Identifying effects of perceived stress on food consumption
- A Human Computation Approach -

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Using human computation approaches for exploring human health phenomena has become an evolving discipline in research, medicine, and in the field of personal informatics like application by the Quantified Self movement in the recent past. Qualitative studies based on questionnaires already identified a correlation between perceived stress and subsequent changes in eating behavior, showing a tendency to a shift from consuming healthy low-fat foods to choosing more unhealthy high-fat foods when participants were stressed. Extensive research generated a wide range of concepts in the field of digital stress measurement, whereas changes in human heart rate variability are considered to be a reliable indicator for perceived stress. Based on recent research results, we propose a human computation system for collecting information about stress and food consumption which exploits high pervasion of mobile devices and sensor-based functions of peripheral fitness trackers to measure human health values and include a subjective rating for experienced stress to enable significant data aggregation and analysis. We outline an incentivization concept for motivating users to contribute and present the system's functions for contributors and stakeholders in detail. Furthermore, we point up system architecture, integrated technologies, and user interface, followed by presenting evaluation criteria, limitations and future perspectives coming along with our concept.
1 INTRODUCTION

In the recent past, there has been extensive research how stress influences the human eating behavior and thereby human health. According to Adam et al.[1] it is proven, that chronic stress can elicit a chemical reaction within the human body, which leads to shift in eating behavior from usually consumed products to foods that are mainly tasty, whereby other characteristics like healthiness of food or common eating habits are mostly neglected by individuals in stress situations. This effect is attributable to the increasing demand for energy-rich foods of the psychological reward system during stress situations. A qualitative user study about how the perception of stress impacts the food choice of individuals comes to a similar conclusion. The interpretation of aggregated date of a questionnaire, which was answered by over 200 participants results in a common trend, showing that the consumption of rather unhealthy foods - or “snacks” - increases in stress situations, while the amount of consumed healthy foods like fruits and vegetables simultaneously decreases. [3] The shift in food consumption from healthy to unhealthy groceries is also revealed in a more recent study, which outlines the change in personal eating from low-fat foods to high-fat foods when stressed. Besides, the study shows, that restrained eaters like dieters or people with health problems are more likely to tend to overeating in stressed periods of time.[7]

As a basis for our proposed human computation system we employ a digital approach for measuring perceived stress and collecting information about food selection. The application suggests recipes based on the collected data. The purpose of this system is to obtain awareness of the user’s food choice during stressful situations which hopefully leads to improved and healthy eating behaviour. The Quantified Self movement (www.quantifiedself.com/) embodies the idea of individuals tracking themselves in daily life. Its distribution has been evolving to a large extent since its foundation in the year 2007. Based on affordable devices like smartphones and peripheral connected devices like activity trackers, a broad variety of body-related data can be retrieved including information from physical activities, health information, food consumption, mental and cognitive states and others.[4] The human heart rate variability (HRV) is defined as the acceleration and deceleration of a human’s heart rate within successive respiration phases and is confirmed as a meaningful indicator for determining human health and stress level [6]. Firstbeat Technologies Ltd. present a method to utilize HRV for measuring stress while also considering respiration rate, body movement and oxygen consumption as additional coefficients [8]. By now, distinct approaches for utilizing mobile applications for stress detection are available in the field of research. Sano et al. [5] present a method for stress detection collecting and aggregating data from a mobile phone (e.g. screen activation, location services, calls, messages) and a wearable sensor (e.g. skin conductance, skin temperature, motion) to determine a human’s perceived stress level. The mobile application Stila (www.stila.pms.ifi.lmu.de/) exploits the heart rate measurement of a peripheral fitness tracker and aims to support learners by monitoring activities and detecting stress in daily life while providing personalized advices to help users improving their learning environment.
1.1 Purpose and human contributions to the system

As mentioned, distress is omnipresent in people's daily life and can lead to serious harms for human health from headache to cardiovascular diseases. Subsequent negative changes in food consumption can even impair these effects or cause other problems like overweight, obesity and diabetes. The objective of our HC concept is helping users to get aware of their eating behavior in stress situations and to reflect and improve their manners in the future. This can for example be the prevention of overweight by prematurely detecting periods with negative stress and suggesting the user to avoid eating unhealthy again. In addition, the system supports the user's nutrition by suggesting recipes based on his optimal daily calorie requirement. Summing up, the HC system raises awareness in terms of (unhealthy) food choice under stress, while recommending recipes for balanced nutrition can involve personal health improvements. With the collection and aggregation of anonymized data sets from the whole community for further statistical analysis creates the potential to extend the "big picture" of human health among researchers and health organizations.

The allocation of personal health information constitutes the main contribution to the proposed HC system. As an individual's food consumption cannot be tracked automatically, the user needs to manually add each meal. For collecting this data, users will be requested to enter their consumed foods in constant intervals. Relevant information for each meal includes: consumed type of food (classification according to nutrition pyramid), timestamp, amount of calories (kCal), subjective / experienced stress level at time of data request. In order to suggest recipes, a digital food inventory has to be maintained by the user. A subjective rating of the perceived stress level since the last food consumption is essential for correctly interpreting the data set measured by the activity tracker. For example, a period of high HRV and a subsequent consumption of energy rich high-fat foods could either arise from an athlete's successful marathon run (positive experience) or a period of extreme work stress. The user needs to wear an activity tracker that captures the heart rate, in order to digitally measure an individual's stress level. Following information will be collected from the activity tracker: HRV, step count, movement (location changes).

2 Functionality of a novel HC system

2.1 User side

The contribution of users facilitates the attainment of self-awareness regarding the physiological and psychological condition by providing insight into eating behavior changes over time with a varying perceived stress levels.

Users have the possibility to define three points of time per day for periodic data input requests - each representing a regular meal: breakfast, lunch and dinner. This individual setting of the time points is necessary, because personal eating habits strongly differ among large groups of people, which are in this case the contributors to our human computation system. For every meal, users will be notified and requested to enter the groceries that (s)he recently consumed or shortly will consume by the system's mobile application. Irregularly consumed meals are considered “snacks” which can be entered additionally using the mo-
bile application, whereby an autonomous user interaction is required. Every entered meal will be classified based on the six food types of the nutrition pyramid /cf [9] and its calories will be calculated. Subsequently, the calories of each meal are be subtracted from the optimal basal metabolic rate (BMR) [10]. The BMR represents the optimal amount of calories per day and is individually calculated for each user. Based on the difference of residual amount of calories and the BMR, recipes will be suggested to users for upcoming meals. The nutrition can be even more supported and personalized by collecting health data due to the user's input, e.g. pregnancy, diabetes, allergies. The system can adjust the recipe suggestion based on these health information and moreover provide advices what to eat and not to eat the best.

The mobile application provides a dashboard for personally analyzing collected data on user level. A filter function helps users to display their preferred data representation, while meaningful visualizations like pie charts and parallel coordinate plots provide deeper insight. Their interpretation answers questions like “What am I likely to eat, when I’m stressed or relaxed?” as well as more sophisticated inquests like “How is the distribution of my consumed foods by type composed within a specific interval” and “Are there any suspicious variations of measured and perceived stress level recognizable in this time?”. Another application feature is a health monitor visualizing the user’s current stress level and a composition of the actual and recommended amount of consumed food types and calories in real-time. The user's current pulse rate, step count and daily movement can be retrieved from the connected fitness tracker and presented to the user if desired. Another important function is managing a virtual food inventory. Users can either scan barcodes with their smartphone camera or simply enter all relevant parameters by hand to add groceries to their inventory.

2.2 Stakeholder side

We regard researchers, health organizations, medics and food communities as possible stakeholders of our human computation system. Researchers and health organizations are able to get insight out of the collected and anonymized data sets arising from our system. They can combine or contrast them to data from related research to expand the big picture of human health and in particular of changes of the eating behavior of humans who are exposed to different intensities of perceived stress in specific situations. A bilateral integration with established food communities creates a mutual benefit for users and the institution itself. Dependent on their average participation level, users will be adequately supplied with (healthy) recipes corresponding to their eating behavior which is abstracted from collected data in the course of time. Furthermore, the integration with food communities creates a revenue stream to fund the HC system by exploiting the direct channel to users for personalized advertisement. Stakeholder from the food industry in general can be integrated. For example, restaurants can be additionally suggested if the user is nearby recognized due to GPS data. Therefore, restaurants provide their menus/ menu of the day to recommend dishes based on the user’s remaining daily calorie intake. Grocery shopping can be assisted by co-operations with supermarkets, where the user can stop by to complete the purchase. Ideally, fresh bio supermarkets are partners. Moreover, the system can provide a shopping list based on the remaining food stock, recipe and preferences.
Additionally, health insurances can also take part as a stakeholder. They can have access to the analyzed health data and integrates a bonus system. Users who are living lifestyle by a balanced diet in this case, can benefit from it as a member of the cooperated health insurance.

2.3 Incentivization Concept

Within living memory, humans care about their medical condition and always find new ways of investigating factors that better or harm health. For this reason, we see the chance to obtain awareness of one's own eating behavior in stressed or relaxed situation and the consequential insights to improve the medical condition as the main incentive for contributors to use our human computation system. With the aim at raising additional motivation for user contribution, we introduce a scoring system for cherishing user participation. With the installation of the mobile application and the creation of a user account, the initial personal score will be set to zero. There will be defined score thresholds representing different ranks or levels. A simple three-level scheme classifies users into the ranks “beginners”, “advanced contributors” and “champions”, dependent on their personal score. The described scoring / ranking creates an incentive by exploiting the users’ ambition to continuously improve their high scores, as known from a large variety of games (with a purpose). The personal score calculation is achieved as follows: Users are prompted to enter their most recent food choice of a defined meal time. Every time a system request is brought to the user’s attention, a countdown of 24 hours for entering information starts to decrease. In the event that the user enters food choice information within the 24 hours interval, a defined amount of points will be accredited to the user’s personal score. In case that the user doesn’t enter information within the countdown interval, points will be subtracted from the overall score. If a user enters information about snacks, which are considered as consumed foods in between regular meals, an additional amount of points will be accredited to the user’s personal score. An optional integration with social media communities creates an additional extrinsic motivation. Most of the largest social networks provide application programming interfaces (API) for third party stakeholders. Two prominent examples are Facebook and Twitter. By using the social media integration, participants of our system are able to communicate, share information and form groups of same interests. Relevant groups are for example vegan eaters, athletes, over-/underweight persons, people suffering from specific diseases like diabetes, and many more. Members of the mentioned exemplary sub-groups may have a demand for sharing information and thoughts like-minded people. In case that users decide to exploit the benefits of the optional social media integration, they can compete with others based on their personal participation score on a voluntary basis. To avoid privacy issues evolving from the publication of detailed information about consumed foods, solely the rare score will be available for publishing. For example a person suffering from obesity would eventually be ashamed in case of publishing unhealthy food choices. Focusing on the participation score evades this issue, while still providing a reliable a value for establishing competition among users.
3 SYSTEM DESIGN AND UI ELEMENTS

3.1 SYSTEM ARCHITECTURE

Our system requires users to have a mobile phone (Android, iOS) for running our mobile application combined with an activity tracker for heart rate measurements to use our mobile application. A shown in figure 3.1 the fitness tracker will send the collected data (Heart rate, step count, etc.) to our app. After each meal, the user inputs his food intake through our app, including when, what and how much he ate, his perceived stress level and stress category. This data together can be stored in a local file and will be sent to a personal database once a network connection can be established. The database will aggregate the user’s information. To give the user feedback about his food consumption relating to his stress levels and categories, algorithms that are further discussed in chapter 3.2 will be applied. The results of the calculations will then be sent back to the user, who now can see the outcome on his user interface. All data transfer needs to be secure and anonymized. For researchers one single user is not relevant, but the conjunction of all users and their data. So all databases need to be combined to one, to gain generic insights. Researchers will have access to this anonymized data. Also a community and the connection to social networks is part of our concept.

3.2 DATA AGGREGATION

Data aggregation can be separated into two aspects. First: Data aggregation for each user, and second data aggregation combining all users for researchers.
Each user is interested in his own data and does not need, but furthermore should not be possible to access others information. The minimum variables in the database are kind of stress, type of food, stress level, date. On our user interface the user gets feedback about which type of food he eats the most for each kind of stress. We are differentiating between distress (stress level > 3) and eustress (stress level < 3) which result from the rating of perceived stress. With that in mind the following algorithms can be defined:

1. **FoodIntake(distress)**: for each kind of stress for each type of food
   \[\frac{\text{Count (type of food)}}{\text{Count (kind of stress food intakes)}}\] when stress level > 3

2. **FoodIntake(eustress)**: for each kind of stress for each type of food
   \[\frac{\text{Count (type of food)}}{\text{Count (kind of stress food intakes)}}\] when stress level < 3

For each stress category the algorithms counts how often the user eats which types of food following the food pyramid. It is then divided by the number of food intakes with the specified stress level to get the ratio. This is needed to show the user a cake diagram with proportions. To filter for a specific time range, the algorithms can be modified to only include the data of that time range.

Additionally part of our concept is to give the user recipe suggestions for his next meal, based on his optimal daily intake and his already consumed calories. To do so, we first need to know the user’s optimal daily intake, the Basal Metabolic Rate, which can be calculated based on his sex, age, height and weight following the Harris-Benedict equation revised by Mifflin & St. Jeor.

- Men: BMR = (10 x weight in kg) + (6.25 x height in cm) - (5 x age in years) + 5
- Women: BMR = (10 x weight in kg) + (6.25 x height in cm) - (5 x age in years) - 161

Second, we need the amount of calories for each meal or snack the user has eaten and subtract it from his daily amount. Based on the result a proper suggestion with the remaining calories can be obtained from the recipe database.

Patterns in multidimensional data sets can be detected using parallel coordinate plots (PCP). Figure 3.2 shows an exemplary PCP based on fictional, exaggerated data with five dimensions ordered as follows: Timestamp, Meal Type, calories (kCal) consumed, Food Type (1=unhealthy to 6=healthy) and Stress Level (1=eustress to 5=distress). The data sets are clustered and color-coded by “Meal Type”. The pattern between the axes “Timestamp” and “Meal Type” indicates a constant reliable data input. More importantly, the graph shows an unhealthy food consumption with high amounts of calories for dinner and the user’s tendency to be stressed in the evening. In the morning and at noon, the user tends to consume a healthier nutrition with smaller amounts of calories. This insight could encourage the user to investigate and change eating behaviors to improve its health conditions. The graph can easily be extended by the dimension ”user” to identify mass phenomenons among groups.

\[^1\]The subjective stress rating is not necessarily hard-wired to the classification with distress and eustress. The formulas can also be merged to one while omitting the parameter ‘stress level’ for generalization.
3.2.2 DATA AGGREGATION COMBINING ALL USERS FOR RESEARCHERS

As mentioned before, researchers need access to all of the users data, to gain universal insights. We need to analyse for each kind of stress what types of food users eat the most at high and low stress level. In contrast to 2.1. We only look at the one type of food with the highest count for each user.

1. **distress**: for each kind of stress for each type of food:
   \[
   \frac{\text{Count all Users}(\text{Max(Count(type of food)) when stress level >3})}{\text{Count of all Users}}
   \]

2. **eustress**: for each kind of stress for each type of food:
   \[
   \frac{\text{Count all Users}(\text{Max(Count(type of food)) when stress level < 3})}{\text{Count of all Users}}
   \]

3.3 TECHNOLOGIES USED FOR THE IMPLEMENTATION

The user-side front-end consists of an application running on a mobile device with a compatible activity tracker like models from FitBit, Garmin or Samsung. Seen from software engineering side, the core of the mobile application is implemented as a web application. A consequential benefit of this method is a high platform independence. The core logic of the app and the basic user interface of the web application will be implemented using HTML5, CSS3 and the ECMAScript library jQuery. All graphics based on data aggregation statistical analysis will be rendered using the D3js library (www.d3js.org/). All connections to the system's backend, to web services, or to social media communities are realized using AJAX (www./learn.jquery.com/ajax/), which is compatible to the jQuery library. Additionally, a large number of free security-related libraries are built on top of jQuery to accomplish encrypted data transfer. All mentioned components provide the capability to implement a powerful responsive state-of-the-art application, which will finally be embedded in an hybrid application framework like ionic (www.ionicframework.com/) running on the native OS (Android, iOS). The backend of the system runs on a dedicated server based on Microsoft Windows Server, what brings the advantage that a broad range of software is compatible with this OS. To provide a state-of-the-art software composition, a web service will be implemented using the server-side javascript framework Node.js, which is

![Figure 3.2: parallel coordinate plot (PCP) for collected aggregated data](image-url)
an optimal choice for networking applications. Nutrition facts are retrieved from APIs like nutritionix (www.nutritionix.com) and recipes are queried from food communities like BigOven (www.bigoven.com). The web service will be used for connections to clients using the mobile application, providing information access for stakeholders and communicating with integrated social media communities. All retrieved user data (stress level over time, food consumption) is stored in a database. Possible database management systems are for example ORACLE, PostgreSQL, or NoSQL approaches [2] representing a non-structured solution. As the backend runs on a Windows Server instance, various software for data aggregation and analysis can also be directly installed on the server. Based IBM’s fee-based product (www.ibm.com/analytics/us/en/technology/spss/) or the popular open source R Project (www.r-project.org/), which is available for free under general public license, are possible solutions for aggregating the collected data and conducting statistical analysis.

3.4 USER INTERFACES OF THE SYSTEM

Requirements to our user interface are comfortable data input (food consumption, inventory) and expressive statistics (awareness) to create high usability. To start, the user first needs to register and give some information about himself: sex, age, height, weight are necessary to calculate the optimal daily calorie amount, and food preferences for recipes. This is only needed once, the app will remember the user. The user icon on the top right corner will bring the user to his profile where he can change or check the settings at any time. The main screen is the home screen which consists of different tiles. The biggest tile on top is to add a meal. Then we have tiles for the food inventory, trends, water consumption and community which have half the size of the top tile. Taping on the plus-button will open a new view where the user can enter the information about his last meal. There is no need to type in all the nutrients, the search bar provides access to a number of different food options based on a big nutrition database API. This makes it easy to find the exact meal the user ate, with all its details. Once the food is selected, the serving can be defined. Necessary input is also whether the meal was breakfast, lunch, dinner or a snack, selectable through the icons. To get a reliable correlation between food choices and stress, we also ask the user to enter their perceived stress level, as well as the type of stress they were feeling since the last meal. After a meal is saved, it is automatically taken into the calculations for trends. The trends tile will lead the user to a detailed view about his past food intakes aggregated with the users measured and perceived stress level and type. Here the user can see for each stress type (personal, environmental, work, leisure stress) what different kinds of food he ate the most. This will be displayed by a pie chart for every stress type, with the proportion of food, classified by the nutrition pyramid. In a more detailed view a line chart will show the history. The "My Food Inventory" view offers the possibility to see the food items and quantity one has at home, as well as to scan new bought groceries. This is helpful to get recipes based on the ingredients that are available at home right now. Finally the "Community" tile will give the user access to the community, where scores can be compared, shared on social media or discussions can take place. Going back to the homescreen can be done by pressing the back arrow on the top left corner or a device’s back button.
4 SYSTEM EVALUATION AND SUCCESS CRITERIA

4.1 LIMITATION OF THE SYSTEM

The major limitation of the system is probably the privacy issue concerning personalized data. Weight and eating behaviour are more or less sensitive data. Therefore, a secure application framework has to be established. Also, the possibility to create anonymized user accounts can be provided. The user could have the opportunity to omit some personal data (weight, sex), instead the system calculates with average values. Furthermore, the mainly intrinsic motivation limits the user circle. Are intrinsic motivations enough for people to use the app? The success criteria for the system are discussed in the section below. Copyright issues can also lead to limitation of the system, e.g. regarding recipes and food databases. Free sources are mostly not extensive enough to offer high quality data and to realize all system functions. Most likely, a budget is needed to pay for usage rights to have access to larger databases. So, stakeholders are required to implement a promising Human Computation system. In addition, network connections and the devices themselves can cause problems, e.g. measuring errors by the fitness tracker or missing data entries. For that, the user can be notified to check their devices or to enter food information.

4.2 SYSTEM EVALUATIONS AND SUCCESS CRITERIA

Because our human computation system strongly depends on food data inputs by the user and therefore is intrinsic motivated, convincing and usable functions are needed to encourage people to use the app. The system won't work without a user, because there wouldn't be data to calculate with. So, the overall question is: How the system has to be designed to encourage the user to enter food data? One obvious requirement for the system is an attractive
interface. This is a design issue, which can be solved with a usability study, like an A/B-Test, where different prototype can be evaluated to find the preferred design. But the main focus should be on the evaluation of the food information entries (inventory and consumption input). The major additional benefit of the system is possibly the recipe suggestion, which relieves the recipe search. People, especially under stress, do not want to spend much time worrying about what to eat and cook. Moreover, they may not have time for grocery shopping. To support the user in a healthy nutrition, the HC system offers recipes based on his individual remaining daily calories and food inventory at home. In order for this function to work properly, the user has to enter his food stock. This method should be easy and quick, so the user is willing to do it. Like already mentioned, barcode scanning is the most efficient and maybe also a more fun way. Additionally, the input field should automatically suggest completion of the user's food input. In general, the inventory input needs to be efficient due to its iterative process. If this food entering process works and is usable, people can be encouraged to use it. Ideally, the user is convinced, that there are in fact improvements of his nutrition by using the HC application. Something like a process indicator could be implemented. To analyze if the user accepts the app functions, the user behaviour and workflow of the app can be tracked. So, we have a better understanding of their needs and improve the functions and content to match their needs. Also, surveys can help to evaluate the system.

5 Future works

The current concept is intended for single users. However, the system could be expanded for a whole household. This means, that the system manages a common food stock and therefore calculates recipes based on this shared inventory. The system also updates the food inventory database, if someone from the shared household cooks a meal from the suggested recipes. However, it is required that all people in the household use the app. With this extension, more people may be encouraged to use the app.

If the usability of the system in ensure, one could focus more on social incentives. In the own concept a social networking platform is embedded. Users may be motivated to share their effort with their friends and motivated by a competitive spirit. But this idea is not really fully developed yet, wherefore in the future this concept can be more examined.

In addition, fitness functions can be integrated. The system can provide fitness instructions and adapt the optimal daily calories based on the user's activities. A suggested nutrition plan can be generated based on his fitness goals. For example, if the user wants to build muscles, another nutrition is required than if he wants to lose weight. With that integration, a more extensive healthy lifestyle can be supported. Healthy life, is not only a healthy nutrition, but a mix of exercises and balanced diet. Because the user already has the possibility to scan his products while grocery shopping, the collected data can be connected to market research organizations. For example, the Gesellschaft für Marktforschung or the Nielsen Homescan Panel analyse people's shopping behaviour by collecting product scans of their test persons' purchases. Our system can also be rolled out within institutions like canteens in schools and universities to raise awareness among pupils and students, support healthy nutrition and generate an improvement to the individual learning behavior in the end.
A broader view of the stressors is also possible for further works. It can be analyzed which stressor (studies, work, environment, etc.) triggers the highest distress, so the user is aware of his own stress indicator. For the present HC system, negative stress is focused. But it is also conceivable to point out, at which situations the user has the less stress or eustress, so he is aware of it and takes advantage from this information. Researches in eustress is still an unexplored field, which is why the HC system provides a big opportunity to give deeper insights in this research area due to the collected data. Distress is typically correlated with negative effects, however, positive stress could also be the cause. Along with the collected perceived stress level a long term study can establish insights into specific stressors.

Based on our proposed concept, analyses of other correlations than stress is also imagina-

ble. The HC system can be extended to explore the influence of food consumption during stress on the development of chronic diseases like Parkinson or multiple sclerosis and provide knowledge to improve patient’s health situation and to mitigate symptoms and counteract the disease process.

Another conceivable field of application is the support of diabetes patients, who use body-integrated sensors to measure their blood sugar level and automatic digital insulin pumps, where captured sensor and injector data can be correlated with the stress and food consumption data to find out, to which extent these parameters influence each others.

REFERENCES


