

# Exploring the Determinants of Body Weight: A Bayesian Analysis of Anthropometric and Demographic Factors Among Female U.S. Army Personnel\*

**Anthropometric Measurements Such as Waist and Thigh Circumference Are Key  
Predictors of Body Weight, While Demographic Factors Play a Secondary Role**

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This study examines the relationship between body weight and key anthropometric and demographic factors among female U.S. Army personnel using a Bayesian regression model. The analysis found that waist circumference and thigh circumference are strong predictors of body weight, while other variables, such as height, age, and military component, show weaker or uncertain associations. These findings highlight the importance of body composition measurements in understanding weight variation and support their use in designing health monitoring programs and military equipment. By identifying key predictors, this research contributes to improving fitness assessments and operational readiness in physically demanding occupations.

## 1 Introduction

Body weight significantly impacts physical performance, health, and operational readiness, particularly in demanding professions such as military service. For the U.S. Army, maintaining optimal weight is essential to meet fitness standards, reduce injury risks, and ensure operational efficiency. While extensive anthropometric and demographic data exist, limited research explores the combined influence of these factors on body weight, particularly among female soldiers (Gordon et al. 2014).

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\*Code and data are available at: [https://github.com/huayan1998/Exploring\\_the\\_Determinants\\_of\\_Body\\_Weight](https://github.com/huayan1998/Exploring_the_Determinants_of_Body_Weight)

This study seeks to address the limited understanding of this issue by utilizing the 2012 U.S. Army Anthropometric Survey (ANSUR II) Female Dataset, which provides detailed anthropometric and demographic measurements of female personnel. Data collection was conducted using standardized instruments such as stadiometers and calipers, ensuring high reliability and consistency (Hotzman et al. 2011; Paquette et al. 2009). Key variables, including height, waist circumference, and thigh circumference, were measured to assess body composition, while demographic factors such as age, ethnicity, and military component were cross-validated with administrative records (Gordon et al. 2014).

The primary aim of this study is to model the relationship between body weight and a set of anthropometric and demographic predictors among female U.S. Army personnel. Specifically, it examines how variations in measurements such as height and waist circumference, alongside demographic factors like age and ethnicity, influence body weight. The goal is to identify significant predictors and develop a reliable predictive model that can guide health monitoring, personalized fitness programs, and ergonomic equipment design.

Preliminary findings underscore the strong predictive power of anthropometric variables in determining body weight, with demographic factors serving as additional contributors. These results support the development of personalized fitness interventions, improved health outcomes, and the optimization of military gear to enhance operational readiness (The OPEN Design Lab 2018; Paquette et al. 2009).

This paper is structured as follows: Section 2 describes the dataset and provides a descriptive analysis of the key variables. Section 3 explains the methodology, including the Bayesian regression model employed. Section 4 presents the findings, highlighting significant predictors and model performance. Section 5 discusses the implications, limitations, and future research directions. Appendix is divided into three sections: Appendix A discusses the data cleaning process, Appendix B provides additional details of the modeling process, and Appendix C outlines an ideal survey methodology for improved data collection.

## 2 Data

The ANSUR II dataset provides comprehensive anthropometric and demographic data for 1,986 female U.S (Natick Soldier Research and (NSRDEC) 2012). Army personnel, collected using standardized protocols to ensure accuracy. Unlike civilian datasets, it uniquely addresses the physical demands and characteristics of military personnel, offering valuable information on factors like fitness, injury risk, and gear design (Hotzman et al. 2011). Its specificity makes it a vital resource for understanding and improving the health, safety, and operational readiness of female soldiers (Paquette et al. 2009).

## 2.1 Measurement

The dataset comprises anthropometric and demographic measurements from 1,986 female U.S. Army personnel, meticulously collected by the Natick Soldier Research, Development, and Engineering Center (NSRDEC) as part of the 2012 ANSUR II survey. Anthropometric variables such as stature, waist circumference, chest circumference, and thigh circumference were measured using standardized protocols with high-precision instruments, including stadiometers, calipers, and tape measures. To ensure accuracy and reliability, the data collection process adhered to rigorous methodological standards, minimizing variability and measurement error. Demographic variables, including age, ethnicity, and military component (e.g., Regular Army, Reserve), were cross-referenced with administrative records, further enhancing the validity of the dataset.

Although other publicly available datasets focus on anthropometric measurements, they are typically centered on civilian populations or mixed-gender samples, which do not capture the unique physical demands and requirements of military personnel. Civilian datasets often lack the detail necessary to account for the operational and performance-based contexts of military service, where precise body measurements can influence uniform design, load-bearing capacity, and overall readiness. Furthermore, military-specific datasets are rarely accessible to researchers due to stringent security and privacy concerns, limiting publicly available data for this specialized group.

The ANSUR II dataset stands out as one of the most detailed and specific sources of anthropometric and demographic data focused on female military personnel. This specificity is essential for understanding the physical characteristics and needs of female soldiers, who face unique challenges compared to their male counterparts. The dataset’s depth enables researchers to analyze relationships between body dimensions and factors such as physical performance, injury risk, and operational readiness. Furthermore, it provides essential information for developing tailored fitness programs, improving gear design, and enhancing health and safety standards in military contexts.

Given its rarity and specificity, the ANSUR II dataset is a vital resource for researchers and policymakers seeking to advance the well-being and effectiveness of female U.S. Army personnel. By enabling analyses that are not possible with civilian datasets, it offers an opportunity to deepen our understanding of the unique anthropometric and demographic characteristics of this population, paving the way for evidence-based interventions and policy decisions.

## 2.2 Data Preprocessing and Tools

All the data analysis was done through R with the aid of various packages in the R programming language (R Core Team 2023). The `tidyverse` package (Wickham et al. 2021) was used to streamline the entire process of data manipulation, transformation, and visualization, ensuring consistency, efficiency, and flexibility throughout the analysis. Its comprehensive suite of

tools enabled the creation of tailored and informative visual outputs, as well as the effective transformation and summarization of complex datasets.

The implementation of Bayesian models was facilitated by `rstanarm` (Goodrich et al. 2022), which provided a straightforward way to fit regression models using Stan. Diagnostic and posterior predictive checks were conducted using `bayesplot` (Gabry et al. 2021), allowing for thorough assessment of model fit through graphical outputs. The `arrow` package (contributors 2021) enhanced data handling by enabling efficient reading and writing of large datasets.

To present data and model outputs effectively, `tinytable` (Quinn 2021) was used to create compact and well-organized summary tables, while `modelsummary` (Arel-Bundock 2021) provided professional-quality regression tables and visualizations, ensuring clarity in summarizing model results. Dynamic and reproducible reporting was achieved with `knitr` (Xie 2021), integrating R code with outputs for seamless inclusion of plots and analysis in the final document. For data cleaning, `janitor` (Firke 2021) was instrumental in preprocessing dirty data into a clean, analysis-ready format.

Finally, the book *Telling Stories with Data* (Alexander 2023) was consulted as a statistical reference, providing valuable insights to support the analysis and visualization strategies employed in this study.

## 2.3 Outcome Variable

### 2.3.1 Body Weight in Pounds

The outcome variable for this study is `weightlbs`, which represents the body weight of female U.S. Army personnel, measured in pounds. This variable serves as the dependent variable in the analysis and reflects the total body mass of each individual. Understanding variations in body weight is essential for assessing physical readiness, identifying health risks, and optimizing the design of military equipment to meet individual needs.

Figure 1 illustrates the distribution of body weight within the sample population. The histogram reveals that the majority of individuals weigh between 120 lbs and 160 lbs, with the distribution displaying a slight right skew. This skew suggests the presence of a small number of individuals with higher body weights, though such cases are relatively infrequent.

## 2.4 Predictor Variables

### 2.4.1 Height

Height, recorded as `heightin` in inches, is a key predictor of body weight. Taller individuals generally possess larger skeletal structures and greater body mass, making height a significant variable for understanding variations in weight among the sample population.

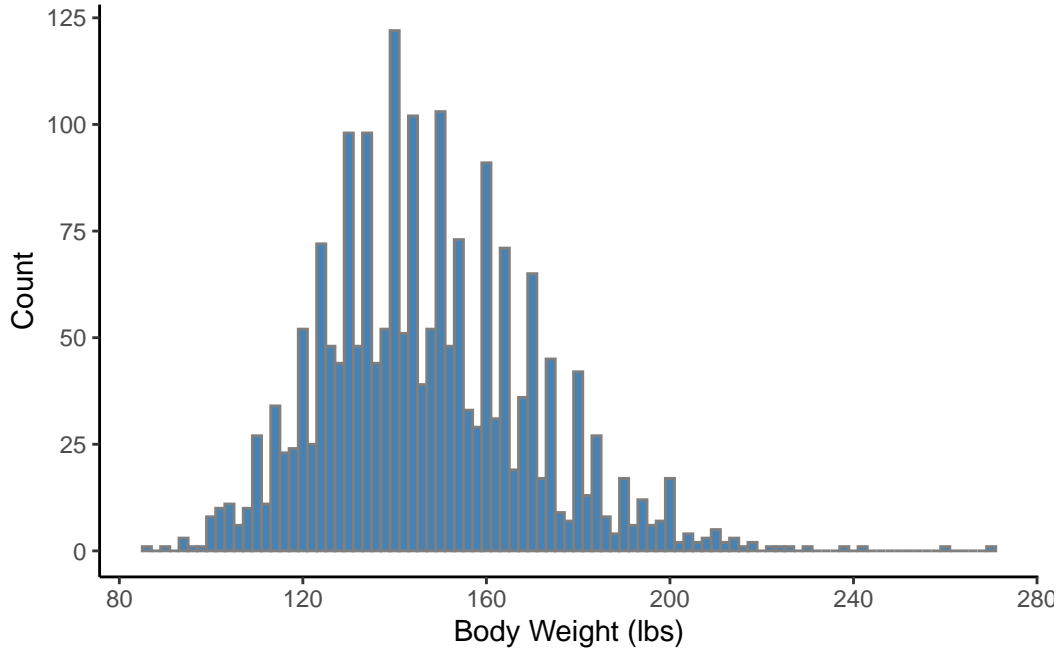


Figure 1: The distribution of body weight among female U.S. Army personnel, showing a central tendency around 120-160 lbs with a slight right skew.

Figure 2 illustrates the distribution of height within the dataset. The majority of individuals have heights ranging from 58 inches to 71 inches, with a central tendency around 63 inches. The distribution is approximately normal, despite a few outliers exceeding 73 inches. These outliers align with the natural variation in height observed among adult females.

#### 2.4.2 Waist Circumference

Waist circumference is a key anthropometric variable that reflects abdominal fat distribution and overall body composition. In this dataset, `waist_circumference` was measured at the narrowest part of the torso using a flexible measuring tape, ensuring both accuracy and consistency.

Waist circumference is a strong predictor of body weight due to its association with abdominal fat and overall body mass. This variable is expected to exhibit a moderate to strong positive correlation with weight, as it effectively reflects central adiposity and overall body composition.

Figure 3 displays the distribution of waist circumference. Most values are concentrated between approximately 65 cm and 90 cm, with a central tendency around the mid-point of this range.

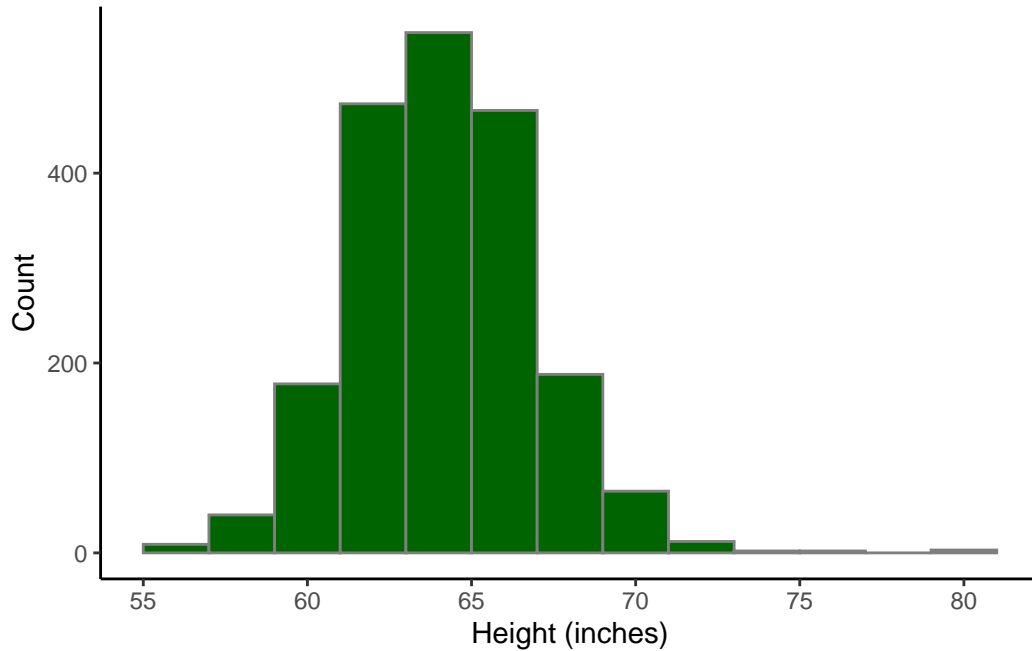


Figure 2: The distribution of height (inches) among female U.S. Army personnel, centered around 63 inches.

Outliers above 115 cm represent a small subset of individuals with unusually large waist circumferences. The overall spread, as indicated by the interquartile range, is moderate.

### 2.4.3 Thigh Circumference

Thigh circumference measures the size of the upper leg and reflects both muscle mass and fat distribution in the lower body. In this dataset, thigh\_circumference was measured at the largest part of the thigh using a flexible measuring tape to ensure consistency.

As shown in Figure 3, the distribution of thigh circumference is slightly narrower compared to that of waist circumference. Most values fall between 50 cm and 65 cm, with a median around 61 cm. A few outliers exceed 75 cm, representing individuals with larger thigh circumferences.

Thigh circumference provides valuable insights into lower body muscle and fat distribution, making it an important predictor of body weight. This variable is expected to positively correlate with body weight, as larger thigh circumferences typically indicate greater overall body mass.

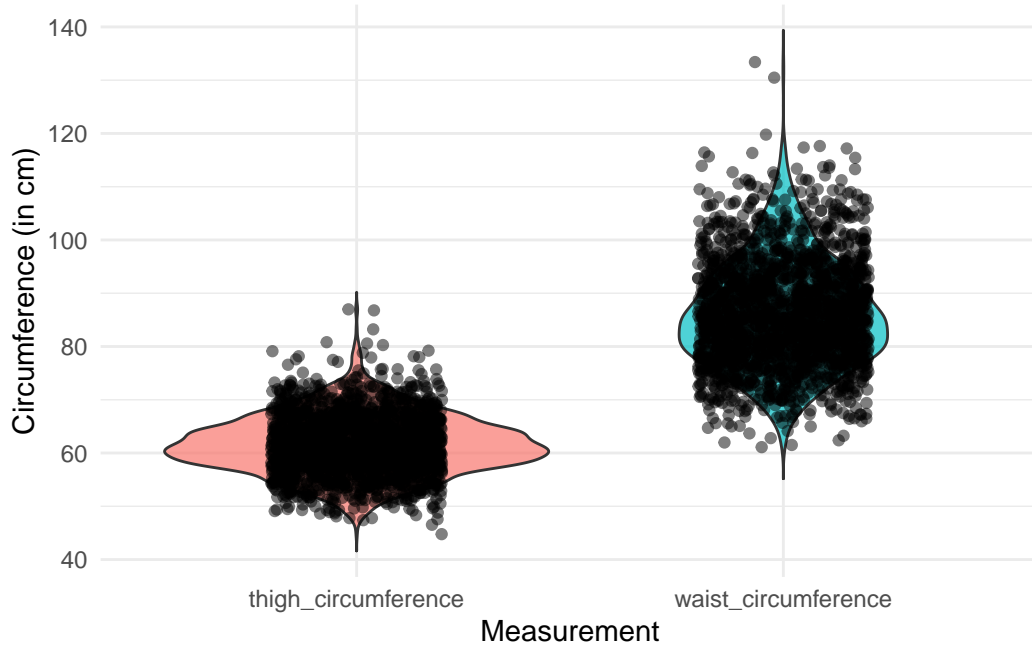


Figure 3: Violin plots showing the distribution of waist and thigh circumferences, with individual data points overlaid to provide a detailed visualization of the data spread.

Table 1: Distribution of age among female U.S. Army personnel, with most individuals between 22 and 34 years old.

| Min | 1st Quartile | Median | 3rd Quartile | Max | Mean     | SD       |
|-----|--------------|--------|--------------|-----|----------|----------|
| 17  | 22           | 27     | 34           | 58  | 28.94361 | 8.332078 |

#### 2.4.4 Age

Age is an important demographic variable in this study, as it encapsulates biological and lifestyle factors that influence body weight. Variations in metabolism, muscle mass, and fat distribution associated with aging play a significant role in shaping body composition. In this dataset, age is measured in years and was self-reported by participants, with additional verification through administrative records to ensure accuracy.

Table 1 presents the distribution of age within the sample population. The majority of individuals are between 22 and 34 years old, with a pronounced peak observed in the late 20s. This age range reflects the demographic composition of the sample and provides a foundation for analyzing age-related influences on body weight.

Table 2: Distribution of military components among female U.S. Army personnel.

| component           | n    | Percentage |
|---------------------|------|------------|
| Army National Guard | 847  | 42.65      |
| Army Reserve        | 119  | 5.99       |
| Regular Army        | 1020 | 51.36      |

#### 2.4.5 Component

The component variable refers to the military branch or service type (e.g., Active Duty, Reserves, or National Guard) of the female U.S. Army personnel. This categorical demographic variable provides valuable insights into lifestyle and activity differences that may influence body weight. For example, Active Duty personnel often exhibit higher physical fitness levels compared to those in the Reserves or National Guard due to differences in daily activity and training regimens.

Table 2 presents the distribution of military components among female U.S. Army personnel, categorized as Regular Army, Army Reserve, and National Guard. The Regular Army constitutes the majority of the sample (51.36%, 1,020 individuals), reflecting high physical activity levels associated with daily duties and training. The National Guard accounts for 42.65% of the sample (847 individuals), representing individuals who balance civilian and military responsibilities with variable activity levels. The Army Reserve, comprising the smallest group (5.99%, 119 individuals), likely experiences lower and intermittent physical activity due to less frequent training requirements.

### 3 Model

#### 3.1 Bayesian Regression Model

A Bayesian regression model was constructed to analyze the relationship between body weight and selected predictors using the cleaned ANSUR II Female Dataset. The model employs a Gaussian likelihood function and was estimated using 1,000 observations randomly sampled from the dataset. The analysis was conducted in R (R Core Team 2023), utilizing the rstanarm package (Goodrich et al. 2022), which provides efficient Bayesian estimation techniques for continuous outcome variables. The dependent variable is body weight (in kilograms), and the following predictors were included:

1. Height (cm): Reflects body size and overall skeletal structure.
2. Waist Circumference (cm): Indicates abdominal fat and body composition.



3. Thigh Circumference (cm): Captures lower body fat and muscle mass distribution.
4. Age (years): Accounts for biological and lifestyle changes over time.
5. Component (categorical): Differentiates between Active Duty, Reserves, and National Guard personnel.

### 3.2 Model Set-up

Let  $y_i$  represent the continuous variable weight (in lbs) for the  $i$ -th individual in the sample. The predictors in the model include:

- $\beta_1$ : The coefficient for height, measured in inches, representing overall body structure and skeletal size.
- $\beta_2$ : The coefficient for waist circumference, which reflects abdominal fat and overall body composition.
- $\beta_3$ : The coefficient for thigh circumference, capturing lower body muscle and fat distribution.
- $\beta_4$ : The coefficient for age, measured in years, accounting for changes in body composition over time.
- $\beta_5$ : The coefficient for component, a categorical variable indicating military branch (Regular Army, Reserves, or National Guard).

Each coefficient  $\beta_j$  represents the effect of the  $j$ -th predictor on body weight, expressed as the expected change in weight associated with a one-unit increase in the predictor, while holding all other variables constant.

The linear predictor  $\eta_i$  for the  $i$ -th observation is defined as:

$$\eta_i = \beta_0 + \beta_1 \cdot \text{height}_i + \beta_2 \cdot \text{waist circumference}_i + \beta_3 \cdot \text{thigh circumference}_i + \beta_4 \cdot \text{age}_i + \beta_5 \cdot \text{component}_i$$

The model assumes a Gaussian likelihood for  $y_i$ , with:

$$y_i \sim \mathcal{N}(\eta_i, \sigma^2)$$

Where:

- $\beta_0$ : The intercept, representing the baseline body weight when all predictors are zero.
- $\sigma^2$ : The residual variance, capturing the variability in body weight not explained by the predictors.

### 3.3 Predictors Choice

The model’s design reflects the characteristics of the dataset to ensure alignment with the nature of the variables and improve the analysis. Anthropometric variables such as height, waist circumference, and thigh circumference were included as continuous predictors to preserve their granularity and enhance sensitivity to subtle variations in body weight. Age was also treated as a continuous variable, rather than being grouped into categories, to avoid arbitrary cutoffs and retain variability, enabling a more precise assessment of its relationship with body weight. The military component variable was modeled categorically, with each group (Regular Army, Reserves, and National Guard) treated as a distinct level to account for structural differences in activity levels and lifestyle among these groups. Additionally, waist and thigh circumferences were rescaled to centimeters for consistency and to reflect standard real-world measurement practices. These decisions ensure that the model effectively utilizes the dataset’s structure while maintaining interpretability and relevance to the research context.

### 3.4 Prior Distributions

The Bayesian regression model utilizes default priors provided by the `rstanarm` package, which facilitate principled and consistent inference. These priors are weakly informative, balancing regularization with the flexibility to adapt to the data:

- **Intercept Priors:** For the model’s intercept  $\beta_0$ , a normal prior distribution is used with a mean of 0 and a standard deviation of 1. This choice reflects the assumption that the baseline body weight (when all predictors are zero) is centered near the observed scale of the outcome variable but avoids imposing overly strong constraints. The standard deviation of 1 allows for reasonable variation, ensuring the prior does not dominate the posterior estimates. Given the scale of the predictors (e.g., height, waist circumference), this weakly informative prior stabilizes the intercept estimate without introducing bias.
- **Coefficient Priors:** Coefficients for the predictor variables  $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$  are assigned normal prior distributions with a mean of 0 and a standard deviation of 1. These priors limit the possibility of overly large coefficient estimates unless strongly supported by the data, introducing a level of regularization to prevent overfitting.

The weakly informative priors are designed to strengthen the model, promoting credible parameter estimates and reliable uncertainty quantification. The use of Bayesian priors adds a layer of rigor, particularly when estimating complex relationships between predictors and body weight. The `rstanarm` package supports the implementation of these priors, making Bayesian inference accessible and effective for this analysis.

### 3.5 Model Justification

The choice of weakly informative priors reflects the exploratory nature of this study, where the goal is to identify significant predictors of body weight without imposing strong assumptions on the parameter estimates. Normal priors centered around zero with a moderate variance ensure that the model is flexible enough to incorporate data-driven insights while avoiding overfitting. This is particularly important given the diversity of predictors, which include anthropometric variables (e.g., waist and thigh circumference) and categorical demographic factors (e.g., military component). The priors help balance the varying scales of these predictors, ensuring interpretability and stability in the posterior estimates.

A Frequentist linear regression model was also initially considered for its simplicity and interpretability; however, it does not provide posterior distributions or credible intervals, which are essential for quantifying uncertainty in this study. By contrast, the Bayesian regression framework provides probabilistic estimates, enabling uncertainty quantification and credible intervals for the coefficients. This approach aligns well with the study’s objectives, where understanding the relative influence of predictors on body weight requires a robust and interpretable model. The `rstanarm` package was chosen for its efficient handling of Bayesian inference and built-in diagnostics, ensuring rigorous validation. The Gaussian likelihood function complements the continuous nature of the outcome variable (body weight), and the model structure strikes a balance between simplicity and capturing key relationships in the data.

### 3.6 Model Selection

The model selection process involved building and comparing two Bayesian regression models using the analysis data: a full model with all predictors and a reduced model with only age and component as predictors. The data was split into training (80%) and testing (20%) subsets for model evaluation. Both models were fit using the `stan_glm` function, and predictions were made on the test set. The models were evaluated using Root Mean Square Error (RMSE) as a metric of predictive performance. The results showed that the full model had a slightly lower RMSE (133.16) compared to the reduced model (134.49), indicating that the additional predictors in the full model improved its predictive accuracy, albeit marginally.

## 4 Results

The Bayesian regression model was developed to investigate the relationship between body weight and key anthropometric and demographic predictors among female U.S. Army personnel. The predictors included height, waist circumference, thigh circumference, age, and military component. The analysis identified significant positive associations between body weight and the anthropometric predictors—height, waist circumference, and thigh circumference—highlighting their strong influence on body weight. Age and military component demonstrated

Table 3: Bayesian Regression Model Results

|                       | Bayesian Regression Model        |
|-----------------------|----------------------------------|
| (Intercept)           | −239.914<br>[−344.267, −138.792] |
| heightin              | 1.109<br>[−0.367, 2.632]         |
| waist_circumference   | 1.033<br>[0.310, 1.777]          |
| thigh_circumference   | 1.525<br>[0.290, 2.734]          |
| age                   | 0.032<br>[−0.639, 0.701]         |
| componentArmy Reserve | −0.015<br>[−1.897, 2.035]        |
| componentRegular Army | −0.043<br>[−1.919, 1.941]        |

smaller but meaningful effects, reflecting their nuanced contributions to variations in body weight. A summary of these findings is presented in Table 3.

The coefficient summary presented in Table 3 highlights the relationships between body weight and the selected predictors among female U.S. Army personnel. Anthropometric variables, particularly waist circumference and thigh circumference, show positive mean coefficients, underscoring their roles as key indicators of body weight. Increases in these measurements are associated with higher body weight, which aligns with established relationships between body dimensions and overall mass.

In contrast, the coefficients for age and height exhibit weak associations, with credible intervals that include zero, indicating uncertainty about their effects on body weight. Similarly, the military component variable shows minimal differences between service categories, suggesting that body weight is largely consistent across Active Duty, Reserves, and National Guard personnel.

The model’s intercept represents the baseline body weight when all predictors are at their reference levels or zero. While this value lacks direct interpretability due to the unrealistic scenario of zero predictors, it provides a conceptual starting point for the model. These results underscore the predictive value of anthropometric measurements in modeling body

weight and highlight the necessity of further examining demographic factors to improve the model’s explanatory power.

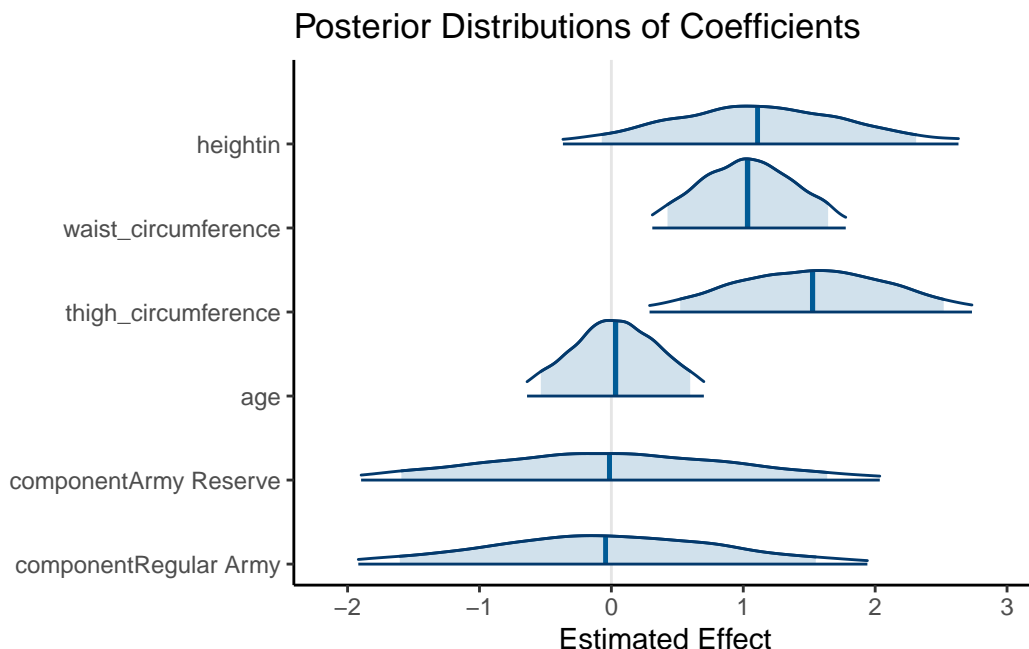


Figure 4: The 89% credible intervals of each coefficients

Figure 4 illustrates the posterior distributions of the coefficients from the Bayesian regression model. Points represent the mean estimates, while horizontal lines indicate the credible intervals. The intercept has a strongly negative estimate with narrow credible intervals, reflecting high certainty in its value. Waist circumference and thigh circumference demonstrate positive effects with relatively narrow credible intervals, indicating reliable and significant associations with body weight. In contrast, height, age, and the military component variables (Army Reserve and Regular Army) exhibit wide credible intervals overlapping zero, suggesting substantial uncertainty and weak or negligible evidence for their effects.

The Bayesian regression analysis underscores the significant positive associations between body weight and anthropometric predictors, particularly waist circumference and thigh circumference, among female U.S. Army personnel. These findings highlight the critical role of body composition measurements in explaining variations in body weight. Conversely, the uncertain effects of height, age, and military component suggest that these factors contribute less reliably to the model, reflecting the multifaceted nature of weight determinants. These results affirm the utility of anthropometric data in health monitoring and fitness interventions while identifying areas for further refinement. Exploring additional predictors may enhance the model’s explanatory power and improve its utility in practical applications.

## 5 Discussion

This study aimed to investigate the relationship between body weight and key anthropometric and demographic predictors among female U.S. Army personnel using a Bayesian regression framework. By incorporating variables such as height, waist circumference, thigh circumference, age, and military component, the analysis highlights the critical role of body composition measurements in predicting body weight while accounting for demographic variability. These findings provide valuable insights into health monitoring and operational readiness, with implications for both military policy and broader public health initiatives.

### 5.1 Understanding Anthropometric Contributions

The results emphasize the significant role of anthropometric variables, particularly waist circumference and thigh circumference, as strong predictors of body weight. These findings align with previous research identifying waist circumference as a key indicator of central adiposity and overall body composition (Heymsfield et al. 2015). Central adiposity is known to be associated with higher risks of cardiovascular disease, metabolic disorders, and reduced physical performance, making it an important measurement for monitoring the health of military personnel. In physically demanding contexts such as military service, excessive central adiposity can impair mobility, endurance, and the ability to perform tasks under pressure.

Similarly, thigh circumference is a significant indicator of lower body strength and fat distribution, as supported by studies linking larger thigh circumference to greater muscle mass and reduced injury risk (Snijder et al. 2005). In the military context, strong lower body muscles are essential for activities such as marching, running, lifting heavy equipment, and maintaining stability during combat operations. The observed positive associations between thigh circumference and body weight reinforce the importance of maintaining lower body muscle mass to support physical performance and reduce the risk of musculoskeletal injuries.

Although height showed a weaker association with body weight, its inclusion remains biologically plausible. Taller individuals typically exhibit larger skeletal structures, greater lean mass, and increased overall body mass. This finding is consistent with literature suggesting that while height is less variable than other anthropometric measures, it contributes to baseline estimations of body weight. In practical terms, height serves as an important reference point when assessing body composition, ensuring that weight management programs account for natural variations in skeletal size and proportionality.

These results underscore the nuanced relationships between body composition and demographic factors, offering a foundation for targeted health interventions within military populations. For example, female soldiers with higher waist circumference might benefit from interventions focused on core strength and fat reduction, while those with lower thigh circumference might require programs aimed at building lower body muscle mass. Such tailored

approaches can enhance fitness outcomes and operational readiness, ensuring that all soldiers meet the physical demands of their roles.

## **5.2 Broader Implications for Health and Military Readiness**

This research highlights the utility of anthropometric measurements in predicting body weight, offering practical applications for health monitoring, fitness interventions, and military equipment design. For instance, the findings could guide the development of tailored fitness programs to address central adiposity (waist circumference) and muscle mass (thigh circumference), improving operational readiness and reducing injury risks. Beyond fitness programs, these findings can inform the design of ergonomic military gear and protective equipment that better accommodates the diverse body shapes and sizes of female soldiers. Properly fitted equipment can enhance mobility, comfort, and performance while lowering the risk of injuries caused by ill-fitting gear.

These findings align with broader public health objectives, such as the World Health Organization's focus on preventing obesity-related conditions through effective weight management strategies. Identifying significant anthropometric predictors of body weight supports initiatives aimed at promoting healthy body composition and reducing the prevalence of chronic diseases. For example, routine monitoring of waist and thigh circumference in both military and civilian populations can serve as an early indicator of health risks, prompting timely interventions and lifestyle adjustments.

The use of Bayesian regression models in this study demonstrates the flexibility and interpretability of these methods for analyzing complex relationships between biological and demographic factors. Bayesian approaches are particularly beneficial in health research due to their ability to incorporate prior knowledge, quantify uncertainty, and provide probabilistic estimates. These features make Bayesian models well-suited for studies involving multifactorial predictors and datasets with inherent variability. For instance, Bayesian frameworks can account for uncertainty in measurement data, producing reliable estimates even when sample sizes are limited.

Additionally, Bayesian methods enable the exploration of posterior distributions and credible intervals, offering a deeper understanding of the relationships between predictors and outcomes. This level of detail is essential for developing evidence-based policies and interventions that consider variability across different subgroups. For example, Bayesian models can identify how the relationship between waist circumference and body weight varies by age group, ethnicity, or military component, enabling more targeted and effective strategies.

## **5.3 Limitations and Future Directions**

While this study provides meaningful findings, it is subject to certain limitations. First, the dataset focuses exclusively on female U.S. Army personnel, which limits the applicability of

findings to male service members or civilian populations. Gender differences in body composition and physical fitness are well-documented, suggesting that extending this analysis to male personnel could reveal additional patterns. Future studies should aim to include a more diverse sample, encompassing multiple genders, age groups, and occupational roles.

Second, the dataset does not include influential lifestyle factors such as physical activity levels, dietary habits, or metabolic rates. These variables have been shown to significantly affect body weight and fitness outcomes. Including such data could enhance the explanatory power and predictive accuracy of future models. For instance, incorporating wearable fitness trackers or dietary logs could provide a deeper understanding of the interactions between lifestyle behaviors and anthropometric measures.

Additionally, while the Bayesian framework produces reliable parameter estimates and credible intervals, hierarchical modeling could strengthen the analysis by capturing subgroup-specific variations. For example, dependencies within military components or geographic regions could be explored using multilevel Bayesian models, which would allow for greater precision in identifying group-level differences while preserving individual variability.

Expanding the dataset's scope to include longitudinal measurements would also enable researchers to study dynamic relationships between body composition, fitness, and operational readiness. Such studies could inform policies for improving physical performance and reducing long-term health risks among service members.



## Appendix

### A Data Cleaning

The raw ANSUR II Female Dataset was systematically cleaned and prepared for analysis to ensure consistency, accuracy, and relevance of the variables. First, the raw dataset was loaded using the `read_csv` function and processed with the `janitor::clean_names()` function to standardize column names, making them easier to interpret and work with. Key variables relevant to the study—such as weight (`weightlbs`), height (`heightin`), waist circumference, thigh circumference, age, and military component—were selected using the `select()` function to focus the analysis on predictors of interest.

Rows with missing values were removed using `drop_na()` to maintain data integrity and ensure a complete dataset for modeling. Several transformations were applied: character columns like the military component were converted to factors, and the age column was explicitly coerced to numeric to prevent data type inconsistencies. Additionally, waist circumference and thigh circumference values were divided by 10 to standardize the unit of measurement (converting millimeters to centimeters), and columns were renamed for clarity. Finally, the cleaned dataset was saved in both CSV and Parquet formats for accessibility and compatibility with various analytical tools. These steps ensured a clean, well-structured dataset, ready for reliable and reproducible analysis.

### B Model Details

#### B.1 Posterior Predictive Check

Figure 5a presents a posterior predictive check to evaluate how well the model predicts the observed data. This diagnostic compares the simulated data from the model's posterior distribution with the actual observed data, providing insights into the model's adequacy. A good fit is characterized by overlapping distributions of predicted and observed values, indicating that the model effectively captures key characteristics of the data.

The posterior predictive check reveals discrepancies between the model's predictions and the observed data. The central tendency of the model's predictions is centered around 0, with a predicted  $\gamma$ -intercept of approximately 0.003. In contrast, the actual data shows a central tendency around 150, with an observed  $\gamma$ -intercept closer to 0.02. This mismatch suggests that while the model captures some aspects of the data distribution, it fails to fully align with the observed scale and central tendency, indicating potential areas for model refinement.

Figure 5b compares the posterior and prior distributions for each parameter in the model. The posterior distributions illustrate the influence of the data on parameter estimates, while the prior distributions represent the initial assumptions before incorporating the observed data.

Notably, parameters such as waist circumference, thigh circumference, and sigma exhibit a significant shift from prior to posterior distributions, indicating that the data strongly informed these estimates. In contrast, parameters like age and military component remain closer to their prior distributions, suggesting weaker evidence from the data to update these estimates. These patterns highlight the varying levels of influence that the data exert on different parameters and underscore the need to consider additional predictors or alternative modeling approaches to improve the model’s explanatory power.

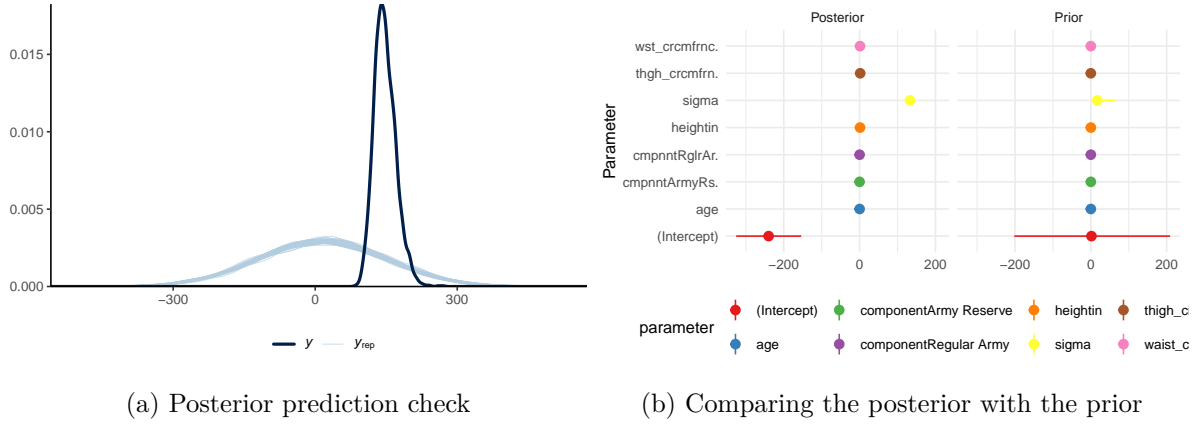


Figure 5: Examining how the model fits, and is influenced by the data.

## B.2 Diagnostics

Figure 6a presents a trace plot, which assesses the convergence of the Markov Chain Monte Carlo (MCMC) algorithm by examining the sampled values for each parameter across iterations. The chains for each parameter exhibit good mixing, with no discernible trends or patterns over the iterations. The consistent overlap of chains indicates that the sampling algorithm has effectively explored the posterior distribution. These results suggest that the Bayesian model’s estimates are reliable and not overly sensitive to initial values or random sampling variation.

Figure 6b displays the Rhat plot, where values close to 1 indicate convergence for each parameter. All parameters have Rhat values near 1.00, well below the threshold of 1.05. This confirms that the chains have successfully converged and the samples accurately represent the true posterior distribution.

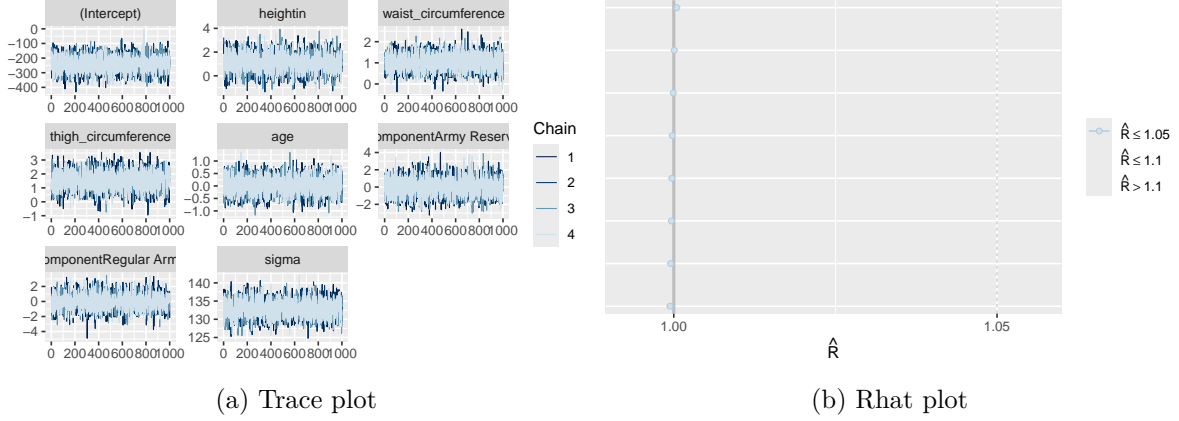


Figure 6: Checking the convergence of the MCMC algorithm

## C Ideal Survey Methodology

### C.1 Budget Allocation

To implement the survey effectively, a budget of \$60,000 has been allocated across key components. Recruitment efforts are estimated to cost \$10,000, including expenses for email campaigns, newsletters, physical flyers, and outreach via social media platforms. Incentives, such as gift cards or community recognition, are also included to encourage participation. Data collection accounts for \$25,000, covering the training of professionals, purchasing and calibrating measurement equipment, licensing survey platforms, and logistics for in-person survey administration. Statistical sampling and quality control measures, such as stratified random sampling, cross-verification, and pilot testing, are allocated \$15,000. Finally, \$10,000 is designated for data analysis and report preparation, ensuring comprehensive reporting and stakeholder communication.

### C.2 Recruitment Strategy

A multi-channel approach will be employed to recruit participants and ensure representation across all military components. Direct outreach through internal military communication systems, including email campaigns, newsletters, and base announcements, will be complemented by online recruitment via social media groups and forums frequented by U.S. Army personnel. In-person recruitment efforts, such as hosting information sessions and setting up booths at military installations, will further support participant engagement. To maximize response rates, incentives like gift cards or recognition within the military community will be offered.

### **C.3 Sampling Method**

The study will utilize a stratified random sampling approach to ensure the sample accurately reflects the diverse population of female U.S. Army personnel. Strata will be defined based on military component (Active Duty, Reserves, National Guard), age groups (18–25, 26–35, 36+ years), and ethnic backgrounds. Participants will be randomly selected within each stratum using computer-generated random numbers, with proportional allocation to mirror population distribution. To ensure adequate representation of smaller groups, such as Reserve personnel or minority ethnic groups, oversampling will be applied, doubling the sample size in these strata to address potential non-response challenges.

### **C.4 Data Collection Process**

Anthropometric measurements, including weight, height, waist circumference, and thigh circumference, will be conducted by trained professionals using calibrated instruments to ensure precision and reliability. Demographic data, such as age, ethnicity, and military component, will be collected via self-reported survey responses and cross-verified with administrative records. Surveys will be administered online using secure platforms like Qualtrics or SurveyMonkey, while in-person administration at military facilities will provide accessibility for personnel without internet access. This dual-mode approach ensures flexibility and inclusivity in data collection.

### **C.5 Quality Control and Validation**

To ensure data accuracy and reliability, several quality control measures will be implemented. Responses will be cross-verified with military records to validate demographic information. Pilot testing will be conducted with a small, diverse sample to refine survey questions and address logistical challenges. Response quality will be assessed by reviewing response times and identifying duplicates using IP tracking for online submissions. Measurement validation protocols, including regular calibration of equipment and standardization of procedures, will minimize variability. Ethical compliance will be ensured through Institutional Review Board (IRB) approval, and data privacy will be safeguarded through anonymization and encryption.

This comprehensive methodology facilitates precise, reliable, and representative data collection while addressing practical, ethical, and logistical considerations. By employing stratified random sampling, rigorous data validation, and inclusive recruitment strategies, the study is well-positioned to yield meaningful insights into the determinants of body weight among female U.S. Army personnel.

## C.6 Ideal Survey Questionnaire

### C.6.1 Section 1: Demographic Information

1. **What is your age?** (Open-ended)

Example answer: 25

2. **Which military component are you currently serving in?** (Multiple-choice)

- Regular Army
- Army Reserve
- National Guard

3. **What is your ethnic background?** (Multiple-choice)

- White
- Black or African American
- Asian
- Hispanic or Latino
- Native American or Alaska Native
- Native Hawaiian or Pacific Islander
- Other (please specify): \_\_\_\_\_

### C.6.2 Section 2: Anthropometric Measurements

*(Instructions: Please provide accurate measurements. Measurements should be taken by a trained professional or using calibrated equipment.)*

4. **What is your body weight in pounds?** (Open-ended)

Example answer: 142

5. **What is your height in inches?** (Open-ended)

Example answer: 64

6. **What is your waist circumference in centimeters?** (Open-ended)

Example answer: 85.0

7. **What is your thigh circumference in centimeters?** (Open-ended)  
Example answer: 62.2

### **C.6.3 Section 3: Additional Information**

8. **Do you have any medical conditions that may affect body weight (e.g., metabolic disorders)?** (Multiple-choice)
- Yes (please specify): \_\_\_\_\_
  - No
9. **How frequently do you engage in physical training as part of your military duties?** (Multiple-choice)
- Daily
  - 3-5 times a week
  - 1-2 times a week
  - Rarely
10. **Do you follow any specific dietary practices or restrictions?** (Multiple-choice)
- Yes (please specify): \_\_\_\_\_
  - No

## References

- Alexander, Rohan. 2023. *Telling Stories with Data*. Chapman; Hall/CRC. <https://tellingstorieswithdata.com/>.
- Arel-Bundock, Vincent. 2021. “modelsummary: Summary Tables and Plots for Statistical Models and Data: Beautiful, Customizable, and Publication-Ready.” <https://CRAN.R-project.org/package=modelsummary>.
- contributors, Apache Arrow. 2021. “arrow: Integration to ‘Apache’ ‘Arrow’.” <https://CRAN.R-project.org/package=arrow>.
- Firke, Sam. 2021. “janitor: Simple Tools for Examining and Cleaning Dirty Data.” <https://CRAN.R-project.org/package=janitor>.
- Gabry, Jonah, Tristan Mahr, Paul-Christian Bürkner, and Martin Modrák. 2021. “bayesplot: Plotting for Bayesian Models.” <https://mc-stan.org/bayesplot>.
- Goodrich, Ben, Jonah Gabry, Imad Ali, and Sam Brilleman. 2022. “rstanarm: Bayesian applied regression modeling via Stan.” <https://mc-stan.org/rstanarm/>.
- Gordon, Claire C. et al. 2014. *2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics*. <https://dacowits.defense.gov/LinkClick.aspx?fileticket=EbsKcm6A10U%3D&portalid=48>.
- Heymsfield, Steven B. et al. 2015. “Waist Circumference as a Measure of Central Adiposity and Its Relationship with Body Composition.” *Obesity*. <https://ajcn.nutrition.org/article/S0002-9165%2823%2924032-0/fulltext>.
- Hotzman, J. et al. 2011. *Measurer’s Handbook: U.S. Army and Marine Corps Anthropometric Surveys, 2010–2011*. <https://www.openlab.psu.edu/ansur2/>.
- Natick Soldier Research, Development, and Engineering Center (NSRDEC). 2012. “ANSUR II Female Dataset.” U.S. Army Anthropometric Survey. <https://data.world/datamil/ansur-ii-female>.
- Paquette, S. et al. 2009. *Anthropometric Survey (ANSUR) II Pilot Study: Methods and Summary Statistics*. [https://archive.org/details/DTIC\\_ADA498172](https://archive.org/details/DTIC_ADA498172).
- Quinn, Michael. 2021. “tinytable: An Extremely Lightweight, Fast, and Flexible Table Container.” <https://CRAN.R-project.org/package=tinytable>.
- R Core Team. 2023. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. <https://www.R-project.org/>.
- Snijder, Marjolein B. et al. 2005. “Thigh Circumference and Its Relationship to Body Composition and Health Outcomes.” *The American Journal of Clinical Nutrition*. <https://ajcn.nutrition.org/article/S0002-9165%2823%2923965-9/fulltext>.
- The OPEN Design Lab. 2018. *Anthropometric Databases*. <https://www.openlab.psu.edu/2018/02/13/anthropometric-databases/>.
- Wickham, Hadley, Mara Averick, Jennifer Bryan, Winston Chang, Lucy D’Agostino McGowan, Romain François, Garrett Grolemond, et al. 2021. “tidyverse: Easily Install and Load the ‘Tidyverse’.” <https://CRAN.R-project.org/package=tidyverse>.
- Xie, Yihui. 2021. “knitr: A General-Purpose Package for Dynamic Report Generation in R.” <https://CRAN.R-project.org/package=knitr>.