ActivityHour IS NULL OR
    TotalIntensity IS NULL
),
dup_steps AS (      -- Repeat the process for the steps table
SELECT
    1 AS UniId,
    COUNT(*) -
(SELECT
    count(*)
FROM
(SELECT DISTINCT
    Id,
    ActivityHour,
    StepTotal
FROM
    hourlysteps_merged) AS t2) AS DuplicatesSteps
FROM
    hourlysteps_merged
),
miss_steps AS (
SELECT
    COUNT(*) AS MissingSteps,
```

```

    1 as UniId
FROM
    hourlysteps_merged
WHERE
    Id IS NULL OR
    ActivityHour IS NULL OR
    StepTotal IS NULL
),
dup_cals as (      -- Repeat the process for the calories table
SELECT
    1 as UniId,
    COUNT(*) -
(SELECT
    count(*)
FROM
(SELECT DISTINCT
    Id,
    ActivityHour,
    Calories
FROM
    hourlycalories_merged) as t2) as DuplicatesCals
FROM
    hourlycalories_merged
),
miss_cals as (
SELECT
    COUNT(*) AS MissingCals,
    1 as UniId
FROM
    hourlycalories_merged
WHERE
    Id IS NULL OR
    ActivityHour IS NULL OR
    Calories IS NULL
)
SELECT          -- Join results from all tables into one
A.DuplicatesIntensities,
B.MissingIntensities,
C.DuplicatesSteps,
D.MissingSteps,
E.DuplicatesCals,
F.MissingCals
FROM
    dup_inten as A
JOIN
    miss_inten as B on A.UniId=B.UniId
JOIN
    dup_steps as C on A.UniId=C.UniId
JOIN
    miss_steps as D on A.UniId=D.UniId
JOIN
    dup_cals as E on A.UniId=E.UniId
JOIN

```

```
miss_cals as F on A.UniId=F.UniId
```

Table 30: 1 records

DuplicatesIntensities	MissingIntensities	DuplicatesSteps	MissingSteps	DuplicatesCals	MissingCals
0	0	0	0	0	0

All three tables are clean, with zero missing values and duplicates.

3.1.2 Joining the Daily tables

Next we will join all 3 of the tables on the Id and ActivityHour columns.

- As discussed earlier, AverageIntensity is not included.
- TotalIntensity is renamed to Intensity
- Like before, we will exclude rows when Steps are less than 1 (equal to 0) as these are likely to be days when the watch wasn't worn or it didn't record anything

```
SELECT
    I.Id,
    I.ActivityHour,
    I.TotalIntensity as Intensity,
    S.StepTotal as Steps,
    C.Calories
FROM hourlyintensities_merged as I
JOIN
    hourlysteps_merged as S
ON
    I.Id = S.Id      -- Join on Id and Activity Hour
AND
    I.ActivityHour = S.ActivityHour
JOIN
    hourlycalories_merged as C
ON
    I.Id = C.Id
AND
    I.ActivityHour = C.ActivityHour
WHERE
    S.StepTotal > 0 -- drop rows where Total Steps = 0
```

3.1.2.1 Review Joined data Lets now the first few rows of the joined dataframe for some quick validation

```
kable(head(hourly_activity,5)) %>%
  kable_styling("striped")
```

		Id	ActivityHour	Intensity	Steps	Calories
		1503960366	4/12/2016 12:00:00 AM	20	373	81
		1503960366	4/12/2016 1:00:00 AM	8	160	61
		1503960366	4/12/2016 2:00:00 AM	7	151	59
		1503960366	4/12/2016 8:00:00 AM	13	250	68
		1503960366	4/12/2016 9:00:00 AM	30	1864	141

The data has been successfully and correctly joined. We will now proceed to the Data Visualization phase.

3.2 Data Visualization and Plots

Now that we have our data we can move forward with the Data Visualization phase. As previously stated, the analysis will remain concise, focusing solely on summary statistics and an examination of how the distributions of the three indicators fluctuate throughout the hours of the day.

3.2.1 Summary Statistics

The initial step involves generating summary statistics to facilitate a more comprehensive understanding of the dataset.

```
kable(hourly_activity %>% summary(digits=2)) %>%  
  kable_styling("striped")
```

Id	ActivityHour	Intensity	Steps	Calories
Min. :1.5e+09	Length:12802	Min. : 0	Min. : 1	Min. : 43
1st Qu.:2.3e+09	Class :character	1st Qu.: 6	1st Qu.: 103	1st Qu.: 77
Median :4.4e+09	Mode :character	Median : 14	Median : 287	Median :100
Mean :4.9e+09	NA	Mean : 21	Mean : 553	Mean :117
3rd Qu.:7.0e+09	NA	3rd Qu.: 26	3rd Qu.: 643	3rd Qu.:134
Max. :8.9e+09	NA	Max. :180	Max. :10554	Max. :948

Some quick insights:

- The mean for Intensity is 21 minutes. This means that on average, in a given hour, respondents engage in 21 minutes of total activity.
- The mean of StepTotal is 553. This means that on average, in a given hour, respondents walk 553 steps.
- The mean of Calories burned is 117. This means that on average, in a given hour, respondents burn 117 calories

3.2.2 Variation in Averages at each Hour of the Day

We will now proceed to delve deeper into these statistics by identifying how the average values vary across each hour of the day.

To prepare for this:

- We must first add two new columns: one representing the hour of the day (in 24-hour format) and another specifying the Day Type (differentiating between Weekend and Weekday)
- Next we will add some text for annotations at 6 pm and 1 pm.
- We will use a for loop to print plots for all 3 indicators (Intensity, Calories and Steps)
- This code computes the average Intensity/Calories/Steps for each hour of the day and then plots the results against time. Distinct plots are generated to compare weekday and weekend averages. A gray line is drawn at peak hours

```
hourly_activity <- hourly_activity %>%  
  mutate(activity_time = mdy_hms(ActivityHour), ##Cleaned ActivityHour  
        hour_of_day = hour(activity_time),      ## Calculate Hour of the day  
        daytype= ifelse(weekdays(activity_time) == "Saturday" |  
                        weekdays(activity_time) == "Sunday",  
                        "Weekend", "Weekday")) ##Calculate DayType  
  
line_data <- data.frame(      #Data to draw vertical lines at peak times  
  daytype = c("Weekday", "Weekend"),    #6 pm on weekdays and 1 pm on weekend  
  x_pos = c(18, 13), # Unique positions for each facet
```

```

    label = c("6 PM", "1 PM") # The text for each facet
  )

for (i in c("Intensity", "Calories", "Steps")) {

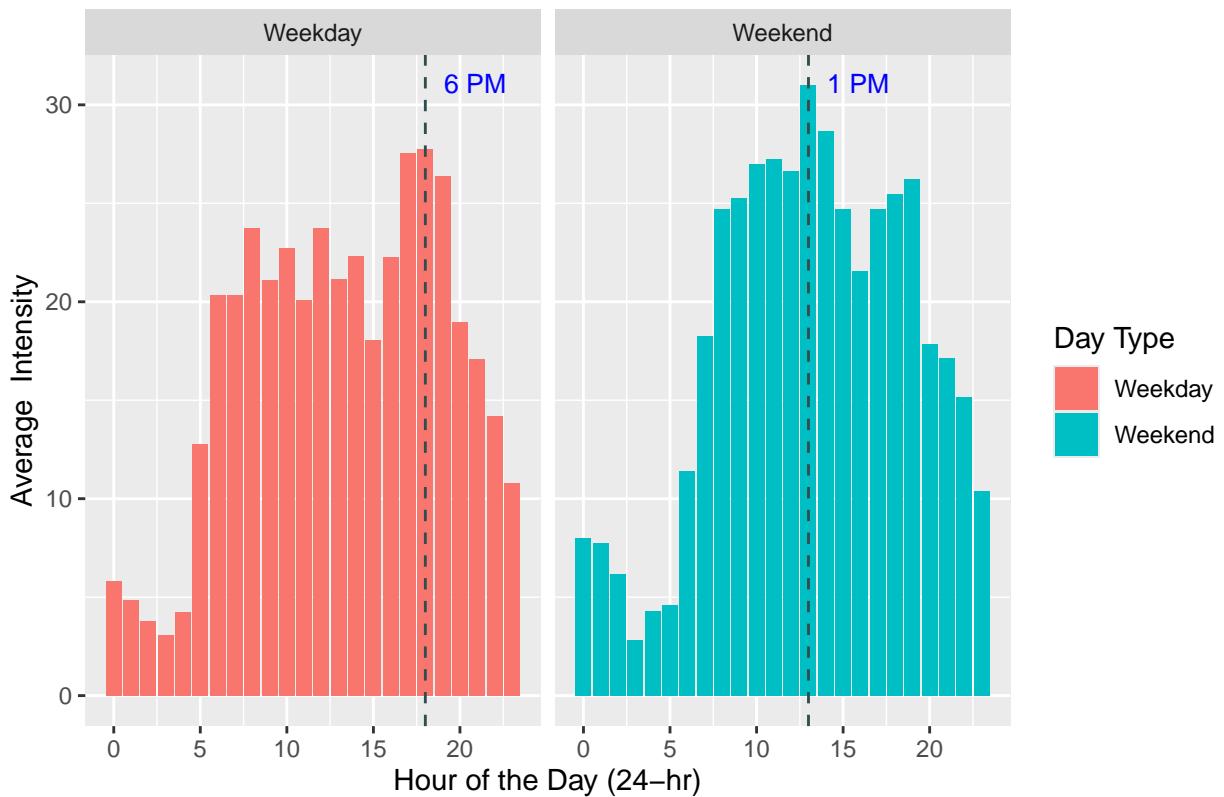
  p <- hourly_activity %>% group_by(hour_of_day, daytype) %>% #For each hour
  summarise(hourly_avg = mean(.data[[i]]), .groups="drop") %>% #Calculate Avg
  ggplot(aes(x=hour_of_day, y=hourly_avg, fill = daytype)) + geom_col() +
  facet_wrap(~daytype) + #Separate plots for Weekday and Weekend
  geom_vline(data = line_data, aes(xintercept = x_pos), # Draw lines
             linetype = "dashed", color = "darkslategray", size = 0.5) +
  geom_text(data = line_data, aes(x = x_pos, y = Inf, label = label), #Add text
            vjust = 2, hjust = -0.3, inherit.aes = FALSE, size=3.5,color='blue') +
  labs(title= paste0("Average ", i, " over Time"), # New Title
       x='Hour of the Day (24-hr)', # New x and y labels
       y=paste("Average ", i), fill="Day Type")

  print(p)
}

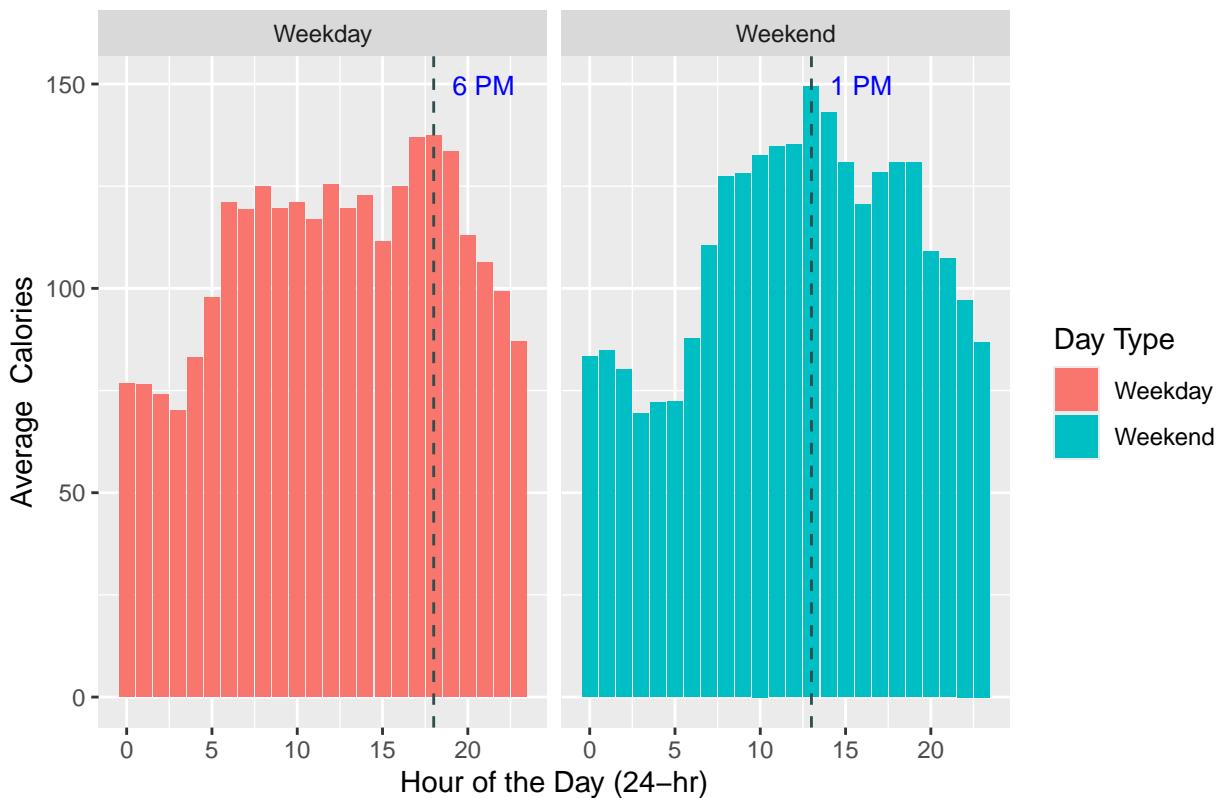
}

```

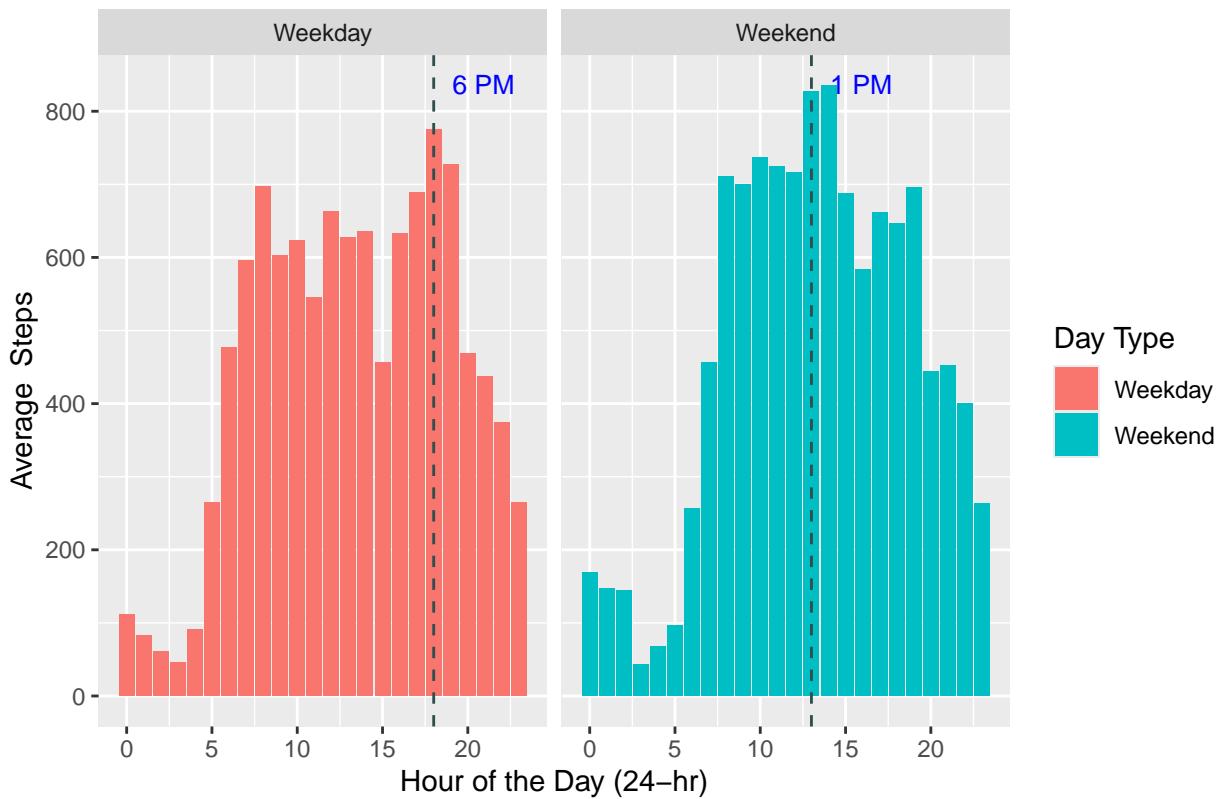
Average Intensity over Time



Average Calories over Time



Average Steps over Time



Intensity, Calorie Expenditure, and Steps exhibit identical patterns, with distinct peaks occurring at the same timestamps on both weekdays and weekend

- They are all observed to increase as the day progresses in charts for both day types before declining later.
- Distinct variations are also evident in the distributions for weekends and weekdays. On weekdays, all 3 indicators peak between 5-7 p.m., while on weekends, the peak is notably around 1 p.m.

This pattern is logical, as individuals on weekdays may engage in planned physical activity (exercise/walks/sports) following the conclusion of typical office hours at 5 p.m. Conversely, on weekends, they have the flexibility to schedule these workouts earlier, such as at 1 p.m., a time that still permits a later start to the day.

This provides an important insight for Bellabeat: reminders prompting users to engage in activity could be strategically timed differently for weekdays and weekends. On weekdays, reminders such as, “Time to take a walk,” or “Time to visit the gym,” could be dispatched at 5 p.m. On weekends, these prompts could be sent at around 12:45 p.m.

4 Conclusion and Recommendations

daily- dist and comp: * calorie burned dist peak is on lower end of recommended range * one third have steps below 6000 * majority participants lightly active * very sedentary lifestyle mean 16 hours, peak 12 hours * activity potentially drops in summers * we have high performers and low performers, mkr strategy should be targeted , varying performance levels. These disparate distribution patterns strongly indicate that a one-size-fits-all approach is ineffective, necessitating the development of user-targeted plans. * 30% walk less than 4 km * sleep is fine with avg of 7-9 hours but bellabeat can help set up sleep schedule. the data suggests that most people only sleep once in a day (presumably at night)

daily: relationships * higher amount of sedentary behavior is associated with lower sleep quality and decreased activity levels. * Minutes Asleep shows surprisingly low, or near-zero, correlations with both Calories and Activity * higher activity levels and step counts have a moderately strong effect on calorie burning

weekends * stronger relationship for sed min and sleep * stronger relationship for calories and activity

hourly: * times for remainder 5-7 on weekend, 1-2 on weekdays

```
# Code to close database connection  
DBI::dbDisconnect(con)
```