SUPPORTING LARGE-SCALE NUTRITION ANALYSIS BASED ON DIETARY SURVEY DATA

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ABSTRACT

While online survey systems facilitate the collection on copious records on diet, exercise and other health-related data, scientists and other public health experts typically must download data from those systems into external tools for conducting statistical analyses. A more convenient approach would enable researchers to perform analyses online, without the need to coordinate additional analysis tools. This paper presents a system illustrating such an approach, using as a testbed the WAVE project, which is a 5-year childhood obesity prevention initiative being conducted at Oregon State University by health scientists utilizing a web application called WavePipe. This web application has enabled health scientists to create studies, enrol subjects, collect physical activity data, and collect nutritional data through online surveys. This paper presents a new sub-system that enables health scientists to analyse and visualize nutritional profiles based on large quantities of 24-hour dietary recall records for sub-groups of study subjects over any desired period of time. In addition, the sub-system enables scientists to enter new food information from food composition databases to build a comprehensive food profile. Interview feedback from novice health science researchers using the new functionality indicated that it provided a usable interface and generated high receptiveness to using the system in practice.

KEYWORDS

Diet and nutrition, Information management and analysis

1. INTRODUCTION

To study diet, health scientists have increasingly turned to surveys and supporting software, including government-supported and commercial systems [16][17][22]. Online collection of survey data has grown in prominence because it enables researchers to reach a large audience cost-effectively [6]. Having collected surveys, however, scientists need to use the data. In this sense, health scientists studying diet face an analogous challenge to that of researchers in other fields of health science, where the rise of “big data” demands making sense of vast quantities of information in hopes of improving outcomes and reducing healthcare costs [15][18].

In the case of scientists studying nutrition, the problem is therefore to find a way of helping them to process large-scale datasets from dietary surveys. A common solution in other areas of health science and healthcare has been to provide interactive visualization methods that aid in exploring and understanding the data [14][19]. The most effective of these visualizations reflect the specific characteristics and nature of the phenomena that they represent. For example, Shneiderman et al have discussed how a visualization of pharmacy data in the EventFlow system revealed crucial insights into patterns of drug use [19]; that particular visualization accommodated the temporal nature of the events visualized. Likewise, a tool for analysing diet datasets should take into account the multi-dimensional aspects of the data including (but not limited to) the temporal nature of food consumption and the relationships among food types, serving sizes and nutrient composition. In this sense, diet is “more than just data”—it shapes the very structure of the problem and, thus, should shape the design of the solution. Unfortunately, researchers interested in studying diet and nutrition currently lack access to such systems for analysing and visualizing large datasets, thus leaving the problem faced by these scientists unsolved.

The WAVE project illustrates this problem and offers a venue for exploring a solution. This is an integrated project (Research, Education, and Extension) involving active teens ages 15-19 in

DOI: 10.5121/hiij.2017.6101

Oregon [24]. The goal is to teach life skills (such as gardening, food preparation, and food preservation skills) in addition to nutrition and physical activity education to support sustainable healthy eating and adequate physical activity among 4-H soccer team players. The project will develop, evaluate, and compare the effectiveness of virtual- and real-world learning environments in reducing unhealthy weight gain and sedentary lifestyle among active youth. Primary caregivers will also receive supplemental lessons to promote learning at home. The two-year pilot study will involve dozens of parent-child pairs, and the two-year intervention will involve hundreds of parent-child pairs. A wide variety of outputs and outcomes are planned to be measured, including BMI, tracking devices, smart phone Apps, food intakes, physical activity levels, and questionnaires. Awards will be presented at the end of the interventions for the healthiest teams. It is expected that teens will be motivated to achieve/maintain healthy lifestyles to prevent unhealthy weight gain.

Among other objectives, this project aims to explore the nutritional profile of subjects, as well as the food sources of nutrients. For example, research questions can include “How much caffeine are subjects consuming and in what forms?” and “To what extent did dietary profiles change after subjects engaged in a targeted educational intervention?” Answering questions like these has historically required exporting the dietary recall records from the online survey system, which is called WavePipe, into separate statistical analysis tools.

Consequently, this paper presents a new WavePipe sub-system enabling scientists to analyse the 24-hour dietary recall data, input new food composition datasheets, and visualize the nutrient analysis in a report, without ever leaving the integrated online data management system. This new software thus illustrates a means of providing diet and nutrition researchers with a seamless, clear, and straightforward process for answering questions like those noted above.

2. BACKGROUND AND REQUIREMENTS

The WAVE project provides a suitable context for exploring how an online information management and analysis sub-system could aid in the collection and analysis of dietary recall records. It a multidisciplinary childhood obesity prevention study conducted at Oregon State University to study whether mixed-reality experiential learning involving virtual world immersive environments are feasible to prevent childhood obesity in high school athletes [24].

WavePipe is the online system used within this project to enable the health scientists to define studies, to enrol subjects, to assign subjects to groups, and to gather data. Of principal interest with respect to the current paper, these data include 24-hour dietary recall data collected via a survey based on the Automated Multiple-Pass Method (AMPM) developed by the USDA [16]. This multi-stage survey provides memory cues and multiple prompts to aid subjects in accurately recalling the foods that they consumed in the preceding 24-hour period [4][12][21] (Table 1). WavePipe has provided functionality for collecting survey data via a web browser, as well as for emailing each subject a link to the survey.

Table 1. Stages of WavePipe’s existing dietary recall survey

AMPM stage	Application in WavePipe surveys
Quick List: User chooses foods from a list	Search interface where users can find and choose food items that they consumed the previous day
Forgotten Foods: User reviews, chooses from oft-forgotten foods	List of beverages and other foods that users review and may check off, selecting additional items consumed
Time and Occasion: User specifies time and meal of each food item	Omitted due to lack of need for these data to answer the specific research questions of this particular project
Detail Cycle: User enters quantity of each item	User selects a unit of measure for each food item (e.g., 1 cup, or 1 ounce) and enters a count for that item
Final Probe: Final prompt to remember forgotten foods	Prompt to reconsider if user wishes to go back and enter data on foods eaten in transit, in meetings, while shopping, at snacks, or other oft-forgotten occasions

The system generates copious amounts of data. For example, a study spanning 2 years could involve sending the survey to each of 720 subjects for 7 days at the end of each quarter in each year (e.g., to coincide with the end of various educational interventions). Such a study would thus yield over 40,000 dietary recall records. Each subject might consume 10 different foods across the meals of each day, and the researcher might be interested in 10 or more distinct nutrients across these foods. Thus, the analysis could involve 400,000 incidents of food item consumption and over 4 million specific values indicating the quantities of nutrients consumed.

With existing software, the process that food scientists would have to go through in order to analyse data is tedious and time consuming. The scientist would have to download the dietary recall record and then analyse the nutrient intake with existing analysis tools (e.g., [13] and [22]). The existing nutrient analysis software (as discussed by Section 6 in more detail) lacked the functionality to analyse the dietary data of *multiple* subjects over a duration of time. Thus, the scientist would need to export subjects' dietary records, manually load each of the 40,000 or more records into the nutritional analysis tool, and then collect the results into a database for statistical analysis. This cumbersome process would not only be too time-consuming for large-scale studies of the type envisioned in the WAVE project, but it also is fraught with opportunities for user error. These considerations led to the requirement for streamlining this process by enabling scientists to conduct analyses within the survey-collection system.

An integrated solution can also provide a means of coping with the diversity of foods consumed by subjects as well as changes in the nutritional content of foods. The USDA National Food Database can be used (as in [13] and [22]) for the analysis of AMPM 24-hour dietary recall data [16], but this database is typically updated every two years [8]. In the interim, new foods become available but are not reflected in food tracker databases. To compound this issue, foods are constantly being reformulated, removed from the market, or replaced with new offerings [2]. Regionally unique foods and ethnic imports further increase the likelihood that food items may be missing in standard databases. Consequently, online analysis of dietary recall data requires a means whereby scientists can upload and modify food profiles indicating information about the nutritional content of food as it becomes available.

3. SOLUTION

This section describes the new sub-system, which has two components. The first is the Diet Analysis component, which enables scientists to access dietary recall records collected with the WavePipe system and to visualize the nutrient profile of the foods. These analyses are configurable, enabling scientists to narrow their analyses to selected nutrients, date ranges, and groups of subjects, thereby directly addressing questions like those mentioned above. The new sub-system's second component allows scientists to extend the database with information about new or modified food items, thereby achieving a more comprehensive food composition database.

3.1. Analysing nutrient profiles

Once the AMPM 24-hour dietary recall survey responses are collected, the scientist can go to the study in the WavePipe web application and click on a new option called "Food Nutrition Analysis." Clicking the option prompts the scientist to enter the start date, end date, and the study group that the scientist is interested in analysing (Figure 1). These dates would typically indicate a range of time over which the scientist had conducted a particular intervention.

The tool then takes the scientist to a page for selecting a list of nutrients to be analysed. The list of 39 distinct nutrients for the scientist to select is fairly long, so they are grouped by water, energy, macronutrients, vitamins and minerals, to avoid overwhelming the user (Figure 2). The list of nutrients is that provided by the SR27 USDA National Database.

On clicking the "Save Nutrients" button, the scientist is taken to the screen where the nutrient data for all the foods, consumed by the subjects in the study group, are displayed (Figure 3). The first column contains all the distinct foods that were consumed by the subjects in the study. The first row in the report contains the names and amount of all the nutrients that the scientist selected in the previous step.

The nutrient data in this table is an aggregate of the foods consumed by the subjects. If multiple subjects in the study consumed the same food, the gram weight for each serving size is obtained, and multiplied with the nutrient concentration for the food. These numbers are added together to obtain a single nutrient value for the food. If the food does not contain a nutrient value in the database (missing value), it is displayed as "null" in the table.

Finally, the sub-system generates a report providing a table for each nutrient previously selected by the scientist (Figure 4). Each nutrient table contains three columns. The first column contains the names of the foods consumed by the subjects in the study. The second column contains the nutrient content of the food. The third column contains the percentage that the food contributes to the total consumption of that nutrient by the group. All the percentages in the third column add up to a 100% so that the scientist view the nutritional percentage breakdown of each food.

This functionality illustrates a concise, integrated approach for directly answering research questions about nutritional profiles without imposing the need for laborious reliance on external tools. The report directly depicts answers to questions about where subjects are getting nutrients of interest. In addition, by comparing answers for different groups of subjects or for a given group of subjects across different date ranges, scientists can see how these nutritional profiles vary as a result of education or other interventions.

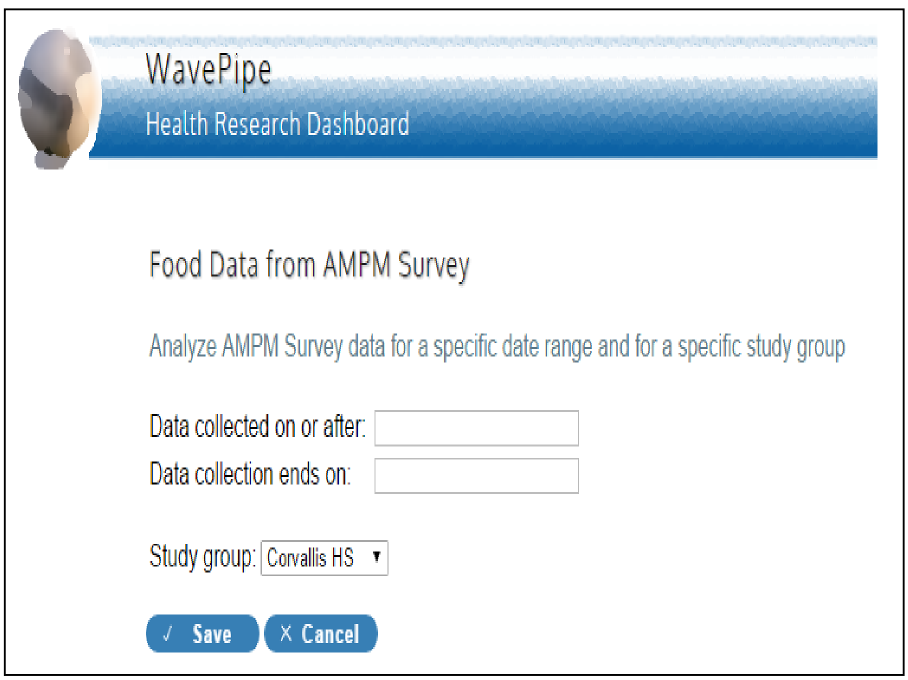


Figure 1. Selection of a date range and subject group within the web application

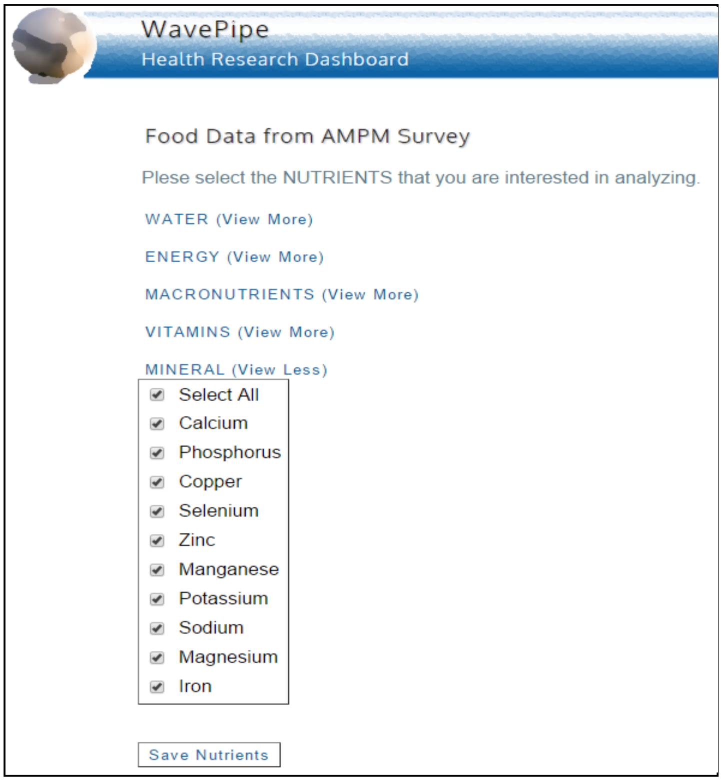


Figure 2. Selection of nutrients to analyse

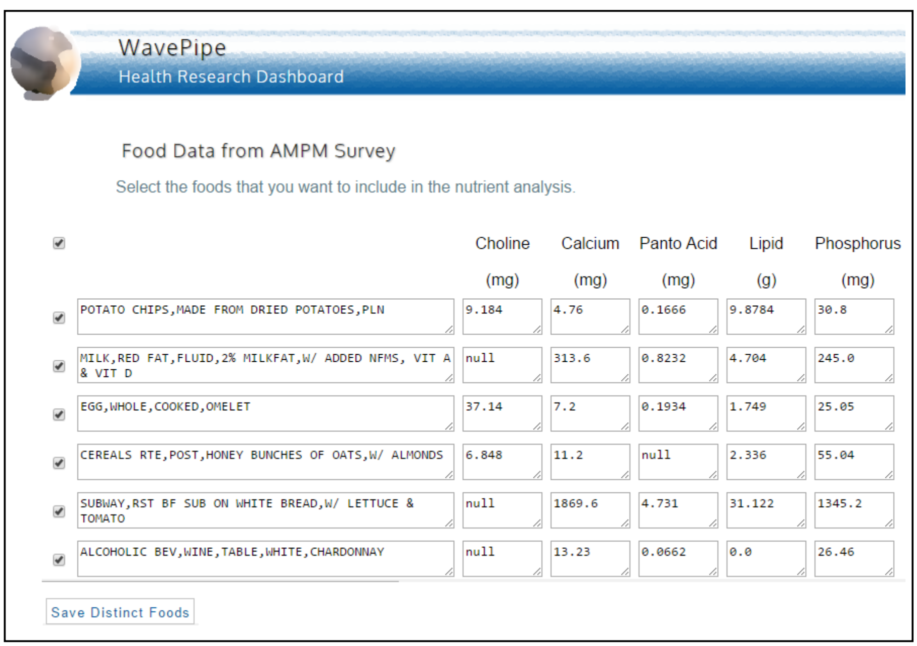
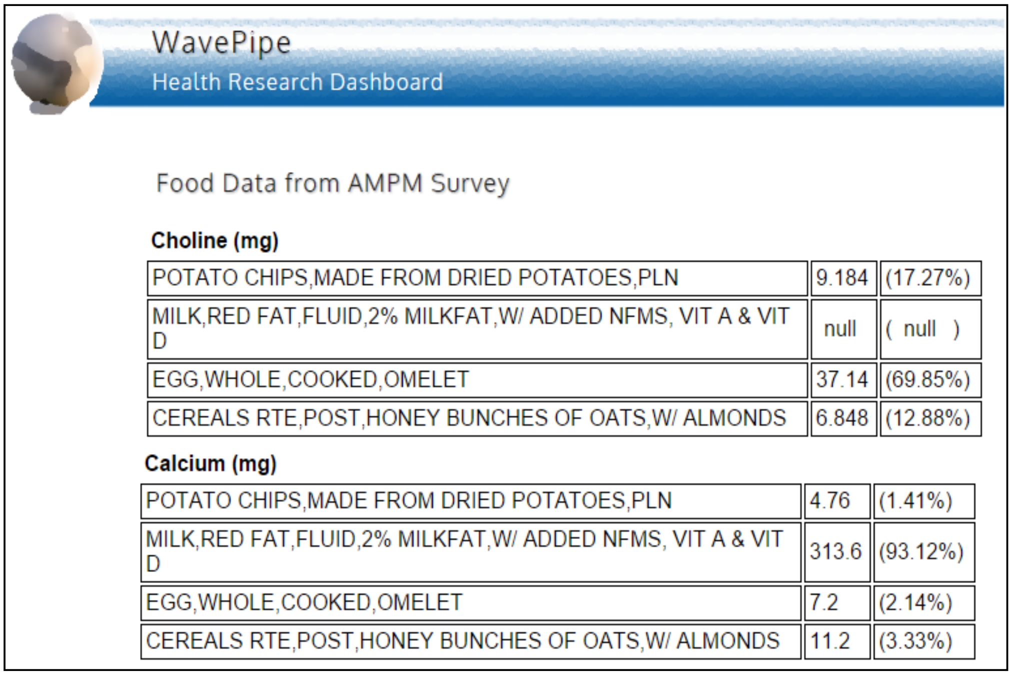


Figure 3. Selection of foods to include in the analysis


WavePipe
Health Research Dashboard

Food Data from AMPM Survey

Choline (mg)

POTATO CHIPS,MADE FROM DRIED POTATOES,PLN	9.184	(17.27%)
MILK,RED FAT,FLUID,2% MILKFAT,W/ ADDED NFMS, VIT A & VIT D	null	(null)
EGG,WHOLE,COOKED,OMELET	37.14	(69.85%)
CEREALS RTE,POST,HONEY BUNCHES OF OATS,W/ ALMONDS	6.848	(12.88%)

Calcium (mg)

POTATO CHIPS,MADE FROM DRIED POTATOES,PLN	4.76	(1.41%)
MILK,RED FAT,FLUID,2% MILKFAT,W/ ADDED NFMS, VIT A & VIT D	313.6	(93.12%)
EGG,WHOLE,COOKED,OMELET	7.2	(2.14%)
CEREALS RTE,POST,HONEY BUNCHES OF OATS,W/ ALMONDS	11.2	(3.33%)

Figure 4. Portion of a report of nutritional profile across foods consumed by subjects

3.2. Adding custom foods to the food-nutrient database

The other new component is a web form that enables the scientist to add new foods to the database (Figure 5). The first text box requires the scientist to enter the name of the food; the second checkbox requires a food ID called a “NDB Number,” is a unique number that is assigned to foods in the USDA Food Composition Database. Thus, the scientist can either overwrite the data for an existing food if desired or can select a unique alphanumeric identifier for a new food item.

Next the scientist can add the “Measurement Description” indicating a kind of serving size and the mass per serving (in units of 100 grams, a common unit of mass used in nutrition research). Each food can have multiple measurement descriptions, and the scientist has the option of adding multiple rows of measurement data. For example, a food such as a “Lobster Bisque” might have a “1 cup” serving consisting of 2.48 units of mass, and a “1 oz” serving consisting of 0.28 units of mass.

Lastly the scientist can enter the nutrient values per 100 grams of the food item. The unit that the nutrient value needs to be in is indicated next to the textbox, and the scientist is responsible for entering appropriate values for the nutrients. The scientist is allowed to add a total of 39 nutrients and therefore most of the nutrients are hidden under the dropdown option. By clicking the “Add More Nutrients” button the scientist can access the complete list of nutrients. If the scientist does not wish to enter the value for a particular nutrient, the scientist is advised to leave the textbox blank and the tool will automatically insert a null value for the nutrient in the database. The nutrient information entered in the form is validated before the scientist can submit the form. This prevents the scientist from inserting invalid information into the database.

After entering all the information in the web-form, the scientist can click the "Save Button" to save the food and its nutrient information in the database. Once the food is saved in the database, it will appear in the AMPM food survey for subjects. This gives them access to the wider range of foods to choose from when creating dietary recall records.

Although the need to add or modify many foods en masse has not manifested within the current project, the component also provides another feature (not currently visible to scientists) whereby a user can upload the same information shown in Figure 5 via spreadsheets. These indicate the lists of foods, serving sizes, and nutritional content. This spreadsheet's format matches that of a file periodically made available with updates to the USDA National Database. Compatibility with this file format will facilitate keeping WavePipe's database up to date in the future.

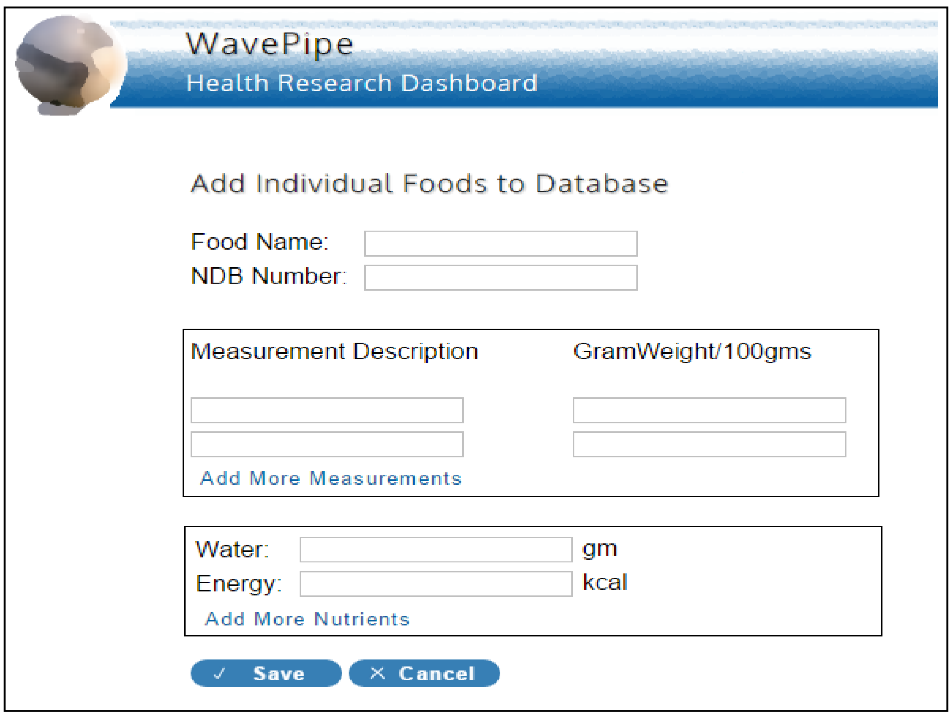


Figure 5. Functionality enabling scientists to augment the food-nutrient databases

5. Preliminary User Feedback

The primary goal of the new sub-system is to facilitate nutrient analyses by health science researchers, including relative novices that may lack experience with statistical analysis tools. Consequently, two student health science researchers were invited to try the system and to provide formative feedback. This information will aid in further refinement of the system.

5.1. Subjects and methodology

We recruited students from the College of Public Health and Human Sciences at Oregon State University. One undergraduate student and one graduate student participated. One was from the Public Health department and the other from the Exercise and Sport Science department.

The study was designed to be completed in 30 minutes. Each participant was given an information sheet containing a list of food items and quantities representative of one day's typical food intake by subjects in the WAVE project. Each then completed an AMPM-style survey with the foods data from the information sheet, generated the nutrient analysis report from the database's accumulated dietary recall records using the new sub-system, and finally provided feedback about the tool by answering a short questionnaire (Table 2). Likert scales offered options of "strongly agree," "somewhat agree," "somewhat disagree," and "strongly disagree."

Table 2. Feedback questionnaire

Background questions	**Response**
What is your experience working with dietary assessment, particularly 24-hour dietary recalls and food frequency questionnaire?	Multiple-choice
What is your experience working with food composition database such as SR27?	Multiple-choice

Formative feedback	
One key purpose is to speed up the nutrient analysis process when using 24-hour dietary recall data, by automating the nutrient analysis and providing % of nutrient contribution by food sources. Do you think this goal is achieved?	4-point Likert
Foods from the AMPM survey and their nutrient profiles are presented in the form of a table. How easy is it to understand this visualization of the data?	4-point Likert
Does this report give you the information to rank food sources based on nutrients of interest?	4-point Likert
Would you like to continue using the tool?	Yes/no
Is there any other feature that you would like to see in this tool?	Open-response

5.2. Results

The participants had had prior experience with conducting health science research related to diet. One had some experience with 24-hour dietary recalls and food frequency questionnaires, but less than one year, and no specific experience with food composition databases. The other had 2 or more years of experience with 24-hour dietary recalls and food frequency questionnaires, as well as 1-2 years of experience working with food composition databases such as SR27.

Both participants were able to complete all of the tasks. Neither took more than a few minutes. Neither needed to ask questions for clarification about how to use the system, nor did either encounter any barriers that involved stopping the process and either going back or restarting.
The participants provided generally positive feedback about the system. Both strongly agreed that the sub-system succeeded in providing a quick means of automating the nutrient analysis of food items. One strongly agreed that the report was easy to understand, and the other somewhat agreed. That participant suggested that the user interface could be clearer if it more explicitly indicated what the percentage on the final report referred to. Both participants strongly agreed that the report did give them the information needed to rank food sources based on nutrients of interest. Both indicated that they would want to continue using the sub-system for conducting dietary recall analyses in the future. Finally, in addition to the suggestion about labelling of the percentages (above), one participant suggested that an interface to view individual subjects' data might be a good feature to add in the future.

6. RELATED WORK

Systems for visualizing health-related data: Visualizations play an increasing role in helping health scientists to make sense of data—particularly in an era of "big data" involving massive amounts of complex, diverse, and potentially erroneous data [18]. Analysing and visually presenting these data can aid in identifying patterns and other insights to aid patient outcomes and to reduce healthcare cost [15][18]. Specific visualizations, for example, can help to highlight distributions of data and uncertainty in measurements [14]. These can inform researchers, healthcare workers and the users who provide the data [19]. Systems like these illustrate the potential value of providing visualizations of health data in general and the desirability of supporting analysis of large-scale food intake datasets.

Systems for large-scale collection of dietary recall data: The most well-established system similar to that presented in this paper is SuperTracker, a web-based tool developed by the United States Department of Agriculture (USDA) and the Center for Nutrition Policy and Promotion (CNPP), which allows the user to track diet and physical activity [22]. The core of the system is a database of over 8000 foods, which has become a de facto standard for nutrition researchers working in this field and a widely-used resource for consumers [1][5]. The database provides data on the nutritional composition of foods based on various data sources including the Food and Nutrient Database for Dietary Studies (FNDDS) and the Food Patterns Equivalents Database (FPED). SuperTracker is the basis for initiatives and "toolkit" extensions aimed at improving public health [5][10].

A functionally similar system, ProNutra, is a web-based tool extended with the ProNESSy module allows dietetic professionals to track weighed food intakes [23]. The system enables health care researchers the ability to design nutrient-intake studies and to efficiently measure, track and manage the preparation and consumption of each user in a study.

The key limitation of systems like those above is that health scientists wishing to analyse the nutritional content of subjects' diets must download dietary recall records to external tools. This requires users to learn multiple tools and to coordinate the flow and formatting of data among those tools. Consequently, the process introduces many opportunities for error in the management, use, and analysis of data.

Systems for individual-level tracking and analysis of dietary recall data: Other web-based systems share the limitation noted above, and in addition also lack support for management of data sets comprising records from groups of users. For example, the Food Works system designed by The Nutrition Company enables individual users to track 24-hour dietary recall, multiple-day records, recipes and menus, which has aided in research on energy intake [17]. Likewise, SuperTracker's consumer-oriented website is also focused on individual-level food tracking and nutrition analysis [22]. Yet another example is the Food Processor, developed by Esha Research, a web-based tool for nutrient analysis with a food composition database that includes foods from USDA databases and the Canadian Nutrient File [3]. These and similar tools can analyse diets at a single record level but, unlike the new WavePipe sub-system, lack support for analysing records from groups of subjects.

Systems for analysis of menus and recipes: A final group of systems with related functionality enable researchers to perform nutrition analysis of menus and recipes. For example, MenuCalc provides restaurant operators with a "do-it-yourself" approach nutritional analysis of menu items [7]. A similar product, NUTRIKIDS system, aids in planning of menus, with a focus on school food service departments aiming to meet nutritional guidelines [9], and health researchers have relied on this system for analysing the nutritional content of school cafeteria menus [20]. These and functionally similar tools are designed to analyse menus rather than dietary recall records.

7. CONCLUSIONS

This work has demonstrated the feasibility of creating an integrated system for collecting and analysing nutritional data based on dietary recall surveys. The resulting functionality, implemented as a sub-system within the WAVE project, substantially improves on the state of the art by eliminating the cumbersome and error-prone process of downloading and analysing data via external tools. The added functionality also enables importing new food information from various nutritional databases as well as creating new entries for individual foods in an effort to build a comprehensive food profile. As an output from this sub-system, a clear and concise report is generated to show a snapshot of nutritional intake for subjects in a specified sub-group. Formative feedback was largely positive and provided some suggestions for enhancing the user interface. These results indicate the viability of this approach as a means for simplifying the process of analysing dietary recall data.

This system provides a basis for further enhancement and evaluation. The WAVE project has embarked on a two-year study applying the WavePipe, which will facilitate a future summative evaluation of its sub-systems, including the one presented in this paper.

ACKNOWLEDGEMENTS

This work was funded by the Agriculture and Food Research Initiative (AFRI) Grant 2013-67001-20418 from the USDA National Institute of Food and Agricultural Science Enhancement Coordinated Agricultural Program. We thank Dr. Siew Sun Wong for guidance and feedback on nutritional science aspects of this work.

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