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Multivariate Analysis of Human Performance STRONG Lab Data

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THESIS

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MULTIVARIATE ANALYSIS OF HUMAN PERFORMANCE STRONG LAB DATA

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Abstract

This study uses multivariate analysis methods to find relationships between nutrition and wellness and nutrition and performance. The nutrition, daily wellness, and weight and bodyfat data are from a study performed by the STRONG lab in the 711th Human Performance Wing. Electronically collected nutrition data along with survey data for 19 individuals over a 12-week study period are examined with a focus on health, fitness, and nutrition. Factor analysis and linear regression are performed and inferences are drawn regarding what effects calories and macronutrient intake have on subjects perceived wellness, weight, and body fat percentage. These insights are discussed in the context of past studies and nutrition subject matter expert opinions. The findings indicate that an increase in total calorie intake is associated with increased motivation, stronger feelings of recovery, increased satiety, and increased body fat percentage. Increased stress and decreased sleep quality are associated with an increase in total calorie intake. An increase in total body weight is associated with an increased intake of fat and carbohydrates. Further conclusions and recommendations are offered.

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I dedicate this thesis to my dogs, who spent countless hours in their crates to support me while I conducted research. Their patience is far greater than I deserve.

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I would like to express my gratitude to my advisor for all the guidance he has given me. I would like to thank the researchers and trainers at the STRONG lab for allowing me to assist in their efforts and create my own research topic. Finally a special thanks my roommate, for motivating me to get work done and helping tire out my dogs so I could sit and write.

Kayla N. Tinucci

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MULTIVARIATE ANALYSIS OF HUMAN PERFORMANCE STRONG LAB DATA

I. Introduction

1.1 Background

The STRONG Lab is part of the 711th Human Performance Wing at Wright Patterson Air Force Base. The purpose of the STRONG Lab is to investigate ideas and perform cutting edge research across a wide range of disciplines within physiology that support optimal human performance for the Airmen of the United States Air Force. Since 2015, the lab has been collecting health and fitness data on active duty individuals in the Air Force. The lab conducts many individual projects to accumulate this data, ultimately resulting in a pool of subjects on which they can test new Air Force gear and gadgets. This thesis examines data associated with an ongoing project focused on physical fitness and diet.

1.2 Data Overview

The lab issues each participating subject a Garmin Fenix 5/5S watch to use for the duration of that subject's individual study. These watches track physical activity on a 24/7 basis, including all steps, workouts, sleep, heart rate, and stress–measured in Heart Rate Variability (HRV). All participants come into the lab for extensive preliminary and final physical testing. They also come in every day for a one-hour prescribed workout, which is recorded via the Garmin watch as well as a chest strap heart rate monitor.

In addition to all physical recorded data, subjects report subjective measures of their health in the form of a Daily Wellness Survey. Every day, subjects answer 15 simple questions on an app called Smartabase. These questions include the following:

- Fluid Intake,
- Urine Color,
- Food Amount,
- Food Goals,
- Nicotine Usage,
- Other Physical Activity,
- Physical Fatigue,
- Emotional Stress,
- Motivation,
- Overall Soreness,
- Sleep Quality,
- Sluggishness,
- Recovery,
- Illness, and
- Injury.

The questions are either on a 7-point Likert scale, or Yes or No. The Daily Wellness Survey is fluid, with questions that change slightly after each 12-week study period to best inform the lab of the performance readiness of their subjects. Moreover, a fluid survey allows the data from the wearable technologies (e.g., Garmin watch) to better align with the given subjective responses. The survey has been fluid since the beginning of data collection, and has evolved to be as minimal as possible while still ensuring the accuracy of the wearables. The survey also provides subjective data that may not be captured from objective physical measures.

The final set of data collected on fitness subjects is nutrition logging. Each subject records the food that they consume using an app called Chronometer and do this at least three days per week. Chronometer gives an extensive breakdown of macronutrients and micronutrients in the diet of each participant. Participants also have unlimited access to a nutritionist on staff to discuss weight and physique goals as well as how they can modify their diet to reach these goals.

1.3 Research Objectives

The main research objective in this study is to analyze the nutrition data in conjunction with the Daily Wellness Survey data to obtain insight regarding the relationship between nutrition and physical performance. The following are some specific research questions guiding this effort.

- Do the total calorie counts and the macronutrient splits from food logs relate to the Daily Wellness Surveys?
  - Do total calories consumed per day and proportion of macronutriets consumed relate to satiety, thirst, perceived recovery, sluggishness, sleep quality, or any other question on the Daily Wellness Survey?
- Does this relationship change over time?
- How do positive performance and physical changes relate to nutrition profiles?
  - Is there a specific behavior exhibited in the nutrition profiles of those that are meeting bodyfat percentage goals, increasing muscle mass, etc?

Answering the research questions will inform the STRONG lab on the results, and assist the joint Service program in addressing combat feeding practices [1].

1.4 Thesis Outline

Chapter II is a literature review of sources regarding the techniques used in this thesis and literature concerning related nutrition and performance research. Chapter III discusses the analyses performed and results obtained while Chapter IV reveals conclusions and recommended future research.

II. Literature Review

2.1 Overview

This literature review discusses the analytical techniques used on the 711th Human Performance Wing health and fitness data.The first section discusses these techniques, and the second section discusses past research that shows how previous researchers have employed these techniques in related studies. These studies include work done to relate k-calorie and macronutrient information to performance and wellness.

2.1.1 Multiple Linear Regression

Multiple linear regression models the relationship between multiple independent, or regressor, variables and a single response variable. Multiple linear regression finds the surface of best fit based on least-squared residuals of the observed points; the difference between the predicted values on this surface and the actual value is called the residual. Multiple linear regression relates the response variable, y, to the k regressor variables, $x_1, x_2, ...x_k$ modeled as such:

$$y = \beta_0 + \beta_1 x_1 + \beta_1 x_2 + ... + \beta_k x_k + \epsilon \tag{1}$$

The interpretation is that for every one-unit increase of an individual regressor, the response in turn increases or decreases by the amount of the corresponding β_j coefficient, holding all other variables constant. The slope of the regression line is, therefore, the average change in y due to change in the x's [2].

In this study, the model captures the relationship between the nutrition profiles and the measures of wellness.

2.1.2 Hypothesis Testing

Hypothesis testing evaluates the significance of the β-coefficients associated with each regressor. The null hypothesis states that there is no relationship between each regressor and the response variable while the alternative hypothesis states that at least one of the regressors contributes significantly to y, thus β_j is not equal to zero:

$$\begin{aligned} H_0 &: \beta_j = 0 \qquad \forall j = 1, \ldots, k \\ H_A &: \beta_j \neq 0 \qquad \text{for some } j = 1, \ldots, k \end{aligned} \tag{2}$$

where β_j is the coefficient for the jth regressor variable [3]. Using the null and alternative hypotheses for significance testing, if a p-value $< \alpha$ (typically 0.05) is obtained, the null is rejected and the test concludes that at least one β_j is significant in explaining variation in the model [4]. When the p-value is found larger than the prescribed cutoff value, we "fail to reject" the null hypothesis meaning the data collected provided insufficient evidence for the rejection. If the overall null hypothesis is rejected, the next step is to examine the significance of each β_j. These tests are based on t-distributions comparing the estimated coefficient to its standard error. Coefficients deemed significant help explain the response variability. Generally, the final regression model focuses on significant β terms.

2.1.3 Factor Analysis

Factor analysis (FA) is an exploratory technique used to investigate the underlying structure of multivariate data. The FA model is based on multiple linear regression, however in this method the manifest variables are regressed on unobservable variables, or latent variables. These are referred to as "common factors." As in multiple regression, the model results in a matrix of coefficients, however in FA the coefficients are more difficult to interpret [4]. These coefficients receive factor loadings. The number of useful factors is determined by the user; typically a number less than the number of total variables considered. In interpretation, the factor structure coefficients allow the analyst to see the correlation coefficients between the manifest variables and the factors. Thus, when manifest variables fall in the same factor loadings with coefficients close to 1 or -1, those manifest variables are structurally related [4].

This is expressed mathematically by first assuming there exists a set of unobserved variables, $X = (x_1, x_2, ..., x_q)$ assumed to be linked to k unobserved common factors $f_1, f_2, ...f_k$, where $k < q$ in a regression model of the following form:

$$\begin{aligned} x_1 &= \lambda_{11} f_1 + \lambda_{12} f_2 + ... + \lambda_{1k} f_k + \mu_1, \\ x_2 &= \lambda_{21} f_1 + \lambda_{22} f_2 + ... + \lambda_{2k} f_k + \mu_2, \\ &\vdots \\ x_q &= \lambda_{q1} f_1 + \lambda_{q2} f_2 + ... + \lambda_{qk} f_k + \mu_q. \end{aligned} \tag{3}$$

The λ_js are essentially the regression coefficients of the x-variables on the factors, known in FA as the factor loadings. These loadings show how each observed variable depends on the common factors. Therefore the factor loadings can be described as a combination of the observed variables of which have the highest value in that factor loading [4]. The benefit of FA is finding a smaller dimension of variables to adequately explain the data.

2.1.4 Model Validation

It is important to test a model in its operational environment to ensure it performs as intended. This is not possible in the current setting. An appropriate technique for model validation in this study is cross validation, or data splitting. Due to the difficulty of collecting new data to validate the performance of the model, instead a small portion (typically 20 percent of the data) is set aside when the model is built

[2]. This smaller portion, called the validation set, is compared to how well the model predicts that validation set. A model that adequately predicts data not employed in the building of that model is desired. Cross-validation gives insight into how the model may perform in the environment for which it is intended. One challenge with cross validation is that it typically performs best with a large number of observations [2].

2.2 Accompanying Research

A variety of research has been done in the health and fitness world that reveals insights on the relationship between energy and macronutrient intake and how this relationship relates to wellness, physique and performance. This section summarizes previous research efforts, both general (i.e., what has been found in this field in terms of optimizing performance) and specific, relating to the analysis techniques employed in this study.

Witard, Garthe and Phillips' [5] research on optimal protein intake for athletes examines how much protein is required for "high quality weight loss," which consists of losing fat without losing lean muscle mass. Contrary to typical national recommendations and guidelines of a protein intake of approximately 0.8-1.0 g/kg body mass to maintain weight and performance, the authors reveal that a protein intake of approximately 1.3-1.7 g/kg body mass is optimal [5]. Moreover, they show the optimal intake range for "high quality weight loss" is approximately 1.6-2.4 g/kg of body mass to promote retention of lean mass [5]. Similarly, Hector and Philips [6] reveal that a protein intake higher than the typical recommended daily allowance (again approximately 1.6-2.4 g/kg of body mass, or 2.3-3.1 g/kg of fat free mass) during energy restriction for athletes results improved high-quality weight loss and improved performance. This equates to a large acceptable macronutrient distribution range

(AMDR) of 10-35% of total energy. Hector and Phillips repeat that athletes need more protein and increased resistance training during energy restriction to maintain lean body mass [6]. In another study, including 25 young, overweight males, Hector et al. [7] find that an increase in protein intake coupled with resistance training during extreme energy restriction (40% over 10 days) is enough to combat the decreased muscle protein synthesis and maintain lean body mass. An important consideration for the analysis of the STRONG lab nutrition data is that a consequence of energy restriction with the goal of weight loss is decreasing lean body mass, which can be as severe as 25% of total weight lost being muscle without adequate protein [7].

Melin *et al.* [8] report that the optimal threshold for energy intake is 45 kcals/kg fat free mass for women, and 40 kcals/kg fat free mass for exercising men. This amount of energy intake is optimal for maintaining performance while eliminating negative health effects of low energy availability. In addition, they note that the energy intake to reach optimal body composition for athletes is a moderate caloric restriction of approximately 300 calories per day with adequate protein intake of 2.0-2.5 g/kg body weight. They further discuss that this should be done in periods of 6-8 weeks, and that low carbohydrate intake has been linked to decreased performance [8]. Similarly, Hector and Phillips [6] recommend a carbohydrate intake of 5-7 g/kg of body mass to maintain performance in a period of energy restriction. A study of gymnasts on a high fat (ketogenic) diet limited to 22g carbs per day found a maintenance of muscle mass and a significant decrease in fat mass, of nearly 2 kg over 30 days [6]. This knowledge of optimal energy intake and macro-nutrient breakdowns for athletes builds a foundation for comparison in analyzing and drawing conclusions from the STRONG lab nutrition data.

In a sample of the Chinese population, Liu *et al.* [9] found the opposite effect from high quality weight loss from high levels of protein intake. Their research examines the total caloric intake as well at the percentage breakdown of macro-nutrient intake of 9,360 Chinese adults. The results reveal a statistically significant positive association between total energy intake and body fat percentage, as well as protein intake and body fat percentage. This is contradictory to the 2019 studies, likely due to the fact that these subjects were not athletes, and the population had a low habitual intake of protein at approximately 12.5% of total daily energy [9]. Interestingly, Liu *et al.* also find that total energy intake explains a large majority of carbohydrate and fat intake, indicating that protein consumption has more variability despite total energy intake [9]. Comparing the studies by Liu *et al.* [9], Melin *et al.* [8], and Witard, Garthe and Phillips [5] allows for a cautious mindset in looking at the STRONG Lab data, and ensures that attention is paid to the difference between athletes and the general population. The STRONG lab subjects, with intense training but not sport athletes, fall somewhere in between the groups of subjects in these past studies.

There are a few studies on perception of wellness and its relationship with nutrition and body composition. One study [6] suggests that satiety improves compliance to a calorie restricted diet. It states that eating high protein foods may help with satiety, due to their high nutrient density. This is an interesting observation to investigate with the STRONG lab data. In their extensive research on how diet promotes sleep duration and quality, Peuhkur, Sihvola and Korpela [10] find that even just one meal heavy with carbohydrates can impact circadian rhythms, thus impacting the perception of sleep quality.

There is inconsistent research regarding the impact of carbohydrates on sleep quality, and very limited research regarding the impact of fat and protein on sleep quality [10]. Peuhkur, Sihvola and Korpela [10] find that higher fat meals and caffeine are associated with a later bedtime. Their study discusses how an increase in carbohydrates is associated with less total sleep and deep sleep, but more REM sleep. Additionally, they find a relationship between perceived sluggishness throughout the day and high fat, low carb morning meals, while protein in the morning meal is associated with alertness [10]. Peuhkur, Sihvola and Korpela repeat that the timing of food intake shows more significant associations with sleep quality than the macronutrient content. This is an important limitation to note since the timing of nutrition intake is not tracked in the STRONG lab study.

An important takeaway from the accompanying research is that there are many uncontrolled factors to take into account when conducting health studies. Hector and Phillips [6] list three other important factors in determining macro nutrient distributions during desired weight loss: the severity of caloric deficit, the leanness of the individual (since leaner adults tend to loose lean body mass quicker) and the training status. Additionally, other factors including sleep; quality and timing of nutrient intake; and supplementation largely effect lean mass retention [6]. Limitations of this variety of study include the short term duration nature of each study, as well as human variability in nutrition and exercise data [7]. Additionally, self-reporting of nutrition data and food logging is generally highly inaccurate, which is why many studies opt for dietary manipulation [7]. Many methods of calculating body fat percentage are subject to high error, although the STRONG lab uses the highly accurate method of Dual-energy X-ray Absorptiometry (DXA). The method of using DXA makes for less confident comparisons to accompanying research when they use other body fat calculation methods [7] [9]. From these comparisons, the information reveals other factors that should be considered in the STRONG lab nutritional analysis.

This accompanying research on energy intake and macro nutrient proportions indicates that there is a trade-off between body composition (namely weight loss) and performance. Specifically, in an energy deficit, a higher protein intake will likely result in a maintenance or increase of lean muscle mass, while a higher carbohydrate or fat intake will result in a decrease of performance, or in the case of this study a decrease in perceived wellness (i.e., not feeling optimal and not performing one's best).

2.2.1 Application of Methods in Accompanying Research

Understanding the methodology used in studies helps ensure accurate results and insights. A summary of previous research efforts in determining a predictive relationship between nutrition and wellness and performance provides a sound statistical groundwork for this study. The reviewed research discusses analytic techniques adapted for this research effort to ensure proper analysis.

Liu *et al.* [9] used general linear regression to conduct a majority of their analysis on relationships between body fat percentage and energy intake. This thesis examines similar relationships using a similar method. Liu *et al.* controls for other factors besides energy intake by incorporating them into a multiple linear regression model and includes logistics regressions for binary (in this case yes or no) variables. Liu *et al.* also uses multivariate adjustments and 95 percent confidence intervals to draw conclusions. Liu *et al.* provides a perfect example for how to associate body fat percentage and energy intake using multiple linear regression, logistics regression, and controlling for additional factors.

Hector [7] *et al.* used general linear regression in their study of young overweight men with 10 days of severe energy restriction. They used a mixed model Analysis of Variance (ANOVA) on body composition and other health factors and performed diet analysis coupled with baseline characteristics using an independent sample Student's t-test. Their data is expressed visually with box and whisker plots.

III. Analysis

3.1 Data Exploration

The STRONG Lab of the 711th Human Performance Wing provided the data described in Chapter I and used in this study. This data are analyzed using factor analysis (FA) and multiple linear regression using JMP PRO 13 software. The first part of the analysis reveals insights on the relationship between nutrition and perceived wellness, gathered from the subjects' Daily Wellness Surveys. The second portion of analysis identifies subjects with optimal performance and analyzes their accompanying specific nutrition profiles. The dataset covers a 12 week period from September to December 2018. Across the 19 subjects there are 7,603 observations.

For this study, the independent variables of interest are average daily calories for each week and average percent of daily calories that come from each protein, carbohydrates, and fat for each week. The data comes from subjects recalling their food intake a minimum of 3 days per week including at least one weekend day. The dependent variables of interest are the daily average of motivation, soreness, emotional stress, satiety, recovery, sluggishness, physical fatigue, and sleep quality for each week. Each of these variables is reported using a 7-point Likert scale, where 0 is "Not at All" and 6 is "Completely." The data for these variables comes from each subject's Daily Wellness Survey, completed a minimum of 5 days a week for the duration of the study. An example of what these questions look like using the Likert scale is seen in Figure 1. The dependent variables for the performance portion of the analysis are weight change and change in bodyfat percentage, which is measured by the highly accurate DXA scan method.

Due to the nature of nutrition studies, it is important to note that any study where participants log their own caloric intake has a chance of being inaccurate. For

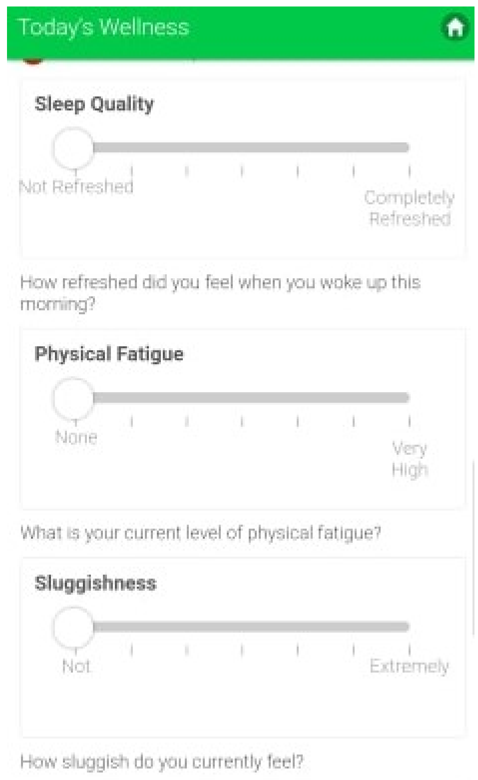

Figure 1. Snippet of Smartabase Daily Wellness Survey

this reason, this study only examines macronutrients and total caloric intake. There is minimal confidence that any micronutrients observed will be highly accurate. This is because subjects are giving their best estimate of their food type and portion size. There is also, while expansive, a limited selection of foods within the app for subjects to choose from, so they may have to make their best guess at what matches best with the type of food they are eating. Additionally, subjects are likely to choose the "easiest" days to track their intake, which are often days where their calorie intake is lowest during the week [11]. As the weeks of the study progress, subjects are likely to become less diligent in their tracking, reducing the accuracy of the data toward the end of the study.

Previous STRONG lab studies using data from Daily Wellness Surveys have determined that the first two weeks of recording wellness are inaccurate, and it takes approximately this long for participants to understand the differences in the questions and for their responses to stabilize. Because of this, the first two weeks of survey data is thrown out, resulting in a testing period of 10 weeks. The time periods are further separated into two periods for each week. The first period for any given week uses the nutrition data and the wellness data from the same week. The next time period for that week uses the nutrition data from the week and compares it to the wellness data of the following week. This results in 20 total time periods over the course of the 10 week span of usable data.

The initial phase of the data analysis uses FA to determine any groupings of all of the variables. Using principal components, six factor loadings were built to represent the data. These factor loadings are shown in Appendix A. This analysis reveals that fatigue and sluggishness make up the same factor, and satiety and motivation make up the same factor for the majority of weeks. This indicates that with deeper analysis we will likely find that eating habits affect fatigue and sluggishness similarly, while satiety and motivation align in a similar manner. Total energy intake loads in its own factor across most weeks, and each week of recovery, emotional stress, and soreness appear sporadically amongst all the factors. Finally, the percentage components for each macronutrient (e.g., carbs, fat, and protein) all appear in the same factor every week. Fat and carbohydrate percentages have an inverse relationship. This makes sense because in the American diet, fat and carbohydrates typically make up the bulk of calories consumed, and it makes sense for one to be eaten in place of the other. Another noteworthy observation from the FA is that none of the nutrition variables fall consistently in the same factor loading as any of the wellness variables. This likely means that no single wellness measure is simply explained by any one nutrition habit.

3.2 Analysis of Nutrition and Wellness

Two models are built for each week in the initial linear regression analysis for nutrition and wellness. The first model is the effect of nutrition quality (total calories consumed, total macronutrients consumed, and percentage of macronutrients consumed) on all wellness factors that same week. The next model is the effect of nutrition quality of one week on wellness the following week. This use of two models allows the analysis to capture delayed effects of eating habits on perceived wellness. These two models each week are captured in the breakdown of the time periods. These initial models reveal high levels of multicolinearity. This indicates that it is unnecessary to include both the total intake of each macronutrient in grams as well as the percentage intake of each macronutrient in the models. Here in, nutrition quality is assessed using only the independent variables of total energy intake and percentage intake of each macronutrient. Using these as the new independent variables has eliminated multicolinearity.

Cross validation is performed using data splitting to ensure the model performs well in its intended environment. Due to the nature of this study, data splitting is chosen since collection of new data for purely validation purposes is outside the scope of this research. Five subjects were chosen at random to be excluded, and a model was built on the remaining 14 subjects. A prediction interval was then created on each of the 19 points. This method of cross validation was run on four different dependent variables, each in a different week, giving 19 resulting 95% prediction intervals for comparison to the actual data points. The model correctly predicted 19 out of 20 of the actual data points to be within the prediction interval, and 15 our of 20 points to be within the confidence interval. These values are shown in Appendix B. This process was done once, but yielded enough data points to mitigate any concerns. This allows for the conclusion that our data is relatively homogeneous: there is nothing overly concerning from the cross validation, so the whole data set may be used to build the full set of models.

One linear regression model is run for each time period: the first time period of the week shows the impact of nutrition on perceived wellness the same week, and the second time period of the week shows the impact of nutrition on perceived wellness the next week. This is done to capture delayed effects that nutrition may have on wellness. The four independent variables used to capture each week's nutrition are the average daily total calorie intake as well as the average daily percentage of each macronutrient intake: fat, protein, and carbohydrates. These variables are run on the 8 dependent wellness variables (i.e., motivation, soreness, emotional stress, satiety, recovery, sluggishness, physical fatigue, and sleep quality), resulting in 8 factors for each of the 20 time periods. The parameter estimates of each significant model are shown in Appendix C. The following equation represents these models

$$
\begin{aligned}
y_{TotalCalories,i} &= \beta_0 + \beta_{1,i}x_{1,i} + \beta_{2,i}x_{2,i} + ... + \beta_{8,i}x_{8,i} + \epsilon_i \quad \forall i \\
y_{\%Carbs,i} &= \beta_0 + \beta_{1,i}x_{1,i} + \beta_{2,i}x_{2,i} + ... + \beta_{8,i}x_{8,i} + \epsilon_i \quad \forall i \\
y_{\%Protein,i} &= \beta_0 + \beta_{1,i}x_{1,i} + \beta_{2,i}x_{2,i} + ... + \beta_{8,i}x_{8,i} + \epsilon_i \quad \forall i \\
y_{\%Fat,i} &= \beta_0 + \beta_{1,i}x_{1,i} + \beta_{2,i}x_{2,i} + ... + \beta_{8,i}x_{8,i} + \epsilon_i \quad \forall i
\end{aligned} \tag{4}
$$

where $k = 1, \ldots, 8$ represent the 8 wellness variables and $i = 1, \ldots, 20$ represent the 20 time periods.

The results for each of these models are shows in Tables 1, 2, 3, and 4, respectively. The green (up) arrows indicate that there is a positive relationship between the wellness variable and the nutrition variable for that week. The red (down) arrows indicate a negative relationship. For example, Table 1 shows a green arrow for fatigue in time period 1. Since Table 1 refers to relationships between total calories consumed and the wellness variables, this green arrow means that there is a positive relationship between fatigue and total calories consumed for the first time period of the study. In other words, an increase in total calories consumed during time period 1 is, on average, associated with an increase in average level of fatigue.

Table 1. Positive and Negative Total Calorie Significance with a 10% Significance Level

	Time Period																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Motivation		↑	↑	↑										↑						
Emotional Stress								↑			↓									
Satiety			↑	↑												↑	↑			
Recovery						↑		↑						↑		↑	↑			
Sluggishness														↑						
Fatigue	↑													↑						
Sleep Quality																↓				
Soreness																				

Table 2. Positive and Negative Carbohydrate Significance with a 10% Significance Level

	Time Period																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Motivation																				
Emotional Stress	↓					↓	↓			↓	↓								↑	
Satiety									↑	↑					↓					
Recovery								↑												
Sluggishness														↓						
Fatigue	↓															↓				
Sleep Quality	↓		↑							↑										
Soreness	↓																			

Table 3. Positive and Negative Protein Significance with a 10% Significance Level

	Time Period																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Motivation																				
Emotional Stress						↓	↓			↓	↓									
Satiety										↑										
Recovery	↑																			
Sluggishness				↓									↓	↓						
Fatigue																	↓			
Sleep Quality										↑										
Soreness							↓													

Table 4. Positive and Negative Fat Significance with a 10% Significance Level

	Time Period																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Motivation										↑					↑					
Emotional Stress						↓				↓	↓							↑		
Satiety									↑	↑								↑		
Recovery								↑												
Sluggishness								↑										↑	↑	
Fatigue	↓											↓								
Sleep Quality			↑							↑					↑					
Soreness	↓																			

The following effects were deemed significant based on a 10% significance level. 10% is chosen rather than the typical 5% because there are many interesting effects that fall just outside the 5% margin. First, as total calories consumed increases, motivation to complete the daily workout increases. This effect is seen in the early weeks of the study (3 out of the first 4 time periods). This makes sense since the more energy a subject consumes, the easier it will be to push themselves physically. In the later weeks of the study, there is some significant evidence that motivation increases as percentage of fat intake increases. There is no evidence of a relationship between motivation and carbs or protein.

Next, emotional stress level decreases as the proportion of protein and carbohydrate intakes both increase. This relationship is found in several sporadic time periods across the study. In addition, there are inconsistent results for how total calorie intake and fat intake affect emotional stress. The middle weeks of the study showed some incomprehensible results for how macronutrients affect stress, which caused a need for a deeper look. While this study examines how food affects wellness, it is known that the inverse can be true of stress. Due to the concern that stress may dictate how the subjects intake nutrients, a full set of models was run on every measure of nutrition for every time period, using emotional stress as the single independent factor. These 80 additional significance tests bring more resolve to the original incomprehensible results for stress. The equation for these models is shown in the following equation:

$$y_{Stress,i} = \beta_0 + \beta_{Cals,i}x_{Cals,i} + \beta_{Carbs,i}x_{Carbs,i} + \beta_{Prot,i}x_{Prot,i} + \beta_{Fat,i}x_{Fat,i} + \epsilon_i \quad \forall i \tag{5}$$

where $i = 1, \ldots, 20$ represent the 20 time periods. The results are shown in Table 5. Again, the colored arrows show where there is a positive or a negative relationship between nutrition and emotional stress. These models show clear relationships consistent from the first time period to the last, with no contradicting results. Stress is associated with an intake of less carbs and more fat in the week of the stress, as well as the following week. This makes intuitive sense; when a subject is stressed emotionally, they will lean toward eating fattier foods. These results indicate that while emotional stress and nutrition are related, nutrition may be better explained by emotional stress rather than nutrition explaining emotional stress. The parameter estimates for these models are shown in Appendix D.

Table 5. Positive and Negative Significance of Emotional Stress with a 10% Significance Level

	Time Period																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Total Calories					↓															
Carbohydrates	↓				↓							↓								
Protein											↓									
Fat					↑	↑												↑	↑	

Satiety is positively related to total calorie intake and fat intake. This result is also fairly intuitive; the more calories consumed and the more calorically dense foods that are consumed, the less hungry a subject feels. These results are very consistent across the second half of the study, however significance is only found once in the first half of the study. The results are inconsistent on the relationship between carbs and satiety.

Recovery from previous workouts increases as total calorie intake increases. It appears that no matter what a subject eats, as long as they are eating, they feel more recovered. This relationship is the strongest in the final 3 weeks of the study. There are no instances of a negative relationship between any nutrient profiles and recovery. This makes sense since energy from food is needed to recover from intense workouts.

There are significant effects from macronutrient breakdowns on sluggishness. The more fat a subject consumes, the more sluggish they feel. The more protein they consume, the less sluggish they feel. However these effects have less frequent occurrences of significance than the other measures of wellness. This could be because sluggishness is a wellness measure that can have more variability and subjectivity between subjects than other measures. Feelings of sluggishness may be more difficult for a subject to isolate and identify than the other measures of wellness.

Feelings of fatigue also show fairly infrequent relationships, although there is indeed evidence of fatigue increasing as total calories increase, and decreasing as carbohydrates and fat percentages increase. These relationships are each seen in exactly two time periods of the study, indicating consistency but also infrequency.

Sleep quality increases as fat intake increases. This is seen fairly regularly across the time periods of study. An increase in carbohydrates appears to increase sleep quality as well, however this relationship is inconsistent across the time periods. Relating data to sleep quality, such as emotional stress, calls for additional analysis to determine if sleep determines nutritional choices rather than the other way around. Additional models were run to see the effects of this relationship between sleep and nutrition:

$$y_{Sleep,i} = \beta_0 + \beta_{Cals,i} x_{Cals,i} + \beta_{Carbs,i} x_{Carbs,i} + \beta_{Prot,i} x_{Prot,i} + \beta_{Fat,i} x_{Fat,i} + \epsilon_i \quad \forall i \quad (6)$$

where $i = 1, \ldots, 20$ represent the 20 time periods. These models reveal less frequent relationships than the similar emotional stress models, however they are highly consistent across all time periods. Again, there is consistency in the inverse relationship between fat and carbohydrates: where fat has a positive effect, carbohydrates have a negative effect. These results reveal that the more a person sleeps, the more inclined they are to eat protein and fat. The less a person sleeps, the more inclined they are to eat more total calories, as well as carbohydrates. This makes sense based on the theory that lack of sleep can contribute to weight gain through an increased tendency to eat overall calories as well as calories from carbohydrates. These results are summarized in Table 6. The parameter estimates for these models are shown in Appendix E.

Table 6. Positive and Negative Significance of Sleep Quality with a 10% Significance Level

	Time Period																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Total Calories																		↓		
Carbohydrates					↓	↓														
Protein						↑														
Fat						↑									↑					

Soreness is the least consistent of all the measures of wellness. No significant effect is found for more than a single time period of the study. Soreness is likely more impacted by intensity of physical activity than nutritional profile.

Most significant effects do not appear to differ based on whether the wellness was measured in the same week as the food consumption or in the next week. The exceptions are motivation and recovery. Motivation in the next week increases from total calorie consumption more frequently than motivation increases in the current week, however there is evidence of both. The same is true of recovery; recovery in the next week increases from total calorie consumption more frequently than a recovery increase from nutrition in the current week. Again there is evidence of both. This means that there is a delayed effect of nutrition on wellness for the factors of motivation and recovery.

These results can also be summarized by independent variable in addition to dependent variable. As total calories consumed increases, the following measures of wellness increase: motivation, recovery, satiety and fatigue. As fat consumption increases, satiety, motivation, and sluggishness increase, and fatigue decrease. As protein consumption increases, sluggishness and stress both decrease. As carbohydrate consumption increases, stress and fatigue decrease and sleep quality increases. These results are met with varying degrees of consistency, frequency, and significance, thus it is perhaps better to look at each component individually rather than to generalize.

After analyzing the reverse relationships for emotional stress and for sleep quality, questions arose regrading potential reverse relationships between nutrition and the rest of the wellness measures. To ensure that no significant relationships were left out of this comprehensive analysis, a regression model examined the nutritional components for each week using each of the wellness factors together as independent variables for each week. These models reveal if there are any instances where wellness impacts nutrition. As expected, these models show inconsistent and infrequent relationships between nutrition and a majority of the wellness measures: soreness, motivation, satiety, recovery and fatigue. Additionally, sleep quality and emotional stress show consistent relationships to what their impact was when ran as the sole independent variable. There are no instances of these relationships having inconsistent effects.

3.3 Wellness Discussion

The following conjectures bring meaning to the results. The first observation to note is how an increase in total calorie intake leads to increased motivation. This relationship is backed up by the fact that spare energy makes it easier to push through a tough workout [11]. In addition, it was found in past STRONG lab research that motivation tends to drop off as the study progresses [12]. This helps to explain that nutrition effects a subject's motivation at first, but then as the motivation drops off, so does the impact of eating well (or poorly). This is seen in the results: motivation is independent of nutrition in the later weeks of the study.

Similar to motivation, the results of the linear regression analysis show that an increase in total calorie intake leads to stronger feelings of recovery. This is a point of interest in current nutrition studies, particularly up-and-coming post-workout nutrition and nutrition timing studies [11]. These results regarding recovery back up the theory that eating enough calories is vital after a workout. Nutritionists believe that individuals who exercise intensely will recover with just the adequate amount of calories; these athletes do not necessarily need high amounts of protein immediately after a workout, which is commonly believed among athletes [11]. There is no evidence that eating large quantities of protein after a workout improves recovery. It is much more important that the total calorie count is met. This relationship between calories and recovery also implies that all of the subjects in the study met their protein needs [11]. As a population of active duty Air Force individuals, the subjects are likely to have no issues meeting daily protein requirements every day. If this was not the case, the results would likely be quite different [11]. Further investigation called for seeing if time trends exist for the weekly average calories eaten among all the participants in the study. This allows us to mitigate concerns that the recovery and calories relationship is strongest at the end of the study only because subjects are eating more calories as a whole as the study progresses to later weeks. Additional statistics reveal that this is not the case. For half the analyzed weeks, the average calorie intake for participants was between 1900 and 2000. The average daily calories by week can be seen in Figure 2. As seen in Figure 2, total calorie intake does not strictly increase as the study weeks progress.

Motivation and recovery both show delayed relationships with nutrition in addition to same-week relationships. This delay may be seen as evidence of over-stressing the body. For example, a subject that is underfueling their body for five days may not show any changes in wellness, however that underfueling catches up to them in the next week. This would cause feelings of recovery or motivation to experience a delayed relationship with nutrition [11].

The results for satiety are noteworthy, particularly in today's craze for the ketogenic diet [11]. Eating more total calories and calories from fat leads to subjects feeling more satisfied and less hungry. The total calorie relationship is intuitive: the more you eat the less hungry you feel. However nutritionists used to believe that protein was the most satiating macronutrient. However this research backs up today's ketogenic craze: eating fat keeps you full [11]. Additionally, this relationship may only be seen in the second half of the study due to the idea of an "increase in training." If subjects are not used to intense workouts, then the initial increase in training (e.g. beginning the STRONG lab workout program) may have impacts that overshadow the effects of nutrition on satiety [11]. Again, these results called for further investigation to see if the identified time trends in the data can be contributed to the subjects eating more fat and calories in the later half of the study. Figures 2 and 3 show that this is not a concern. Neither total calories nor any metric of fat intake shows a strict increase in the second half of the study.

Stress and sleep are both seen to affect how much a person eats in total calories. Less sleep leads to eating more calories and more carbs. This relationship (along with many other factors) is why people gain weight when they don't sleep enough [11]. Regardless of macronutrient, if a person overeats in total calories, they will gain weight. The identified relationship between sleep and nutrition supports what nutri-

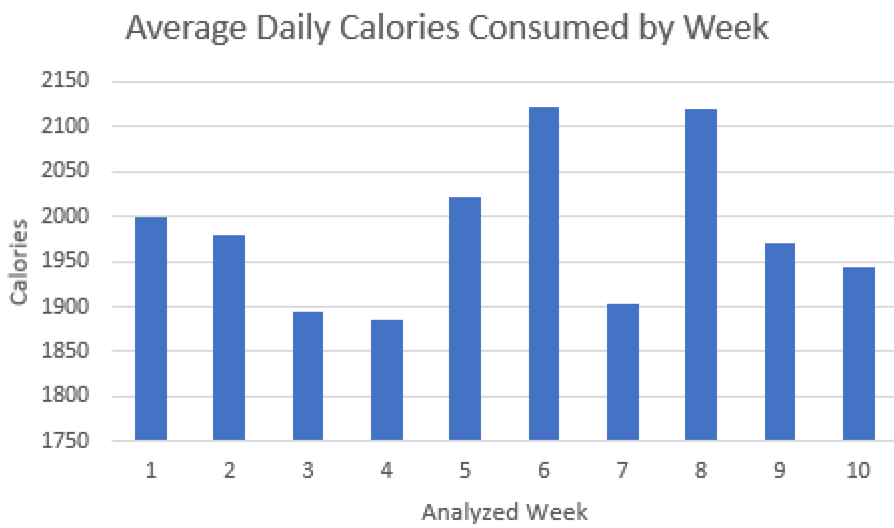

Figure 2. The average daily calories consumed across all participants, measured weekly

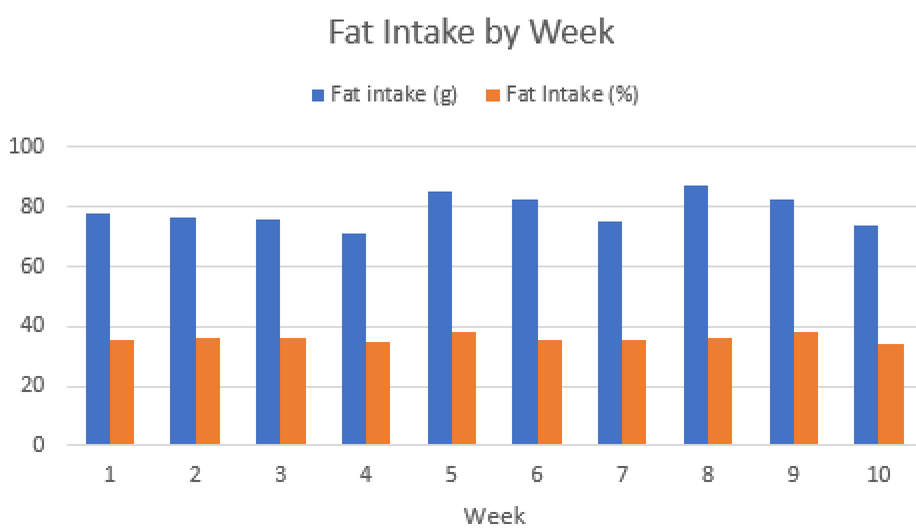

Figure 3. The average daily fat intake consumed across all participants, measured weekly by both grams and percentage of total calories

tionists believe [11]. The increase in total calories from increased stress also supports what nutritionists believe, however the surprising result here is that increased stress is associated with an increase in fat intake. While this is not a commonly discussed relationship among nutritionists, it makes logical sense: when people are stressed they lean toward more fatty foods such as desserts and potato chips [11]. Biologically it makes sense as well: if a caveman were in a stressful situation (e.g. getting chased by a tiger) they would want to eat more fat to protect themselves against danger and save calories in case they cannot get any later on [11]. Additionally, while there are clear effects of perceived stress and sleep on nutrition, there are effects of nutrition on sleep and stress; however they are inconsistent.

Relationships between sluggishness, fatigue, and soreness and nutrition are likely less prevalent and less consistent than other measures of wellness because these variables are overshadowed by some confounding variable. For example, it is likely that the intensity of the previous day's workout is more closely related to soreness than nutrition; without controlling that variable no relationship emerges. In addition, these three measures of wellness (i.e., sluggishness, fatigue, and soreness) are more difficult for a subject to identify and report how they feel [11]. Analysts in previous STRONG lab studies used Partial Triadic Analysis (PTA) to reduce the dimensions of multiple Daily Wellness Survey datasets [12]. This analysis shows that soreness and physical fatigue to appear on the same vector, meaning they are closely related and tend to confound [12]. This research was conducted before the addition of the "sluggishness" variable to the Daily Wellness Surveys. Due to the results of the PTA, we take a closer look at the wellness measure variables from the factor analysis conducted in the data exploration phase of analysis. It is seen that, using six factors, sluggishness, fatigue, and soreness all appear in the same factor for a majority of the weeks of the study. Recovery, however, does not appear in the same factor, which contradicts the results of the PTA [12]. This difference could be due to the inclusion of sluggishness into the Daily Wellness Surveys.

3.4 Analysis of Nutrition and Performance

General statistics from the performance data reveal that 7 subjects lost weight and 10 subjects gained weight over the course of the study. There were two subjects that did not have metrics for the final two weeks of the study. These two subjects have been marked as incomplete and left out of the performance portion of this analysis. For those that lost weight, the average is a decrease of 2.8 pounds. For those that gained weight, the average is an increase of 7.43 pounds. The overall average weight change is an increase of 3.22 pounds. Subjects on average decreased their bodyfat percentage by 1.21%. Only two subjects increased their bodyfat percentage, and both of those subjects also increased in weight. The data does not include performance goals, and thus analysis cannot be done that includes information of when an increase in weight is a positive change versus a negative change.

The collected data for weight change and bodyfat percentages was aggregated to total average weight change and bodyfat change for each individual. This is because, while some individuals had multiple measurements, the only weeks with all individuals recorded weight and DXA scan results are the first and last weeks of the study. This limits the analysis that can be done, as there is no way to track changes and relationship of nutrition and performance over time, only the change that occurred in each individual between week one and week 12.

Linear regression analysis was used to see how macronutrient breakdowns influence both change in bodyfat percentage and change in weight. Interestingly, there is no relationship between what types of calories a subject eats and their bodyfat percentage. However, both carbohydrate intake and fat intake are related to weight change. For every one pound increase in a subject's weight, that subject ate, on average, 1.27% more of their calories from carbohydrates and 1.12% more of their calories from fat. An increase in protein intake is associated with neither weight gain nor weight loss. These results clearly indicate that macronutrient breakdowns have a much larger effect on weight change than on fat loss or muscle gain. These results for macronutrients contradict what nutritionists generally believe [11]. Macronutrient breakdown explains 42% of the variation in weight change.

This study finds no relationship between protein and performance. This is interesting as protein is the primary focus of a majority of the previous studies in this industry. This is likely due to the fact that the population of active duty United States Air Force members typically meets its daily protein requirements. We speculate that if biological protein requirements were not met, results would be drastically different [11].

Linear regression analysis was then conducted to see how total calorie intake impacts weight change and bodyfat change. Interestingly, the results represent the opposite of the macronutrient results. There is no significant impact on weight change from total calorie intake. This lack of significance is the same regardless of controlling for age and gender, and even macronutrients. However, when controlling for age and gender, the models show that total calorie intake does have a significant effect of bodyfat percentage. Gender, age, and total calorie intake explain 39% of the variation in change in bodyfat percentage. Again, this contradicts what nutritionists typically believe. The common belief is that total calories determine weight, while specific nutrients eaten impact a subject's lean mass and fat mass [11].

Due to the fact that the size of an individual dictates how many calories their body needs, a metric was created to represent appropriate intake. This metric is the total average calorie intake divided by the subject's initial weight, or calories per pound.

This metric replaces the raw total calorie count and allows the analysis to capture any biases that may been seen in the results due to the size of the participant. The regression models using this metric reveal the same relationships between nutrition and performance as seen with pure total average calorie intake. Thus, there is no evidence that the initial size of the participant impacts their performance.

IV. Conclusions and Future Research

4.1 Conclusion

This study used linear regression and other methods of multivariate analysis to gain insights regarding the relationships between nutrition and wellness and nutrition and performance. Most of the results of the relationships between wellness and nutrition are found to be consistent with previous research and the general theories of nutritionists. The relationships between nutrition and performance are less intuitive. The summary results are outlined in the following paragraphs:

There are many observed relationships between the data from the subjects' nutrition logs and their daily wellness surveys. First, an increase in total calorie intake leads to increased motivation. Motivation tends to drop off as the weeks of the study progress. An increase in total calorie intake leads to stronger feelings of recovery, and thus eating enough calories is vital after a workout. There is no evidence that eating large quantities of protein after a workout improves recovery. It is much more important that the total calorie count is met. Next, eating more total calories and calories from fat leads to subjects feeling more satisfied and less hungry. Stress and sleep are both seen to affect how much a person eats in total calories. Less sleep leads to eating more calories, and more carbs. More stress leads to eating more calories and more fat. Finally, relationships between sluggishness, fatigue, and soreness and nutrition are less prevalent and less consistent than other measures of wellness because these variables are overshadowed by some confounding variable.

There are additional observed relationships between the subjects' nutrition logs and their weight and bodyfat changes. First, there is no relationship between what types of calories a subject eats (macronutrients) and their bodyfat percentage. However, both carbohydrate intake and fat intake are positively related to weight change.

Next, there is no evidence of a relationship between protein and weight or protein and bodyfat. Finally, there is no significant impact on weight change from total calorie intake, however the models show that total calorie intake does have a significant effect of bodyfat percentage.

The nature of these results is evidence that when using a "Black Box" technique, the analyst cannot be replaced with a computer. In this study, it was necessary to consult with a nutritionist to understand the findings. The results of the utilized machine learning techniques require intuition and knowledge of the data to draw conclusions. These types of thoughts and inputs cannot be done with a computer.

4.2 Recommendations for Future Research

For this research, one major limitation was the data. This is something that can easily be improved for future research. One recommendation is to conduct more frequent bodyfat data in the form of consistent weekly weigh-ins and monthly DXA scans. This will allow for better use of performance data and time trends within performance. Additionally, it is important to ensure that age and gender demographics are included to conduct more tailored research on calorie intake.

The next recommendation is improved goal annotations. This includes answers to questions such as: is a weight increase a good thing or a bad thing for this person? Is this person eating more/less than what the nutritionist recommended? Is the goal for this subject to lose fat, gain muscle mass, or something else? Recording answers to these questions will allow the STRONG lab to better apply the results of the analysis to future subjects. The future analyst will have a better idea of what performance changes are constituted as positive and negative, and therefore will be able to identify what nutrition profiles are effective versus ineffective.

Additionally, further investigation should be conducted with micronutrients. This may require some more specific nutrition logging, for example a minimum of five days a week instead of three, or perhaps a day a week that is logged with nutritionist supervision. These additional requirements are necessary in order to mitigate some of the error that comes with increasingly specific nutrition logging.

Hydration and wellness is another area of interest that can be investigated in future research. This would require subjects to record the amount of water that they drink every day. The analyst would then use that information in conjunction with the nutrition data and the Daily Wellness Surveys (particularly the urine color section) to draw results.

Finally, an interesting area of study would be that of specific diets. It would be useful to analyze the relationships between nutrition and wellness and nutrition and performance for subjects partaking in specific diets. These diets include, but are not limited to, ketogenic, vegan, vegetarian, and paleo style. Analyzing these diets in comparison to more general diets would allow for insights into how the body reacts differently when fed with only specific breakdowns of macronutrients and types of foods.

Appendix A: Factor Loadings

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Average of Energy (kcal)	0.496	1.062	0.235	0.073	-0.608	0.332
Average of Energy (kcal) 2	0.668	0.329	0.090	0.167	-0.054	0.460
Average of Energy (kcal) 3	0.715	0.491	0.123	0.245	0.005	-0.084
Average of Energy (kcal) 4	0.724	0.363	0.403	0.265	0.006	0.228
Average of Energy (kcal) 5	0.663	0.524	0.072	0.035	-0.084	0.103
Average of Energy (kcal) 6	0.693	0.504	0.196	0.337	0.029	-0.009
Average of Energy (kcal) 7	0.564	0.593	-0.109	-0.137	-0.181	-0.140
Average of Energy (kcal) 8	0.780	0.007	-0.084	-0.016	-0.416	0.121
Average of Energy (kcal) 9	0.578	0.592	0.005	0.242	0.157	0.206
Average of Energy (kcal) 10	0.676	0.101	0.129	0.178	-0.091	0.427
Average of Energy (kcal) 11	0.707	0.518	-0.024	0.146	0.167	-0.039
Average of Energy (kcal) 12	0.584	0.426	-0.184	0.122	0.055	0.160
Average of Protein (g)	0.204	1.222	0.170	-0.033	-0.061	0.352
Average of Protein (g) 2	0.290	0.501	0.103	-0.038	0.042	0.757
Average of Protein (g) 3	0.344	0.626	0.103	0.222	0.242	0.233
Average of Protein (g) 4	0.393	0.605	0.306	0.143	0.159	0.419
Average of Protein (g) 5	0.075	0.683	0.096	-0.178	0.084	0.155
Average of Protein (g) 6	0.248	0.661	0.269	0.228	0.270	0.361
Average of Protein (g) 7	0.273	0.500	0.018	-0.165	-0.230	0.497
Average of Protein (g) 8	0.623	0.025	-0.046	-0.002	-0.345	0.595
Average of Protein (g) 9	0.174	0.639	0.079	0.030	0.253	0.521
Average of Protein (g) 10	0.276	0.278	0.218	-0.085	0.462	0.451
Average of Protein (g) 11	0.275	0.719	-0.308	-0.014	0.165	0.284
Average of Protein (g) 12	0.347	0.377	-0.192	0.118	0.085	0.542
Average of Carbs (g)	0.627	0.909	0.254	0.133	-0.880	0.299
Average of Carbs (g) 2	0.859	0.141	0.020	0.169	0.135	0.099
Average of Carbs (g) 3	0.929	0.221	0.059	0.115	-0.027	-0.003
Average of Carbs (g) 4	0.885	0.143	0.273	0.174	-0.009	0.151
Average of Carbs (g) 5	0.942	-0.031	0.024	-0.005	-0.067	0.109

Average of Carbs (g) 6	0.917	0.262	0.127	0.198	0.029	-0.067
Average of Carbs (g) 7	0.860	0.241	-0.136	-0.175	0.109	-0.309
Average of Carbs (g) 8	0.937	-0.033	-0.097	-0.139	-0.164	-0.039
Average of Carbs (g) 9	0.777	0.290	-0.075	0.071	0.032	0.030
Average of Carbs (g) 10	0.897	0.023	-0.016	0.201	-0.098	0.184
Average of Carbs (g) 11	0.935	0.170	-0.116	0.176	-0.037	-0.054
Average of Carbs (g) 12	0.788	0.126	-0.287	0.004	-0.015	-0.033
Average of Fat (g)	0.425	1.118	0.222	0.043	-0.467	0.342
Average of Fat (g) 2	0.192	0.614	0.135	0.114	-0.421	0.347
Average of Fat (g) 3	0.204	0.715	0.095	0.219	-0.007	-0.301
Average of Fat (g) 4	0.207	0.611	0.512	0.252	-0.013	0.256
Average of Fat (g) 5	-0.119	0.808	0.136	0.128	-0.041	-0.074
Average of Fat (g) 6	0.206	0.695	0.257	0.327	-0.018	-0.008
Average of Fat (g) 7	-0.087	0.748	0.064	-0.023	-0.386	-0.116
Average of Fat (g) 8	0.216	0.179	-0.027	0.130	-0.677	0.060
Average of Fat (g) 9	-0.042	0.778	0.010	0.278	0.127	-0.088
Average of Fat (g) 10	0.364	0.453	0.152	0.151	-0.082	0.497
Average of Fat (g) 11	-0.085	0.590	0.265	0.106	0.293	-0.245
Average of Fat (g) 12	0.256	0.535	0.077	0.324	0.030	0.061
Average of % Protein	-0.722	0.429	-0.146	-0.261	1.297	0.027
Average of % Protein 2	-0.480	0.384	0.010	-0.251	0.254	0.550
Average of % Protein 3	-0.421	0.283	-0.110	0.046	0.351	0.484
Average of % Protein 4	-0.478	0.415	-0.447	-0.062	0.176	0.256
Average of % Protein 5	-0.549	0.431	-0.006	-0.240	0.194	0.040
Average of % Protein 6	-0.631	0.277	-0.079	-0.034	0.264	0.471
Average of % Protein 7	-0.133	0.166	0.089	-0.116	-0.134	0.819
Average of % Protein 8	-0.004	0.125	0.027	-0.057	-0.072	0.815
Average of % Protein 9	-0.330	0.325	0.069	-0.273	0.180	0.481
Average of % Protein 10	-0.544	0.111	0.213	-0.180	0.540	-0.062
Average of % Protein 11	-0.366	0.495	-0.337	-0.209	0.081	0.530
Average of % Protein 12	-0.171	0.187	-0.041	0.060	0.130	0.814
Average of % Carbs	0.425	-0.994	0.029	0.194	-0.912	-0.216

Average of % Carbs 2	0.720	-0.421	-0.069	0.162	0.478	-0.229
Average of % Carbs 3	0.850	-0.242	-0.006	-0.044	-0.045	0.180
Average of % Carbs 4	0.878	-0.226	0.037	-0.054	-0.087	-0.014
Average of % Carbs 5	0.837	-0.449	-0.037	-0.041	-0.059	0.134
Average of % Carbs 6	0.892	-0.269	0.038	-0.073	-0.023	-0.085
Average of % Carbs 7	0.702	-0.440	-0.110	-0.004	0.463	-0.326
Average of % Carbs 8	0.556	-0.091	-0.112	-0.131	0.738	-0.267
Average of % Carbs 9	0.722	-0.160	-0.241	-0.062	-0.092	-0.167
Average of % Carbs 10	0.811	-0.114	-0.347	0.139	-0.169	-0.068
Average of % Carbs 11	0.819	-0.182	-0.172	0.069	-0.178	-0.056
Average of % Carbs 12	0.633	-0.395	-0.222	-0.225	0.057	-0.349
Average of % Fat	0.145	1.234	0.154	-0.050	0.039	0.350
Average of % Fat 2	-0.456	0.580	0.087	-0.086	-0.633	-0.105
Average of % Fat 3	-0.672	0.450	-0.102	-0.023	-0.037	-0.249
Average of % Fat 4	-0.826	0.314	0.206	-0.039	0.077	-0.024
Average of % Fat 5	-0.732	0.521	0.100	0.081	0.040	-0.164
Average of % Fat 6	-0.817	0.361	0.071	-0.085	-0.055	-0.107
Average of % Fat 7	-0.635	0.589	0.229	-0.017	-0.269	-0.015
Average of % Fat 8	-0.688	0.449	0.073	0.049	-0.068	-0.076
Average of % Fat 9	-0.553	0.481	0.098	0.067	0.068	-0.343
Average of % Fat 10	-0.449	0.703	0.159	0.040	-0.091	0.075
Average of % Fat 11	-0.732	0.312	0.293	-0.035	0.120	-0.289
Average of % Fat 12	-0.651	0.461	0.400	0.258	-0.209	-0.213
Average of Motivation	-0.073	-0.042	0.568	-0.030	-0.423	0.138
Average of Motivation 2	0.160	0.144	0.557	0.376	-0.278	0.113
Average of Motivation 3	-0.012	0.390	0.590	-0.066	0.055	0.467
Average of Motivation 4	0.103	0.146	0.599	0.006	-0.255	-0.065
Average of Motivation 5	0.091	0.048	0.677	0.000	-0.303	0.169
Average of Motivation 6	0.114	0.394	0.580	-0.048	-0.197	0.063
Average of Motivation 7	0.132	-0.007	0.475	-0.472	-0.099	-0.088
Average of Motivation 8	-0.010	0.072	0.391	0.386	0.010	-0.233
Average of Motivation 9	-0.076	0.377	0.250	-0.226	-0.216	0.289

Average of Motivation 10	0.188	0.505	0.160	-0.063	-0.102	0.355
Average of Motivation 11	0.448	0.300	0.487	-0.003	-0.225	0.008
Average of Motivation 12	0.343	0.308	0.410	-0.047	-0.073	0.155
Average of Overall Soreness	-0.122	-0.223	0.500	-0.149	0.137	-0.103
Average of Overall Soreness 2	-0.357	0.081	0.318	0.212	0.011	0.084
Average of Overall Soreness 3	-0.103	-0.157	0.502	0.736	-0.185	-0.195
Average of Overall Soreness 4	-0.133	0.251	0.436	0.013	-0.134	-0.564
Average of Overall Soreness 5	-0.073	-0.154	0.445	0.557	0.179	0.221
Average of Overall Soreness 6	0.096	-0.243	0.542	0.057	-0.459	-0.236
Average of Overall Soreness 7	0.046	0.194	-0.072	0.195	0.016	0.040
Average of Overall Soreness 8	0.006	0.008	0.387	0.574	0.060	-0.181
Average of Overall Soreness 9	0.263	0.450	-0.213	0.233	-0.026	-0.069
Average of Overall Soreness 10	-0.004	0.229	-0.077	0.682	0.029	-0.267
Average of Overall Soreness 11	0.162	0.434	0.434	0.495	-0.139	-0.144
Average of Overall Soreness 12	-0.098	-0.148	0.320	0.369	-0.062	-0.407
Average of Emotional Stress	-0.292	-0.338	-0.031	0.233	-0.407	-0.035
Average of Emotional Stress 2	-0.347	0.130	-0.215	0.354	-0.188	0.007
Average of Emotional Stress 3	-0.381	0.132	0.491	0.105	-0.257	-0.171
Average of Emotional Stress 4	-0.121	-0.144	0.380	0.043	0.092	-0.528
Average of Emotional Stress 5	-0.446	-0.147	0.379	0.196	-0.265	-0.511
Average of Emotional Stress 6	-0.318	-0.269	0.155	0.457	-0.230	-0.317
Average of Emotional Stress 7	-0.210	0.240	0.082	0.574	-0.020	-0.228
Average of Emotional Stress 8	-0.481	-0.241	0.316	0.243	-0.310	-0.355
Average of Emotional Stress 9	-0.041	-0.029	0.139	0.422	0.452	-0.569
Average of Emotional Stress 10	-0.209	0.132	-0.188	0.755	-0.341	-0.169
Average of Emotional Stress 11	-0.214	0.041	0.467	0.331	-0.361	-0.438
Average of Emotional Stress 12	-0.312	0.084	0.367	0.141	-0.035	-0.539
Average of Food Amount	-0.184	0.081	0.093	-0.166	-0.611	0.042
Average of Food Amount 2	-0.148	0.038	0.257	0.026	-0.515	0.082
Average of Food Amount 3	0.023	0.225	0.826	-0.080	-0.349	-0.028
Average of Food Amount 4	0.047	0.015	0.840	0.062	-0.286	0.057
Average of Food Amount 5	-0.077	0.079	0.927	0.056	-0.251	0.137

Average of Food Amount 6	0.036	0.141	0.277	-0.154	-0.446	0.005
Average of Food Amount 7	0.006	0.100	0.773	0.183	-0.242	0.167
Average of Food Amount 8	-0.065	0.293	0.514	-0.311	0.068	0.238
Average of Food Amount 9	-0.309	-0.077	0.218	0.172	-0.241	0.032
Average of Food Amount 10	-0.255	-0.078	0.506	0.222	-0.491	0.221
Average of Food Amount 11	0.014	0.196	0.762	0.352	-0.144	-0.005
Average of Food Amount 12	-0.134	0.372	0.688	-0.090	0.229	0.188
Average of Recovery	0.152	0.405	0.088	-0.167	0.228	0.062
Average of Recovery 2	-0.117	0.235	0.051	-0.043	0.064	-0.450
Average of Recovery 3	-0.067	0.052	0.169	0.171	-0.065	0.260
Average of Recovery 4	0.035	-0.165	0.657	0.182	0.189	-0.146
Average of Recovery 5	-0.235	0.444	0.193	-0.019	0.204	0.285
Average of Recovery 6	0.301	0.160	0.691	-0.195	-0.190	-0.047
Average of Recovery 7	-0.185	0.520	0.444	-0.088	0.209	-0.275
Average of Recovery 8	-0.051	0.388	0.523	0.156	0.136	-0.124
Average of Recovery 9	-0.261	0.199	0.414	0.369	0.021	0.061
Average of Recovery 10	0.088	0.410	-0.174	0.204	0.352	0.124
Average of Recovery 11	0.257	-0.076	0.079	0.201	0.134	0.176
Average of Recovery 12	0.176	0.499	0.383	0.034	0.362	-0.084
Average of Sluggishness	-0.285	0.154	0.496	-0.151	0.151	-0.375
Average of Sluggishness 2	-0.751	-0.039	0.139	0.174	0.051	-0.206
Average of Sluggishness 3	-0.074	-0.349	0.621	0.124	0.280	-0.236
Average of Sluggishness 4	-0.128	0.291	0.524	0.265	0.150	-0.116
Average of Sluggishness 5	-0.199	0.037	0.694	0.373	0.181	-0.286
Average of Sluggishness 6	-0.168	0.014	0.533	0.191	-0.104	-0.261
Average of Sluggishness 7	-0.189	0.386	0.472	0.210	0.097	-0.272
Average of Sluggishness 8	-0.277	0.005	0.508	0.464	-0.323	-0.289
Average of Sluggishness 9	0.112	0.215	0.569	0.161	0.016	0.007
Average of Sluggishness 10	-0.100	0.456	-0.009	0.473	0.009	0.093
Average of Sluggishness 11	-0.370	0.490	0.464	0.165	0.010	-0.388
Average of Sluggishness 12	-0.293	0.193	0.403	0.249	-0.132	-0.632
Average of Physical Fatigue	0.234	0.240	0.587	-0.004	0.042	0.153

Average of Physical Fatigue 2	-0.312	-0.098	0.593	0.047	0.245	0.015
Average of Physical Fatigue 3	-0.099	0.103	0.378	0.657	0.035	-0.186
Average of Physical Fatigue 4	-0.036	0.028	0.446	0.311	-0.033	-0.282
Average of Physical Fatigue 5	0.066	0.016	0.489	0.518	0.093	-0.293
Average of Physical Fatigue 6	-0.425	-0.042	0.562	0.209	0.222	0.204
Average of Physical Fatigue 7	-0.046	0.232	0.747	0.149	-0.026	0.208
Average of Physical Fatigue 8	-0.249	0.175	0.593	0.355	-0.220	0.102
Average of Physical Fatigue 9	-0.030	0.397	0.163	0.260	-0.103	0.068
Average of Physical Fatigue 10	-0.457	0.275	0.020	0.539	0.177	-0.044
Average of Physical Fatigue 11	-0.253	0.263	0.509	0.373	-0.130	-0.189
Average of Physical Fatigue 12	-0.095	0.279	0.502	0.215	0.116	0.027
Average of Sleep Quality	-0.081	0.353	-0.043	0.042	-0.428	-0.010
Average of Sleep Quality 2	0.045	0.301	0.198	0.247	-0.145	0.034
Average of Sleep Quality 3	-0.114	0.459	0.399	0.129	-0.230	-0.078
Average of Sleep Quality 4	0.018	0.480	0.570	-0.125	-0.014	-0.046
Average of Sleep Quality 5	-0.450	0.317	0.146	0.043	0.127	-0.051
Average of Sleep Quality 6	0.055	0.117	0.732	0.018	-0.312	0.210
Average of Sleep Quality 7	-0.223	0.089	0.674	0.217	0.039	0.054
Average of Sleep Quality 8	-0.156	0.237	0.593	-0.134	0.383	0.156
Average of Sleep Quality 9	0.140	-0.030	0.411	0.473	0.080	-0.242
Average of Sleep Quality 10	-0.298	0.386	0.044	0.335	0.154	-0.062
Average of Sleep Quality 11	-0.043	-0.063	0.589	0.014	-0.387	-0.255
Average of Sleep Quality 12	0.076	0.243	0.562	-0.107	0.287	0.152

Appendix B: Cross Validation Models

The tables in this appendix show the results of the cross-validation of the baseline models for the 5 randomly chosen subjects. When the actual value shown in the first column of each table is green, it represents the fact that that value falls within the 95% confidence interval. It can be noted that the model has trouble correctly predicting zero values.

Table 8. Cross Validation of Motivation in Week 3

Motivation Week 3 Actual Value	Predicted Value	Lower 95% CI	Upper 95% CI
0	6.713044253	1.897017871	11.52907064
5	3.551021731	1.742406849	5.359636612
0	12.77482583	-1.592488047	27.1421397
0	2.570514499	0.23076657	4.910262428
5	4.297068896	1.512707885	7.081429907

Table 9. Cross Validation of Soreness in Week 3

Soreness Week 3 Actual Value	Predicted Value	Lower 95% CI	Upper 95% CI
5	5.716623824	1.354649561	10.07859809
3	1.374867106	-0.263232634	3.012966847
5	13.8133124	0.800540375	26.82608441
0	0.109536847	-2.009621032	2.228694725
3	2.91211961	0.390266508	5.433972712

Table 10. Cross Validation of Stress in Week 8

Stress Week 8 Actual Value	Predicted Value	Lower 95% CI	Upper 95% CI
5	1.985100289	1.684624879	5.654825456
0	2.099656404	-2.110747792	2.088565015
0	1.115756474	0.764322748	2.995835696
0	1.321922834	0.932214651	3.576060318
0	2.080157348	-2.190748949	1.969565746

Table 11. Cross Validation of Satiety in Week 8

Satiety Week 8 Actual Value	Predicted Value	Lower 95% CI	Upper 95% CI
0	3.08918644	1.638010076	7.816382956
6	3.267457129	1.815049928	8.349964187
5	1.736325258	2.93916602	6.411816535
3	2.057158581	2.291380528	6.405697689
5	3.23711296	1.78144579	8.255671711

Appendix C: Baseline Models

This appendix shows the parameter estimate results of all significant baseline models for each time period.

Motivation: N/A

Stress:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.585717	4.723698	2.66	0.0177*
Average of Energy (kcal) 3	0.0005627	0.000756	0.74	0.4684
Average of % Protein 3	-0.096242	0.084018	-1.15	0.2700
Average of % Carbs 3	-0.159727	0.065283	-2.45	0.0272*
Average of % Fat 3	-0.093594	0.070982	-1.32	0.2071

Satiety: N/A

Recovery:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.051488	4.16064	-0.97	0.3456
Average of Energy (kcal) 3	0.0001488	0.000666	0.22	0.8262
Average of % Protein 3	0.1497847	0.074003	2.02	0.0612
Average of % Carbs 3	0.0663387	0.057501	1.15	0.2667
Average of % Fat 3	0.0541843	0.062521	0.87	0.3998

Sluggishness: N/A

Fatigue:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.020536	3.871735	3.88	0.0015*
Average of Energy (kcal) 3	0.0019618	0.00062	3.16	0.0064*
Average of % Protein 3	-0.050755	0.068864	-0.74	0.4725
Average of % Carbs 3	-0.231818	0.053509	-4.33	0.0006*
Average of % Fat 3	-0.186439	0.05818	-3.20	0.0059*

Sleep Quality:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.238945	4.551166	1.81	0.0903
Average of Energy (kcal) 3	0.0011729	0.000729	1.61	0.1283
Average of % Protein 3	-0.03172	0.080949	-0.39	0.7007
Average of % Carbs 3	-0.117906	0.062899	-1.87	0.0805
Average of % Fat 3	-0.049742	0.06839	-0.73	0.4782

Soreness:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.036834	4.347519	3.46	0.0035*
Average of Energy (kcal) 3	0.0014495	0.000696	2.08	0.0549
Average of % Protein 3	-0.105954	0.077327	-1.37	0.1908
Average of % Carbs 3	-0.193997	0.060084	-3.23	0.0056*
Average of % Fat 3	-0.154277	0.06533	-2.36	0.0321*

Figure 4. Time Period 1 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 3 (the first week of usable data) on wellness week 3.

Time Period 2: Effect of Study week 3 on Study week 4

Motivation:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.633523	8.719493	-0.07	0.9430
Average of Energy (kcal) 4	0.0023076	0.00069	3.34	0.0044*
Average of % Protein 4	-0.020914	0.094737	-0.22	0.8283
Average of % Carbs 4	-0.052308	0.098806	-0.53	0.6043
Average of % Fat 4	0.0594595	0.101686	0.58	0.5674

Stress: N/A

Satiety: N/A

Recovery: N/A

Sluggishness: N/A

Fatigue: N/A

Sleep Quality: N/A

Soreness: N/A

Figure 5. Time Period 2 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 3 on wellness week 4.

Motivation:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3236772	9.855026	0.03	0.9742
Average of Energy (kcal) 4	0.0015031	0.00078	1.93	0.0731
Average of % Protein 4	-0.052187	0.107075	-0.49	0.6330
Average of % Carbs 4	-0.011372	0.111673	-0.10	0.9202
Average of % Fat 4	0.0587259	0.114929	0.51	0.6168

Stress: N/A

Satiety:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.0940819	7.67056	1.06	0.3080
Average of Energy (kcal) 4	0.0016473	0.000607	2.71	0.0160*
Average of % Protein 4	-0.136706	0.08334	-1.64	0.1217
Average of % Carbs 4	-0.096982	0.08692	-1.12	0.2821
Average of % Fat 4	0.001373	0.089454	0.02	0.9880

Recovery: N/A

Sluggishness: N/A

Fatigue: N/A

Sleep Quality:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-23.11784	7.525117	-3.07	0.0077*
Average of Energy (kcal) 4	0.0009227	0.000596	1.55	0.1422
Average of % Protein 4	0.1177774	0.08176	1.44	0.1703
Average of % Carbs 4	0.2561589	0.085271	3.00	0.0089*
Average of % Fat 4	0.3304536	0.087758	3.77	0.0019*

Soreness: N/A

Figure 6. Time Period 3 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 4 on wellness week 4.

Motivation:

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.738036	7.810462	1.50	0.1536
Average of Energy (kcal) 4	0.001604	0.000618	2.59	0.0203*
Average of % Protein 4	-0.166665	0.08486	-1.96	0.0683
Average of % Carbs 4	-0.128827	0.088505	-1.46	0.1661
Average of % Fat 4	-0.053461	0.091085	-0.59	0.5660

Stress: N/A

Satiety:

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.3493744	7.27553	0.46	0.6519
Average of Energy (kcal) 4	0.001476	0.000576	2.56	0.0216*
Average of % Protein 4	-0.121806	0.079048	-1.54	0.1442
Average of % Carbs 4	-0.043324	0.082443	-0.53	0.6069
Average of % Fat 4	0.0802449	0.084847	0.95	0.3593

Recovery: N/A

Sluggishness:

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.5593965	6.600078	0.54	0.5976
Average of Energy (kcal) 4	0.0006328	0.000522	1.21	0.2445
Average of % Protein 4	-0.126613	0.07171	-1.77	0.0978
Average of % Carbs 4	-0.029379	0.074789	-0.39	0.7000
Average of % Fat 4	0.059525	0.07697	0.77	0.4513

Fatigue: N/A

Sleep Quality: N/A

Soreness: N/A

Figure 7. Time Period 4 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 4 on wellness week 5.

Time Period 5: Effect of nutrition week 5 on wellness week 5

Motivation: N/A

Stress: N/A

Satiety: N/A

Recovery: N/A

Sluggishness: N/A

Fatigue: N/A

Sleep Quality: N/A

Soreness: N/A

Figure 8. Time Period 5 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 5 on wellness week 5.

Motivation: N/A

Stress:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	35.021129	10.29545	3.40	0.0043*
Average of Energy (kcal) 5	-0.000514	0.000733	-0.70	0.4941
Average of % Protein 5	-0.483976	0.138366	-3.50	0.0036*
Average of % Carbs 5	-0.31505	0.103527	-3.04	0.0088*
Average of % Fat 5	-0.21985	0.100324	-2.19	0.0458*

Satiety: N/A

Recovery:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-13.91157	12.561	-1.11	0.2867
Average of Energy (kcal) 5	0.0016058	0.000894	1.80	0.0940
Average of % Protein 5	0.1499266	0.168814	0.89	0.3895
Average of % Carbs 5	0.1448936	0.126309	1.15	0.2706
Average of % Fat 5	0.1475813	0.122401	1.21	0.2479

Sluggishness: N/A

Fatigue: N/A

Sleep Quality: N/A

Figure 9. Time Period 6 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 5 on wellness week 6.

Motivation: N/A

Stress:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	21.592159	9.868705	2.19	0.0449*
Average of Energy (kcal) 6	-0.000043	0.000561	-0.08	0.9400
Average of % Protein 6	-0.310477	0.102167	-3.04	0.0083*
Average of % Carbs 6	-0.224966	0.103249	-2.18	0.0457*
Average of % Fat 6	-0.088693	0.112299	-0.79	0.4420

Satiety: N/A

Recovery: N/A

Sluggishness: N/A

Fatigue: N/A

Sleep Quality: N/A

Soreness:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.287585	10.62582	1.63	0.1246
Average of Energy (kcal) 6	-0.000469	0.000604	-0.78	0.4495
Average of % Protein 6	-0.204536	0.110005	-1.86	0.0827
Average of % Carbs 6	-0.11809	0.11117	-1.06	0.3049
Average of % Fat 6	-0.121788	0.120915	-1.01	0.3298

Figure 10. Time Period 7 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 6 on wellness week 6.

Motivation: N/A

Stress:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	10.813217	8.927819	1.21	0.2446
Average of Energy (kcal) 6	0.0011274	0.000507	2.22	0.0421*
Average of % Protein 6	-0.156505	0.092426	-1.69	0.1111
Average of % Carbs 6	-0.160252	0.093405	-1.72	0.1068
Average of % Fat 6	-0.033935	0.101592	-0.33	0.7430

Satiety: N/A

Recovery:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-29.46187	12.60957	-2.34	0.0338*
Average of Energy (kcal) 6	0.0013062	0.000717	1.82	0.0884
Average of % Protein 6	0.2140353	0.130542	1.64	0.1219
Average of % Carbs 6	0.2604046	0.131924	1.97	0.0671
Average of % Fat 6	0.413814	0.143488	2.88	0.0114*

Sluggishness:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-9.77793	9.790921	-1.00	0.3338
Average of Energy (kcal) 6	0.0008496	0.000557	1.53	0.1477
Average of % Protein 6	-0.017218	0.101362	-0.17	0.8674
Average of % Carbs 6	0.0758094	0.102435	0.74	0.4707
Average of % Fat 6	0.227114	0.111414	2.04	0.0595

Fatigue: N/A

Sleep Quality: N/A

Soreness: N/A

Figure 11. Time Period 8 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 6 on wellness week 7.

Time Period 9: Effect of nutrition week 7 on wellness week 7

Motivation: N/A

Stress: N/A

Satiety:

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-28.72288	15.73965	-1.82	0.0880
Average of Energy (kcal) 7	-0.000827	0.000956	-0.87	0.4003
Average of % Protein 7	0.2981335	0.181994	1.64	0.1222
Average of % Carbs 7	0.3367783	0.169432	1.99	0.0654
Average of % Fat 7	0.3856351	0.158515	2.43	0.0280*

Recovery: N/A

Sluggishness: N/A

Fatigue: N/A

Sleep Quality: N/A

Soreness: N/A

Figure 12. Time Period 9 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 7 on wellness week 7.

Motivation:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-16.68989	15.78492	-1.06	0.3071
Average of Energy (kcal) 7	-0.001563	0.000958	-1.63	0.1237
Average of % Protein 7	0.0453663	0.182518	0.25	0.8071
Average of % Carbs 7	0.2644214	0.169919	1.56	0.1405
Average of % Fat 7	0.2858689	0.158971	1.80	0.0923

Stress:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	36.661721	13.48742	2.72	0.0159*
Average of Energy (kcal) 7	-0.000248	0.000819	-0.30	0.7664
Average of % Protein 7	-0.385205	0.155952	-2.47	0.0260*
Average of % Carbs 7	-0.377424	0.145187	-2.60	0.0201*
Average of % Fat 7	-0.288305	0.135833	-2.12	0.0509

Satiety:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-34.58697	12.90826	-2.68	0.0172*
Average of Energy (kcal) 7	-0.000549	0.000784	-0.70	0.4947
Average of % Protein 7	0.468274	0.149255	3.14	0.0068*
Average of % Carbs 7	0.3874896	0.138953	2.79	0.0138*
Average of % Fat 7	0.3793513	0.13	2.92	0.0106*

Recovery: N/A

Sluggishness: N/A

Fatigue: N/A

Sleep Quality:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-30.88702	16.28957	-1.90	0.0774
Average of Energy (kcal) 7	-0.000295	0.000989	-0.30	0.7698
Average of % Protein 7	0.3950623	0.188353	2.10	0.0533
Average of % Carbs 7	0.318767	0.175352	1.82	0.0891
Average of % Fat 7	0.3496775	0.164053	2.13	0.0500*

Soreness: N/A

Figure 13. Time Period 10 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 7 on wellness week 8.

Motivation: N/A

Stress:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	27.270855	7.194903	3.79	0.0026*
Average of Energy (kcal) 8	-0.00137	0.000501	-2.73	0.0182*
Average of % Protein 8	-0.378267	0.096548	-3.92	0.0020*
Average of % Carbs 8	-0.205394	0.07094	-2.90	0.0134*
Average of % Fat 8	-0.181008	0.072172	-2.51	0.0275*

Satiety: N/A

Recovery: N/A

Sluggishness: N/A

Fatigue: N/A

Sleep Quality: N/A

Soreness: N/A

Figure 14. Time Period 11 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 8 on wellness week 8.

Motivation: N/A

Stress: N/A

Satiety: N/A

Recovery: N/A

Sluggishness: N/A

Fatigue:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-16.2294	9.568828	-1.70	0.1156
Average of Energy (kcal) 8	0.0011017	0.000667	1.65	0.1243
Average of % Protein 8	0.1859863	0.128403	1.45	0.1731
Average of % Carbs 8	0.1343645	0.094346	1.42	0.1799
Average of % Fat 8	0.1961723	0.095985	2.04	0.0636

Sleep Quality: N/A

Soreness: N/A

Figure 15. Time Period 12 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 8 on wellness week 9.

Motivation: N/A

Stress: N/A

Satiety: N/A

Recovery: N/A

Sluggishness:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.7399979	5.341715	1.82	0.0897
Average of Energy (kcal) 9	0.0016734	0.000992	1.69	0.1137
Average of % Protein 9	-0.163677	0.084242	-1.94	0.0724
Average of % Carbs 9	-0.107773	0.067291	-1.60	0.1316
Average of % Fat 9	-0.067932	0.056754	-1.20	0.2512

Fatigue: N/A

Sleep Quality: N/A

Soreness: N/A

Figure 16. Time Period 13 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 9 on wellness week 9.

Motivation:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.158667	7.001372	0.31	0.7624
Average of Energy (kcal) 9	0.0037652	0.0013	2.90	0.0117*
Average of % Protein 9	-0.001382	0.110416	-0.01	0.9902
Average of % Carbs 9	-0.090708	0.088198	-1.03	0.3212
Average of % Fat 9	-0.077449	0.074387	-1.04	0.3154

Stress: N/A

Satiety: N/A

Recovery:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.042931	8.221669	0.37	0.7168
Average of Energy (kcal) 9	0.003045	0.001527	1.99	0.0659
Average of % Protein 9	0.0288092	0.129661	0.22	0.8274
Average of % Carbs 9	-0.115174	0.10357	-1.11	0.2849
Average of % Fat 9	-0.066584	0.087352	-0.76	0.4586

Sluggishness:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.367637	4.15857	2.73	0.0162*
Average of Energy (kcal) 9	0.002569	0.000772	3.33	0.0050*
Average of % Protein 9	-0.151321	0.065583	-2.31	0.0368*
Average of % Carbs 9	-0.207743	0.052387	-3.97	0.0014*
Average of % Fat 9	-0.07276	0.044183	-1.65	0.1219

Fatigue:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.4485894	5.029881	0.88	0.3914
Average of Energy (kcal) 9	0.0019223	0.000934	2.06	0.0587
Average of % Protein 9	-0.100569	0.079325	-1.27	0.2255
Average of % Carbs 9	-0.134147	0.063363	-2.12	0.0526
Average of % Fat 9	0.0334026	0.053441	0.63	0.5420

Sleep Quality: N/A

Soreness: N/A

Figure 17. Time Period 14 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 9 on wellness week 10.

Motivation:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-8.591978	7.668233	-1.12	0.2828
Average of Energy (kcal) 10	0.0009618	0.000863	1.11	0.2854
Average of % Protein 10	-0.013725	0.154425	-0.09	0.9305
Average of % Carbs 10	0.0891819	0.08978	0.99	0.3387
Average of % Fat 10	0.1794827	0.087004	2.06	0.0597

Stress: N/A

Satiety:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.504123	4.029229	4.34	0.0008*
Average of Energy (kcal) 10	-0.000283	0.000454	-0.62	0.5441
Average of % Protein 10	-0.28725	0.081142	-3.54	0.0036*
Average of % Carbs 10	-0.148466	0.047174	-3.15	0.0077*
Average of % Fat 10	-0.005296	0.045716	-0.12	0.9095

Recovery: N/A

Sluggishness: N/A

Fatigue: N/A

Sleep Quality:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-11.2299	9.082522	-1.24	0.2382
Average of Energy (kcal) 10	-0.000263	0.001022	-0.26	0.8011
Average of % Protein 10	0.1495965	0.182906	0.82	0.4282
Average of % Carbs 10	0.0841959	0.106338	0.79	0.4427
Average of % Fat 10	0.2171111	0.10305	2.11	0.0551

Soreness: N/A

Figure 18. Time Period 15 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 10 on wellness week 10.

Motivation: N/A

Stress: N/A

Satiety:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-7.662942	9.229602	-0.83	0.4240
Average of Energy (kcal) 10	0.0014897	0.000812	1.84	0.0936
Average of % Protein 10	0.1295142	0.14959	0.87	0.4051
Average of % Carbs 10	0.0364554	0.10085	0.36	0.7246
Average of % Fat 10	0.1321729	0.104086	1.27	0.2303

Recovery:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.0675764	6.582217	0.47	0.6503
Average of Energy (kcal) 10	0.0011785	0.000579	2.04	0.0666
Average of % Protein 10	0.0374766	0.106682	0.35	0.7320
Average of % Carbs 10	-0.007001	0.071923	-0.10	0.9242
Average of % Fat 10	-0.053138	0.07423	-0.72	0.4890

Sluggishness: N/A

Fatigue:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.505873	9.12884	1.70	0.1175
Average of Energy (kcal) 10	2.3739e-5	0.000803	0.03	0.9769
Average of % Protein 10	-0.17542	0.147957	-1.19	0.2608
Average of % Carbs 10	-0.199047	0.099749	-2.00	0.0714
Average of % Fat 10	-0.038064	0.102949	-0.37	0.7186

Sleep Quality: N/A

Soreness: N/A

Figure 19. Time Period 16 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 10 on wellness week 11.

Motivation: N/A

Stress: N/A

Satiety:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.0348543	4.8871	1.03	0.3250
Average of Energy (kcal) 11	0.0032586	0.001037	3.14	0.0094*
Average of % Protein 11	-0.15904	0.089376	-1.78	0.1028
Average of % Carbs 11	-0.117858	0.057645	-2.04	0.0656
Average of % Fat 11	0.0222519	0.057912	0.38	0.7081

Recovery:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.3816013	2.271258	1.49	0.1646
Average of Energy (kcal) 11	0.0011448	0.000482	2.38	0.0368*
Average of % Protein 11	-0.010688	0.041537	-0.26	0.8017
Average of % Carbs 11	-0.008674	0.02679	-0.32	0.7522
Average of % Fat 11	-0.020414	0.026914	-0.76	0.4641

Sluggishness: N/A

Fatigue:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.5666887	5.557557	1.00	0.3380
Average of Energy (kcal) 11	-0.00062	0.001179	-0.53	0.6093
Average of % Protein 11	-0.196165	0.101637	-1.93	0.0798
Average of % Carbs 11	0.0003123	0.065553	0.00	0.9963
Average of % Fat 11	0.0774763	0.065857	1.18	0.2643

Sleep Quality: N/A

Soreness: N/A

Figure 20. Time Period 17 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 11 on wellness week 11.

Motivation: N/A

Stress:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.992968	5.815535	-0.34	0.7373
Average of Energy (kcal) 11	-0.000521	0.000962	-0.54	0.5974
Average of % Protein 11	-0.126314	0.092108	-1.37	0.1935
Average of % Carbs 11	0.0592879	0.067281	0.88	0.3942
Average of % Fat 11	0.1524912	0.068991	2.21	0.0456*

Satiety:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-6.779792	6.464999	-1.05	0.3134
Average of Energy (kcal) 11	0.0002254	0.001069	0.21	0.8363
Average of % Protein 11	0.0838766	0.102394	0.82	0.4275
Average of % Carbs 11	0.089195	0.074794	1.19	0.2544
Average of % Fat 11	0.1511513	0.076696	1.97	0.0704

Recovery: N/A

Sluggishness:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-3.154116	4.443612	-0.71	0.4904
Average of Energy (kcal) 11	-0.000785	0.000735	-1.07	0.3047
Average of % Protein 11	-0.088243	0.070379	-1.25	0.2320
Average of % Carbs 11	0.0831326	0.051409	1.62	0.1299
Average of % Fat 11	0.1535833	0.052716	2.91	0.0121*

Fatigue: N/A

Sleep Quality: N/A

Soreness: N/A

Figure 21. Time Period 18 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 11 on wellness week 12.

Motivation: N/A
Stress: N/A
Satiety: N/A
Recovery: N/A
Sluggishness:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-24.25706	12.87475	-1.88	0.0862
Average of Energy (kcal) 12	-0.000133	0.000474	-0.28	0.7839
Average of % Protein 12	0.1368591	0.133484	1.03	0.3272
Average of % Carbs 12	0.2239415	0.125712	1.78	0.1024
Average of % Fat 12	0.4115523	0.135967	3.03	0.0115*

Fatigue: N/A
Sleep Quality: N/A
Soreness: N/A

Figure 22. Time Period 19 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 12 on wellness week 12.

Motivation: N/A
Stress:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-40.51348	22.2646	-1.82	0.1116
Average of Energy (kcal) 12	-0.001095	0.000897	-1.22	0.2618
Average of % Protein 12	0.3867827	0.229146	1.69	0.1353
Average of % Carbs 12	0.4695554	0.209545	2.24	0.0600
Average of % Fat 12	0.474999	0.24919	1.91	0.0983

Satiety: N/A
Recovery: N/A
Sluggishness: N/A
Fatigue: N/A
Sleep Quality: N/A
Soreness: N/A

Figure 23. Time Period 20 Results: Screenshot of model parameter estimates for all significant effects. This is the effect of nutrition week 12 on wellness week 13.

Appendix D: Stress Models

The following figures show just the time periods where stress impacts nutrition.

Total Calories: No Effect

Carbs:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	43.438471	3.677167	11.81	<.0001*
Average of Emotional Stress 3	-2.690213	1.331741	-2.02	0.0585

Protein: No Effect

Fat: No Effect

Figure 24. Time Period 1 Results: Screenshot of model parameter estimates for all significant effects of stress. This is the effect of stress on nutrition.

Total Calories:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2104.0466	144.631	14.55	<.0001*
Average of Emotional Stress 5	-116.3176	54.15874	-2.15	0.0464*

Carbs:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	48.767346	3.684935	13.23	<.0001*
Average of Emotional Stress 5	-3.24168	1.379866	-2.35	0.0312*

Protein: No Effect

Fat:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	32.047499	2.896527	11.06	<.0001*
Average of Emotional Stress 5	1.9428483	1.084638	1.79	0.0911

Figure 25. Time Period 5 Results: Screenshot of model parameter estimates for all significant effects of stress. This is the effect of stress on nutrition.

Total Calories: No Effect

Carbs: No Effect

Protein: No Effect

Fat:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	32.23856	2.169554	14.86	<.0001*
Average of Emotional Stress 5	1.7489055	0.83352	2.10	0.0503

Figure 26. Time Period 6 Results: Screenshot of model parameter estimates for all significant effects of stress. This is the effect of stress on nutrition.

Total Calories: No Effect

Carbs: No Effect

Protein:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	22.158931	1.30259	17.01	<.0001*
Average of Emotional Stress 8	-1.093459	0.545888	-2.00	0.0636

Fat: No Effect

Figure 27. Time Period 11 Results: Screenshot of model parameter estimates for all significant effects of stress. This is the effect of stress on nutrition.

Total Calories: No Effect

Carbs:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	42.317582	2.723784	15.54	<.0001*
Average of Emotional Stress 8	-2.004767	1.108119	-1.81	0.0881

Protein: No Effect

Fat: No Effect

Figure 28. Time Period 12 Results: Screenshot of model parameter estimates for all significant effects of stress. This is the effect of stress on nutrition.

Total Calories: No Effect

Carbs: No Effect

Protein: No Effect

Fat:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	29.733446	2.298338	12.94	<.0001*
Average of Emotional Stress 11	1.564231	0.771037	2.03	0.0635

Figure 29. Time Period 18 Results: Screenshot of model parameter estimates for all significant effects of stress. This is the effect of stress on nutrition.

Total Calories: No Effect

Carbs: No Effect

Protein: No Effect

Fat:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	29.986333	2.008495	14.93	<.0001*
Average of Emotional Stress 12	1.7405086	0.705827	2.47	0.0272*

Figure 30. Time Period 19 Results: Screenshot of model parameter estimates for all significant effects of stress. This is the effect of stress on nutrition.

Appendix E: Sleep Models

The following figures show just the time periods where sleep impacts nutrition.

Total Calories: No Effect

Carbs:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	52.559613	5.686016	9.24	<.0001*
Average of Sleep Quality 5	-2.78033	1.401512	-1.98	0.0637

Protein: No Effect

Fat: No Effect

Figure 31. Time Period 5 Results: Screenshot of model parameter estimates for all significant effects of sleep. This is the effect of sleep on nutrition.

Total Calories: No Effect

Carbs:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	50.494853	4.454114	11.34	<.0001*
Average of Sleep Quality 5	-3.017878	1.110523	-2.72	0.0141*

Protein:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	19.27187	2.802923	6.88	<.0001*
Average of Sleep Quality 5	1.2638667	0.698839	1.81	0.0873

Fat:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	27.401931	3.069099	8.93	<.0001*
Average of Sleep Quality 5	2.2527249	0.765204	2.94	0.0087*

Figure 32. Time Period 6 Results: Screenshot of model parameter estimates for all significant effects of Sleep. This is the effect of Sleep on nutrition.

Total Calories: No Effect

Carbs: No Effect

Protein: No Effect

Fat:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	33.253879	1.950225	17.05	<.0001*
Average of Sleep Quality 10	1.3050493	0.561852	2.32	0.0337*

Figure 33. Time Period 15 Results: Screenshot of model parameter estimates for all significant effects of Sleep. This is the effect of Sleep on nutrition.

Total Calories:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2292.9207	234.9153	9.76	<.0001*
Average of Sleep Quality 11	-137.5263	72.89873	-1.89	0.0818

Carbs: No Effect

Protein: No Effect

Fat: No Effect

Figure 34. Time Period 18 Results: Screenshot of model parameter estimates for all significant effects of Sleep. This is the effect of Sleep on nutrition.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This study uses multivariate analysis methods to find relationships between nutrition and wellness and nutrition and performance. The nutrition, daily wellness, and weight and bodyfat data are from a study performed by the STRONG lab in the 711th Human Performance Wing. Electronically collected nutrition data along with survey data for 19 individuals over a 12-week study period are examined with a focus on health, fitness, and nutrition. Factor analysis and linear regression are performed and inferences are drawn regarding what effects calories and macronutrient intake have on subjects perceived wellness, weight, and body fat percentage. These insights are discussed in the context of past studies and nutrition subject matter expert opinions. The findings indicate that an increase in total calorie intake is associated with increased motivation, stronger feelings of recovery, increased satiety, and increased body fat percentage. Increased stress and decreased sleep quality are associated with an increase in total calorie intake. An increase in total body weight is associated with an increased intake of fat and carbohydrates. Further conclusions and recommendations are offered.

15. SUBJECT TERMS

Performance monitoring, nutrition, wellness, multivariate analysis

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