Is It Possible to Satisfy the RDA?

Justin Sharber

9/10/2019

Executive Summary

The nutrient Recommended Daily Allowances (RDA) represent the U.S. government's recommendations for the daily intake of various nutrients. This report takes interest in satisfying RDA using natural foods and without the help of nutritional supplementation or fortification.

The report is an exercise in data analysis. It does not represent mature nutritional research, nor does it represent nutritional advice.

This project asks three questions:

1. Is it possible for a young man to satisfy is RDA across all nutrients in a natural, healthy way (without supplementation, etc.)? Or are some RDA set too high to be satisfied in this way?
2. What is the ideal diet of natural, healthy food toward meeting all RDA?
3. If a person follows the government's dietary recommendations, how close are they expected to come to satisfying the RDA?

An analysis of foods for nutritional value by calorie (or "nutrient density") finds that leafy green vegetables, mushrooms, and oysters to be the most nutritious. But in terms of nutritional value by mass, seafood, seeds, and nuts are the most nutritious.

The hypothesis was that it is *not* possible to satisfy all RDA under the given constraints. One nutrient, Fluoride, does prove impossible to meet. But on a diet of mainly high-nutrient vegetables, a person could well exceed their RDA for almost all other nutrients. Thus the hypothesis is rejected.

The report also constructs ideal diets for a few different types of diets (ex: vegetarian, vegan). It approaches the construction of the ideal diet as a special kind of knapsack problem, where the value function changes with each iteration of food choice. A Python class called a "Gut" is constructed for this purpose. An over-satisfaction factor is implemented to the value function to reign in the Gut's aggressive approach to eating mostly nutrient-dense vegetables.

This project generally supports the RDA as currently specified, as well as the MyPlate dietary recommendations. Eating a variety of natural foods shows to be a fairly successful strategy in meeting nutritional RDA.

Specifying the Problem

Background

Nutrients are substances used to fuel, build, and maintain the body. They fall into several categories. *Macronutrients* are the nutrients people need in large amounts: protein, carbohydrates, and fats. Fiber is a class of complex carbohydrates; it is not technically a separate macronutrient, but it does have a separate RDA, so is treated separately here. *Micronutrients*, vitamins and minerals, are only needed in small amounts. *Vitamins* are complex, organic compounds. *Minerals* are elements or inorganic compounds.

The U.S. government has made dietary recommendations to the public since 1894, and during World War II, the recommendations were first cast as RDA. RDA are set to meet the dietary requirements for 97% of the population. The calculation starts with the Estimated Average Requirement, the point at which 50% of the population shows some sign of deficiency. Nutrition scientists use a bell-curve model and add two standard deviations of intake to result in the RDA. (Smolin and Grosvenor, 34-8)

Nutrition science involves multiple layers of variability. One important variable is "bioavailability," the proportion of an ingested nutrient that the body absorbs and uses. For minerals, bioavailability varies by food, meal, and person. For example, minerals from animal sources are better absorbed than minerals from plants. If multiple minerals of similar kinds are ingested at the same time, they can compete for absorption. And the body can be selective about which minerals to absorb. (Smolin and Grosvenor, 442-3)

Data

This project will use the USDA National Nutrient Database for Standard Reference, Release 28. (My Food Data: Nutrition Facts Database Tools and

Spreadsheet) RDA values and calorie goal come from Smolin and Grosvenor (2013). A list of RDA is also available online, although several values differ (Health Supplements Nutritional Guide: Recommended Daily Allowances).

Caveats

This report is an exercise in data analysis. This project does not represent mature nutritional research, *nor does it represent nutritional advice*. This report's analysis of nutrients and ideal diet are based solely on the data.

Some nutrients have Upper Limits set as well, but this project will not factor these in. It will make some note that one can have too much of a nutrient, but rely on the RDA for a target.

Analyzing the Data

Curating the Data

The USDA's Standard Reference 28 dataset contains records for over 6,300 foods. Particularly for meats, the same basic food could have hundreds of different records, corresponding to different cuts and preparation methods, representing a fair amount of redundancy for the purposes of this project. The dataset also includes many foods that are not well suited for the project, including the following.

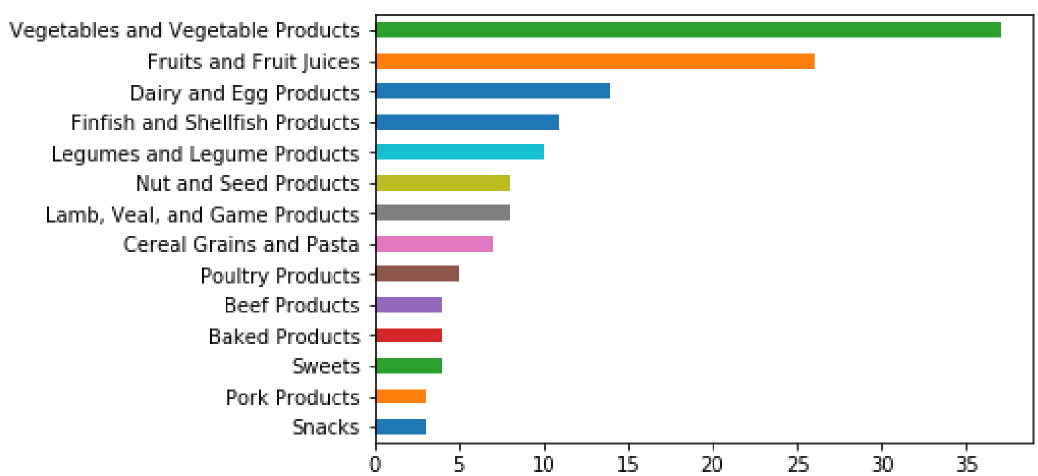
Example Food	*Problem*
Egg, whole, raw, fresh	– Inedible.
Dairy cream substitute, flavored, liquid	– Artificial.
Ice cream, soft serve, chocolate	– Not nutrient-dense, unnecessary.
Chili powder	– Cannot be eaten in significant portions, could skew results.
KRAFT FREE Singles American	– Name-brand, beyond scope.

It proved easier to choose good foods directly, rather than to develop rules that would filter out every unhelpful record. Thus, a subset of the foods was chosen on an individual basis. Foods were chosen on their most common preparation methods. For meats, baked or roasted preparations were preferred. Fruits were taken raw. Vegetables were taken raw, unless not usually eaten in that form; carrots were taken as raw, but broccoli was taken as cooked.

The curated subset contains 136 core foods. The vegetable and fruit categories represented the most real variety in food type—37 different vegetables were included. Out of 961 records for beef, 4 were selected:

- Braised beef brisket
- Braised arm pot roast
- Roasted bottom round
- Broiled top sirloin

The counts of food groups in the curated data set are shown below.



This project examines all nutrients that are both included as features in the SR28 dataset and have set RDA. There are 26 of these, below.

Nutrients in the Project	
Macronutrients	Protein, carbohydrates, fiber.
Vitamins	Vitamin A, thiamin (B1), riboflavin (B2), niacin (B3), vitamin B5, vitamin B6, folate (B9), vitamin B12, vitamin C, vitamin D, vitamin E, choline.
Minerals	Calcium, copper, fluoride, iron, magnesium, manganese, phosphorus, potassium, selenium, sodium, zinc.

Best Sources of Nutrients

The main questions of this project revolve around nutrient density: how much nutrition each food has, relative to the calories that food contains. Thus the analysis of nutrients will be in these terms.

Which foods are the best sources of each nutrient, per calorie? A table was generated connecting each nutrient to its best food source, below.

The best source for protein per calorie is haddock. Raspberries provide the most

ple nutrients. Clearly the property of

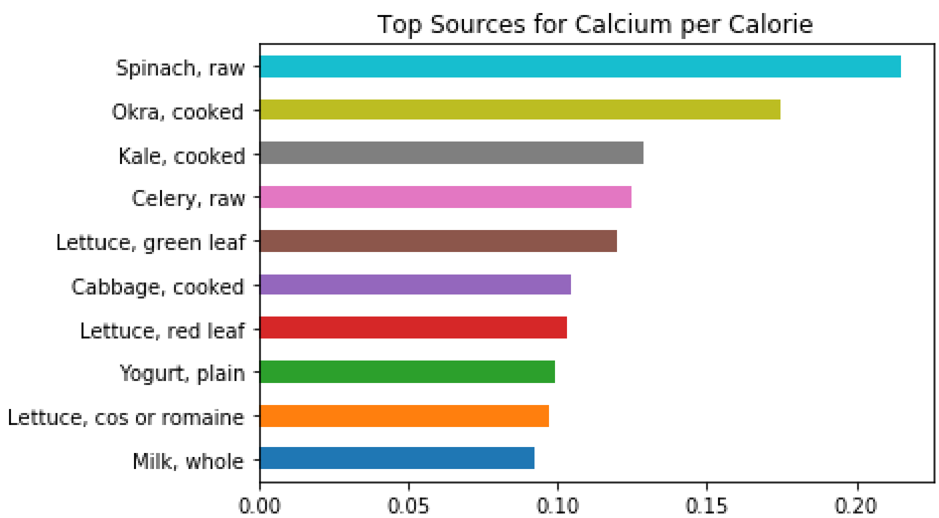
nly spread across foods. Just 5 foods

utrients, shown below.

Best Sources of Nutrients						
Nutrient	Food	Proportion RDA		Nutrient	Food	Proportion RDA
Protein	Fish, haddock	0.2		Vitamin A	Lettuce, cos or romaine	8.54
Carbohydrates	Limes, raw	0.14		Vitamin B1	Asparagus, cooked	0.31
Fiber	Raspberries, raw	0.16		Vitamin B2	Mushrooms, white	0.41
Calcium	Spinach, raw	0.22		Vitamin B3	Mushrooms, white	0.5
Copper	Mushrooms, morel	1.12		Vitamin B5	Mushrooms, white	0.77
Fluoride	Asparagus, cooked	0.01		Vitamin B6	Okra, cooked	0.33
Iron	Mushrooms, morel	2.46		Vitamin B9	Spinach, raw	1.05
Magnesium	Spinach, raw	0.43		Vitamin B12	Mollusks, oyster	6.41
Manganese	Spinach, raw	0.85		Vitamin C	Peppers, sweet	1.48
Phosphorus	Mushrooms, morel	0.45		Vitamin D	Mushrooms, morel	0.55
Potassium	Spinach, raw	0.26		Vitamin E	Spinach, raw	0.29
Selenium	Mollusks, oyster	0.89		Choline	Egg, whole	0.17
Sodium	Asparagus, cooked	0.36				
Zinc	Mollusks, oyster	2.6				

Best Source Foods	
Spinach, raw	6
Mushrooms, morel	4
Mushrooms, white	3
Mollusks, oyster	3
Asparagus, cooked	2

The top sources for calcium per calorie are shown below. Milk may be a tasty source of calcium, but per calorie it falls well below other sources.



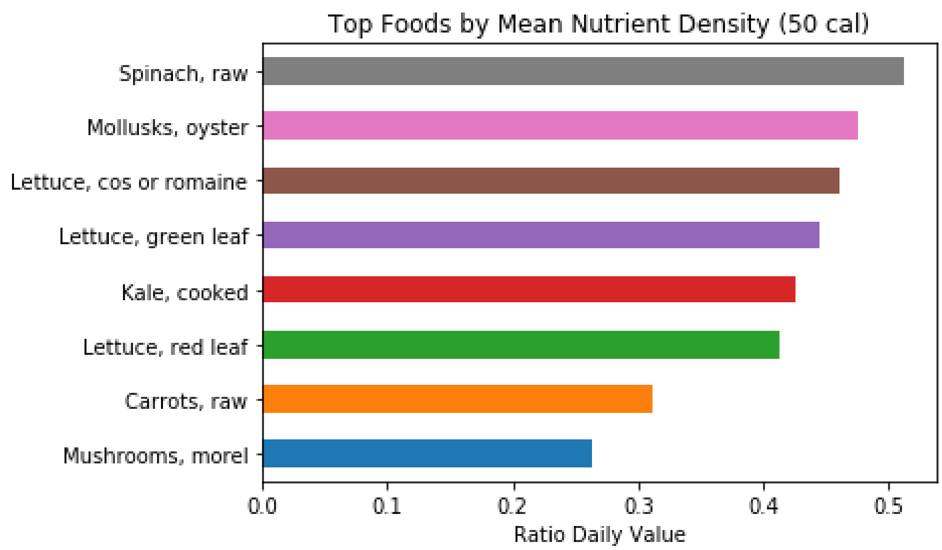
The most difficult nutrient to find naturally is Fluoride. Asparagus is the best source for this nutrient, but a decent portion of 50 calories only provides *1%* of the RDA.

The Most Nutrient-Dense Foods

Which foods are the most nutrient-dense? For this analysis, a serving size of 50 calories was chosen, or about an egg's worth of calories (60). Proportions of

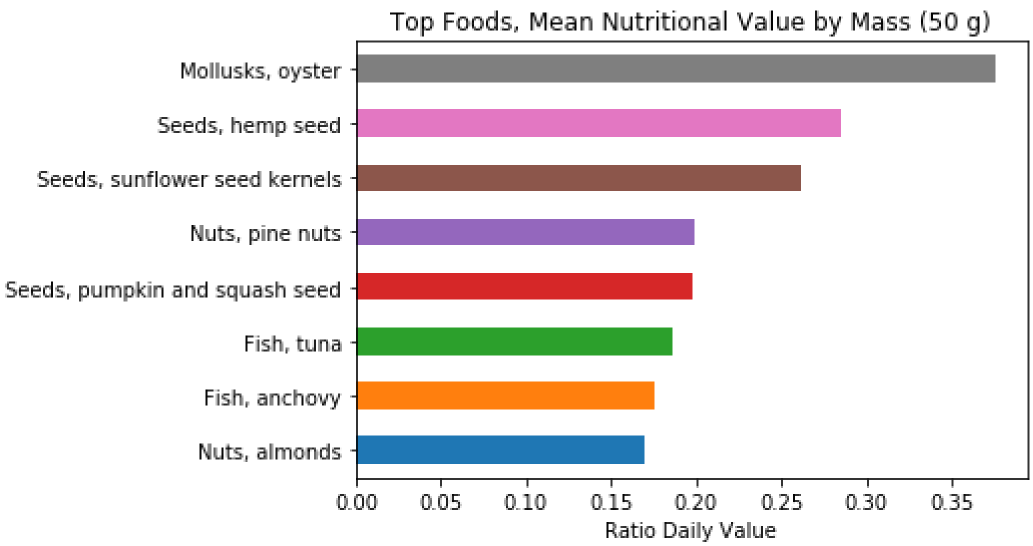
RDA values were tallied for all nutrients without weights. This is to say, all nutrients were treated as equal: selenium had the same import as protein.

The top eight most nutrient-dense foods are shown below. Of these top foods, most are vegetables. Five of the top eight foods are leafy greens. Only one food is an animal.



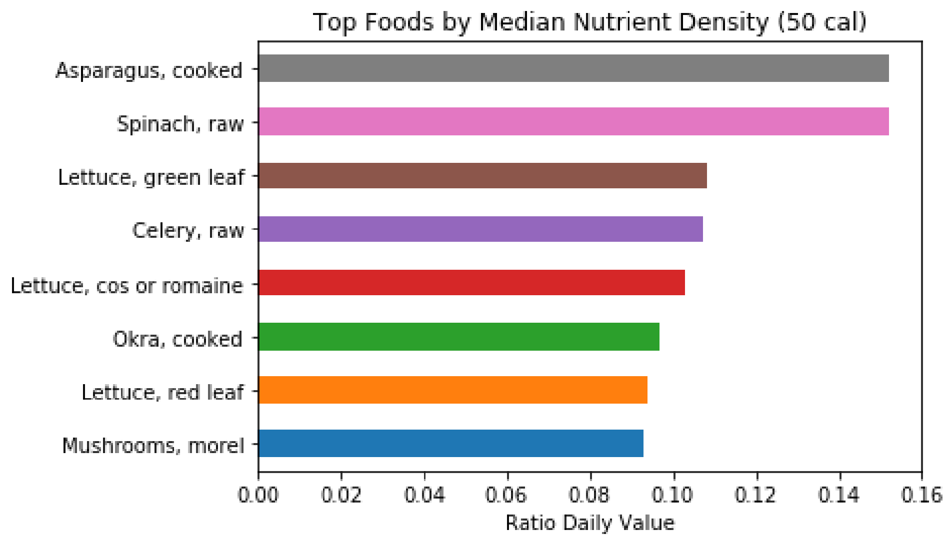
50 calories of spinach provides a huge amount of nutrition with an average of 51% of the RDA across nutrients. But one should note that, given that spinach is a low-calorie food, this is a large helping—about 5 cups chopped.

The prominence of vegetables in this ranking can be attributed to two factors: vegetables are high in nutrients, and they are also low in calories. While nutrient density is the operative notion for this project, it may be helpful to compare this to nutritional value by mass. This ranking is shown below.



This is a very different list. Here the most valuable foods are seafood, seeds, and nuts. Only one food, oysters, appears in both lists.

A potential problem with ranking foods by density is skewness. The top foods tend to have skewed distributions of nutrients: very high amounts in a few nutrients, modest or low values in the rest. In this case, the median can be a more helpful sense of "average" than the mean. The most nutrient dense foods by median are shown below.



The median nutrient densities are much lower than mean, signaling the skew of the nutritional profiles. But the ranking is quite similar, with spinach is still tied for first. The one animal has fallen from the list, leaving only plants and mushrooms.

In the next section, this project will attempt to determine whether all RDA are satisfiable based on natural foods by simulating an idealized diet. Based on this analysis, we would expect vegetables to be the first choices in that diet, and they will be.

Is it Possible to Satisfy All RDA?

Hypothesis

Our ancestors, from cavemen to the people of the 19th Century, should have been able to get all the nutrition they needed from the foods available. If the RDA are appropriately set, if they are correct, then it should be possible to satisfy them with natural foods alone. Let *natural food* denote any food that is grown or raised on a farm, or produced with parochial technology from other natural foods. Thus chicken, apples, and pasta are natural foods, but soda and cheese puffs are not.

The term “natural foods” excludes two groups of nutrition, broadly construed. One is supplements, which includes nutrient supplements like vitamin pills, and foods artificially enriched with nutrients, such as many breakfast cereals. Supplements make it trivial to satisfy the RDA, as a multivitamin contains 100% or more of the RDA for many nutrients. The other group is junk foods. Because junk foods are very low on nutrition, including them would make little difference except to increase the range of foods that would have to be considered. But either way, they do not count as “natural” in the definition of this project and do not need consideration. In short, “natural foods” exclude enriched foods because they could make satisfying the RDA too easy, and junk foods because they will not help.

This project selects a moderately active 28-year-old male of healthy weight as its abstract test subject. The average calorie need per day for this subject to maintain weight is 2600. (Smolin and Grosvenor, 47) The subject is further specified as 5’11” and 160 lb.

Subjectively, this author is suspicious of RDA values. They seem too high, with foods often being counted as good or excellent sources of a nutrient while providing a small fraction of the RDA. Also, despite a thoroughgoing scientific basis for RDA, the specification of these values does not entail that all RDA can be satisfied at the same time on the basis of natural foods. Thus, this project’s hypothesis is framed in the negative.

Basic Hypothesis	It is not possible for a 28-year-old male to satisfy all his nutritional RDA on the basis of natural foods at a maintenance calorie intake.

Methodology

In terms of data science, the question of whether a person can satisfy their RDA within a calorie limit is a complex version of the knapsack problem. The basic knapsack problem takes the paradigm of trying to pack a knapsack with valuable things, like gold nuggets and computer chips. The goal is to maximize the value of the knapsack (i.e. its contents) within limited space or weight. This problem is relatively simple. It has a single variable for cost (space or weight), and a single variable for value (price). Both variables remain fixed for each item and never need to be recalculated.

But with the current problem, there are many factors (different nutrients) that contribute to the nutritional value of a food and must be combined explicitly. More importantly, the value of eating a food depends on what nutrients have already been consumed. The value of a nutrient is small or zero once the RDA for that nutrient has been satisfied.

These differences complicate the project over a basic knapsack problem. Overall value is dynamic. But the relative value of a food changes depending on the contents of the "gut." Thus, the value of each food must be recalculated continually throughout the process.

A Python class called a “Gut” was created for the purpose of running the backpack analysis. For each iteration, the Gut evaluates all foods for which has the highest nutritional value for it at that stage, relative to the nutrition the gut already contains. Every time the Gut eats a food, it adds the food’s name, its nutrients, and its calories as contents. In the next iteration, the balance of nutrients will have changed, and the “Gut” must re-evaluate foods to decide which to add next.

A serving size of 50 grams was chosen for all foods, about the mass of a medium egg.

Testing the Hypothesis

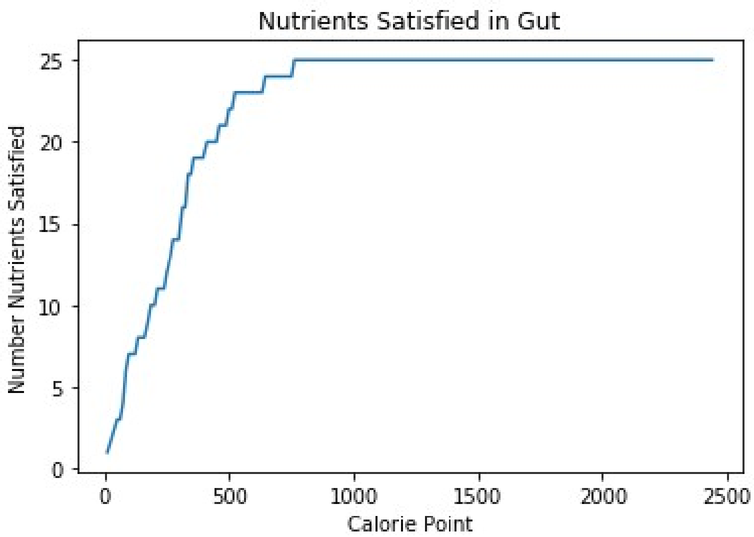
On the initial run of the Gut, almost all nutrients *were satisfied* on the basis of the curated set of natural foods. Only one, Fluoride, was not. The median satisfaction of nutrients was 7.68 RDA values, over 7 times the required amount.

The Gut started with spinach, oysters, and mushrooms. But at some point, the Gut started eating asparagus and nothing else. The disconcerting diet is summarized below, in servings of 50 grams.

Food	Servings
Asparagus, cooked	173
Spinach, raw	17
Cauliflower, raw	10
Mushrooms, morel	9
Mushrooms, white	3
Raisins, seedless	1
Mollusks, oyster	1

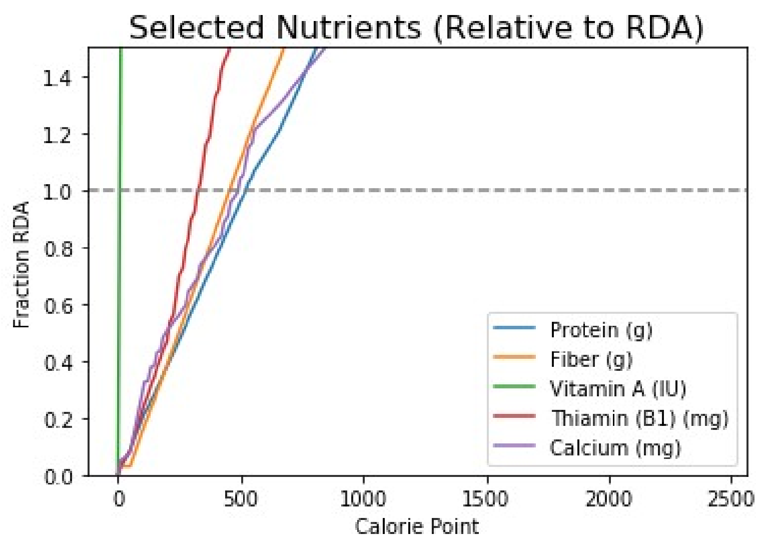
The Gut consumed about 8.5 kilograms, or 19 pounds, of cooked asparagus. Nobody wants that.

One would expect more variety in the diet. However, there is a reason for this behavior. The Gut satisfied *all other nutrients* at only 760 calories (shown below). From that point on, it devoted its attention obsessively to maximizing Fluoride.



Asparagus is the best source of Fluoride per calorie, but only provides *1%* of RDA in a significant, 50-calorie serving. The value function for this version of the Gut is rather basic; it focuses only on maximizing unsatisfied nutrients. With no other goals, the Gut obsessively ate asparagus until it had filled its calorie goal.

Several key nutrients were chosen to show a profile for the Gut's progress over time. The initial plot treats the RDA as a ceiling. But with a diet of vegetables, the Gut's nutrients quickly go off the chart. In particular, the Gut's RDA for vitamin A is satisfied in the first 12 calorie snack; this nutrient is shown only as a vertical line.



The Gut's nutrient levels at the end are impressive, even for nutrients with the lowest levels of satisfaction. It satisfied almost half of its requirement for Fluoride. It satisfied roughly 1.5 times its requirement for vitamin D, 3 times the requirement for calcium, and 4.5 times its requirement for protein (almost solely on vegetables). Its most over-satisfied nutrient was vitamin A, 53 times the RDA.

Technically, the hypothesis is falsified by the one outstanding nutrient. But for all intents and purposes, the hypothesis is wrong. If calories are the only limitation, the RDA for almost all nutrients is easily achievable on the basis of natural foods. Thus the best *representation* of the results is a rejection of the hypothesis.

Basic Hypothesis: Rejected	
Median Nutrient Satisfaction	7.7
Unsatisfied Nutrients	1 / 26

The Ideal Diet, By the Numbers

Eating 19 pounds of asparagus is hardly ideal. This report will move on to two follow-up questions.

1. Can a more realistic and balanced diet be achieved on the numbers alone, particularly by adjusting the Gut's value function?
2. How realistic is it for a person to satisfy their RDA with less calculated, more random eating?

The Value Function

The basic implementation of the Gut had two shortcomings.

1. The Gut will stop at nothing (short of the calorie goal) to try to satisfy an outstanding nutrient, even eating one food (the asparagus) in huge amounts.
2. Instead of getting too little of many nutrients, the Gut actually gets far too much. Getting several times the RDA for some nutrients is no problem, but a median satisfaction of over 7 times the recommended amount is probably too high.

In fact, both of these shortcomings can be solved with one feature: penalizing over-satisfaction. The basic value function of the Gut places no penalty on taking in more of a nutrient than is required. Penalizing over-satisfied nutrients naturally solves the second problem.

One could solve the first problem of obsessive eating with a separate factor, penalizing foods that have been eaten previously. But penalizing over-satisfaction also steers the Gut *away from* nutrient dense foods as the Gut's nutrients fill up. In turn, this tends to solve the first problem anyway.

Two parameters were added to the Gut to penalize over-satisfaction. The first is a *target factor*. The target factor specifies what proportion of the RDA is considered ideal. 1.0 times the RDA (or 100%) is the natural choice, but raising that ceiling a little to 1.5 gives the Gut some wiggle room in satisfying nutrients.

The second parameter is an *over-satisfaction factor*, specifying the penalty for over-satisfying nutrients. An over-satisfaction factor of 1.0 means that the Gut penalizes over-satisfaction the same as under-satisfaction, and treats getting too much as just as bad as getting too little. An over-satisfaction factor of 0 means the value function places no penalty on over-satisfied nutrients—this is equivalent to the original hypothesis test.

Various over-satisfaction factors were tested, and 0.1 seemed the best overall: dramatically reducing over-satisfaction while maintaining the highest number of satisfied nutrients.

The Ideal Diet, By the Numbers

The "Ideal Diet" presented here is the best diet this project can produce. It is intended to maximize nutrient satisfaction, based solely on the data provided and a knapsack methodology with a "greedy" algorithm. With a target of 1.5 times the RDA for nutrients and an over-satisfaction factor of 0.1, the Gut chose a diet which is summarized below. With this diet, the median nutrient satisfaction was dramatically reduced to 2.5 times the RDA, while Fluoride remained the only unsatisfied nutrient.

The Ideal Diet			
Food	*Serv.*	*Food*	*Serv.*
Turnips, cooked	9	Mushrooms, morel	2
Honey	8	Mushrooms, Chanterelle	2
Okra, cooked	8	Nuts, almonds	1
Asparagus, cooked	7	Pork, cured	1
Mushrooms, white	4	Mollusks, oyster	1
Spinach, raw	3	Fish, salmon	1
Artichokes, (globe or french)	2	Broccoli, raw	1
Pickles, cucumber	2	Egg, whole	1
Cauliflower, raw	2		

This ideal diet shows more variety than that from the basic hypothesis test. There is a wider variety of vegetables, and the Gut enjoyed small helpings of pork, egg, fish, and nuts.

At the outset, the Gut eats exactly what we would expect given the nutritional analysis earlier: a mix of spinach, oysters, asparagus, and mushrooms, alternating frequently between them as one or the other as the relative importances of the nutrients shift.

The Gut exhibits four big phases of eating foods.

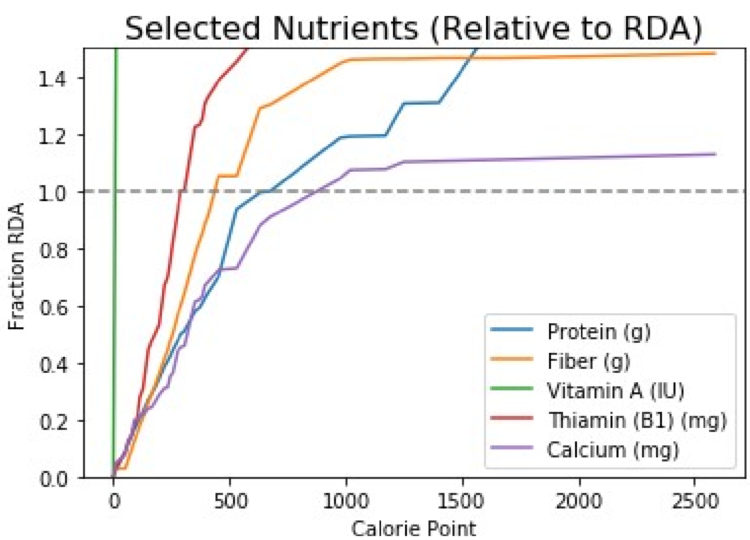
1. 0 – 230 calories: A mix of spinach, asparagus, oysters, and mushrooms.
   Mean relative nutrient density for spinach against 50 calories: 51% RDA.

2. 230 – 350 calories: Mostly okra.
   Mean density for okra: 13%.

3. 530 – 630: Mostly turnips, with pickles and almonds.
   Mean density for turnips: 5%.

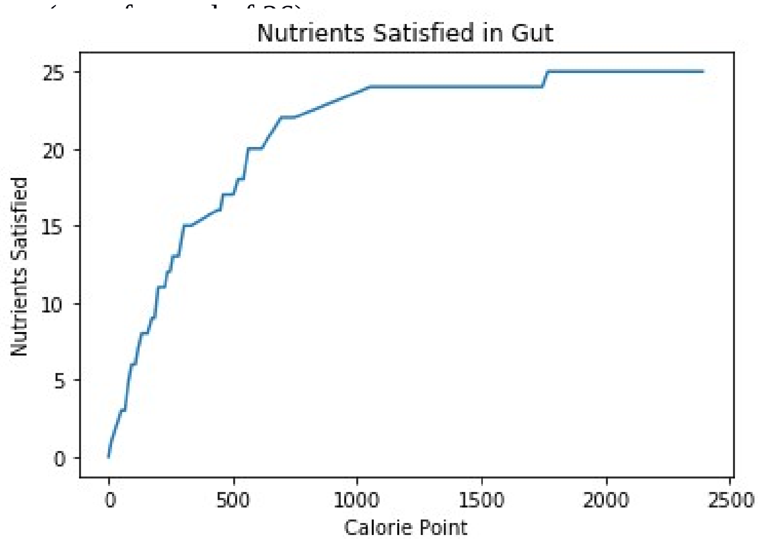
4. 1020 – 2600: Mostly honey, with a piece of pork and an egg.
   Mean density for honey: 1%.

As the Gut satisfies more nutrients, it chooses foods with complementary nutritional profiles and with less nutrition overall. At the end of the diet, the Gut takes in honey, which very low nutrient density, effectively filling out its calories to round out the diet.



Plotting selected nutrients shows the Gut's nutrients growing more slowly, and some successfully leveling off near their RDA limits.

Nutrient satisfaction grows more slowly than in the basic version. It still plateaus at 25 nutrie



The "Ideal … r, it could be improve … satisfaction … the beginning, … stead, if the Gut we … diet, it may satisfy … d diet. The diet wi … e seen. But the nex … proach.

Project "Ideal Diet"	
Median Nutrient Satisfaction	2.5
Unsatisfied Nutrients	1 / 26

MyPlate Eating Recommendations

As previously noted, this project's Ideal Diet does not show much variety, and does not look too appetizing. But nutrition scientists and the US government make much more relaxed dietary recommendations. The government's recommendations used to be summarized by the Food Pyramid, and are now available on ChooseMyPlate.gov. By modifying the Gut class, this project can simulate the effect of randomized eating within those guidelines. How nutritious a diet does this recommendation produce?

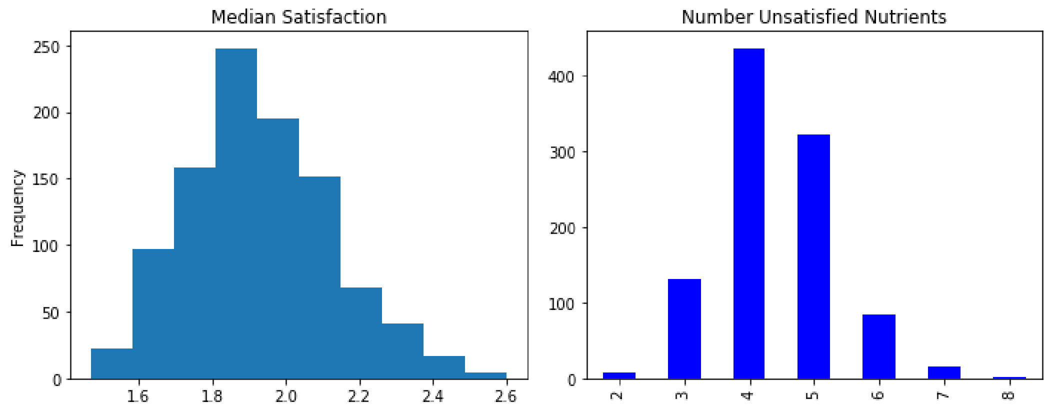
This project's abstract subject is 5'11", 160 lb, and moderately active. The dietary recommendations have their own set of serving sizes, and need to be taken with some modification for this project. This project converts the servings given into the best equivalents in terms of calories. Fruits and vegetables offered some ambiguity into translating into calories; they were given higher calorie counts rather than lower to give the MyPlate recommendations their best chance at success. The original recommendations and the adaptation for this project are given below.[1]

1 For convenience, this project keeps eggs grouped with dairy following SR28, while MyPlate groups them with proteins. The impact on results should be minor.

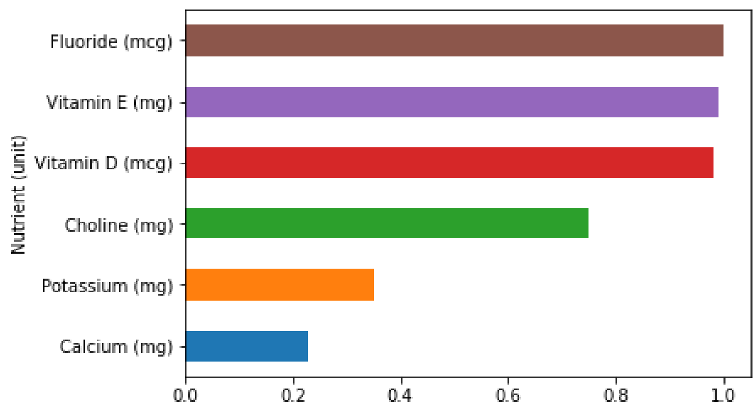
Food Group	MyPlate Servings	Conversion to Calories
Fruits	2.5 cups	300
Veggies	3.5 cups	150
Grains	10 ounce equivalents	1100
Protein	7 ounce equivalents	400
Dairy	3 cups (equivalents)	450
Treats	(None)	200

A new version of the Gut class, RandomGut, was written to simulate a person following these recommendations, choosing from the curated set of foods at random, in serving sizes of 50 calories. In the simulation, the Gut first eats from the fruit group, choosing fruits at random until it has had the recommended amount or more (here, 300 calories). It then moves through the subsequent food groups this way until reaching "Snacks," finishing out the remaining calories.

The RandomGut was simulated 1000 times, with surprisingly good results. The average of the median RDA satisfaction across simulated instances was 1.93, a good level of satisfaction seeming to be too high. The average number of unsatisfied nutrients was 4.4, higher than the ideal diet. But out of a total of 26 nutrients, this represents over 80% satisfaction of the RDA. The frequencies for median satisfaction and unsatisfied nutrients are shown below.



Six nutrients went unsatisfied any significant frequency: vitamin D, vitamin E, choline, calcium, potassium, and fluoride (of course). Some of these nutrients are anticipated by nutritional science. A DRI workshop listed vitamin D, vitamin E, and potassium among the "unrealistic nutrients" which very few Americans meet the RDA. (Sheffer and Taylor, 17) The rates of various nutrients going unsatisfied are shown below.



It is impressive that eating according to recommendations, without specifically trying to eat the optimum diet, achieves such a high level of RDA satisfaction. The result shows that either the RDA or the guidelines are imperfect, but generally supports the nutritional advice provided by MyPlate.

Random eating based on MyPlate	Averages
Median Nutrient Satisfaction	1.93
Unsatisfied Nutrients	4.4 / 26

Summary

This project has produced happy results. It finds that the RDA are generally satisfiable based on natural foods alone. It also finds that the USDA's MyPlate dietary recommendations do a fairly good job in satisfying RDA.

This project has a companion Jupyter Notebook on GitHub where the reader can review more analyses of the data. The reader can choose foods to analyze, choose nutrients and show their top sources, and run simulations of eating according to the MyPlate recommendations.

References

ChooseMyPlate.gov. (2019). The USDA. Online at https://www.choosemyplate.gov.

Health Supplements Nutritional Guide: Recommended Daily Allowances. (2017). Online at https://tools.myfooddata.com/nutrition-facts-database-spreadsheet.php.

My Food Data: Nutrition Facts Database Tools and Spreadsheet. (2019). Online at https://tools.myfooddata.com/nutrition-facts-database-spreadsheet.php.

Smolin and Grosvenor. (2013). *Nutrition: Science and Applications* (Third Edition). Wiley.

Sheffer and Taylor. (2008). *The Development of the DRIs, 1994-2004, Lessons Learned and New Challenges*. Workshop Summary. Online at https://www.nap.edu/read/12086.