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Telehealth-Based Nutrition Management in Support of Diabesity Therapy

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Thanks

First of all, I want to thank my family, that guided me throughout all the steps I took in my life, so far, and without whose support and help I would not have been able to study and become who I am.
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Veronika Schusterbauer

Abstract

The global prevalence of diabetes and overweight is rising exponentially. Diabetes type 2, often occurs in the context of overweight and obesity, which is described by the word diabesity. A lifestyle intervention, including medical nutrition therapy as well as physical activity, is one of the keystones in treatment and prevention of diabesity and its longterm complications.
This thesis covers the inclusion of an electronic nutrition diary into an existing telehealth system. Therefore requirements for the front end as well as the back end of the system were determined in discussions with nutrition experts. Furthermore the system's Android application was extended for the sector of nutrition. It now enables patients to take pictures of their meals and access nutrition information from a food composition database, via an integrated search function. Consequently, it empowers patients to keep an electronic nutrition diary. The usability of the application was assessed in a field trial.
After one week intense utilisation, the test users gave an overall positive feedback. Thus, the technical feasibility was demonstrated. Requests for additional requirements and feature extensions, like inclusion of regional food items into the food composition database, should be discussed with nutrition therapists and resolved before routine use.

Key words: nutrition assessment, telemedicine, obesity, diabetes mellitus, Android

Zusammenfassung

Diabetes und Übergewicht steigen weltweit exponentiell an und erreichen bald pandemische Ausmaße. Häufig tritt Diabetes Typ 2 im Kontext von Übergewicht oder Adipositas auf. Zusammenfassend nennt man dieses Phänomen "Diabesity". Eine wirksame Methode, "Diabesity" zu behandeln, beziehungsweise Folgeschäden zu verhindern, oder Diabetes vorzubeugen, ist eine langfristige Lebensstil-Intervention. Diese sollte sowohl eine medizinische Ernährungstherapie als auch sportliche Betätigung beinhalten.

In diesem Zusammenhang, setzt sich die vorliegende Arbeit damit auseinander, einen bestehenden Telegesundheitsdienst um ein elektronisches Ernährungstagebuch zu erweitern. In Gesprächen mit Ernährungsexperten, wurde ein Entwurf für ein System erarbeitet, der sowohl Anforderungen an das Frontend als auch das Backend enthält. Es wurde eine bestehende Android Applikation um den Bereich Ernährung erweitert. Sie ermöglicht es den Patienten nun Bilder ihrer Mahlzeiten aufzunehmen und über eine integrierte Suche Informationen zu Nährwerten aus einer Ernährungsdatenbank abzurufen und somit ein elektronisches Ernährungstagebuch zu führen. In einem Feldtest wurde die Einsetzbarkeit der Applikation erfasst.

Die Rückmeldungen der Tester waren, nach einer Woche intensiver Nutzung, vorwiegend positiv. Somit wurde die technische Umsetzbarkeit erwiesen. Anmerkungen zu zusätzlichen Anforderungen und Erweiterungen, wie die Verwendung einer regionalen Ernährungsdatenbank, sollten mit Ernährungsexperten diskutiert und vor einer routinemäßigen Verwendung umgesetzt werden.

Schlüsselwörter: Ernährungserhebung, Telemedizin, Adipositas, Diabetes mellitus, Android

Contents

List of Abbreviations

AIT AIT Austrian Institute of Technologiy GmbH

API Application Programming Interface

App Application Software

BEE Basal Energy Expenditure

BLE Bluetooth Low Energy

BLS Bundeslebensmittelschlüssel

BMI Body Mass Index

BU Bread Units

DALY Disabilty Adjusted Life Years

DEX Dalvik Executable

DMP Disease Management Program

EAN European Article Numbering

EuroFIR European Food Information Resource

FFA Free Fatty Acids

FFQ Food Frequency Questionnaire

HIS Hospital Information System

HCP Healthcare Professionals

HTTP Hypertext Transfer Protocol

ICT Information and Communication Technology

IDE Integrated Development Environment

JSON JavaScript Object Notation

JWT JSON Web Token

KIT Keep in Touch

KMC KIOLA Mobile Client

MET Metabolic Equivalent

NFC Near Field Communication

NoSQL Not only SQL

ÖNWT Österreichische Nährwerttabelle

REST Relational State Transfer

SQL Structured Query Language

TLS Transport Layer Security

UI User Interface

UPC Universal Product Code

VAEB Versicherungsanstalt für Eisenbahnen und Bergbau

VCS Version Control System

WHO World Health Association

XML Extensible Markup Language

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1. Introduction

1.1. Motivation

Diabesity is a combination of the words **diab**etes and ob**esity** and was invented to name the occurrence of diabetes type 2 in the context of obesity [6]. Prevalences for both diseases have increased exponentially over the last decades and have been described as pandemic. From 1980 to 2013, the global prevalence for overweight people, including obese, has risen by 27.5 % amongst adults and 47.1 % when it comes to children. This results in to a total of 2.1 billion overweight and obese people in 2013, whereas in 1980 it has only been 921 million [7, 8]. In a quite comparative period of time, namely from 1980 to 2014, the global prevalence of diabetes has increased from 4.3 % to 9.0 % and from 5.0 % to 7.9 % for men and women respectively. That means a total of 422 million adults with diabetes in 2014, compared to 108 million in 1980 [2]. The graphical representation of the diabetes prevalence in men can be found in figure 1.1.

Insulin deficiency and insulin resistance are the two metabolic factors most closely connected to obesity, as well as diabetes type 2. A partial insulin resistance can be compensated by an increased insulin production by the pancreatic beta cells. Therefore, not all obese individuals develop diabetes. Apparently an elevated level of Free Fatty Acids (FFA)s in the blood plasma plays a major role in both factors.

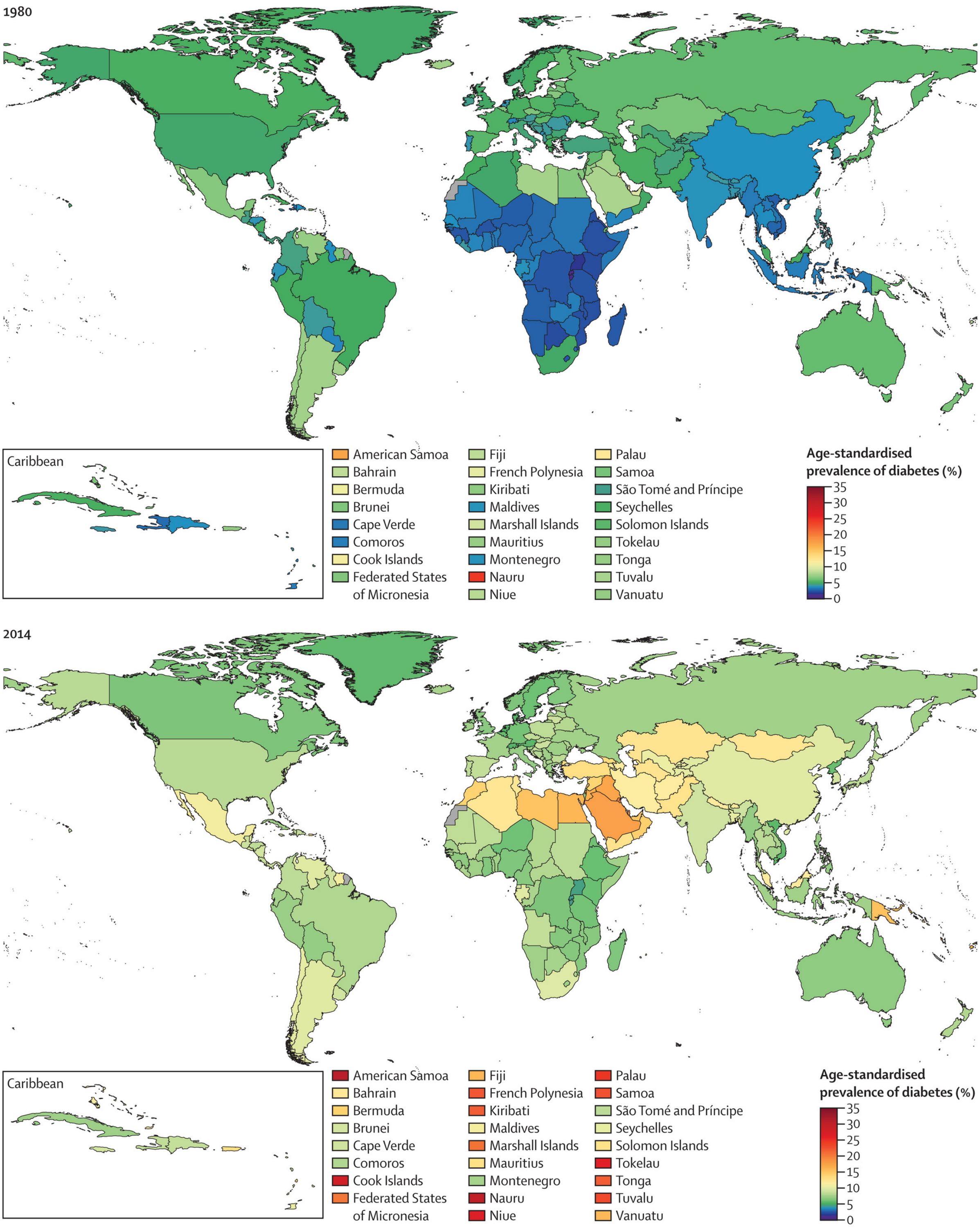


Figure 1.1.: Age-standardised prevalence of diabetes in adult men by country in 1980 and 2014 [2].

Elevated levels of FFAs occur due to fatty acids from dietary intake and in obese individuals also from lipolysis of the fatty tissue, whereas central abdominal fat is a higher risk factor [9–11].
The health impacts of both diseases are enormous. Obesity is connected to several chronic diseases, such as hypertension, heart diseases and of course diabetes, which can have quite severe long-term complications. The most common ones include artery and peripheral vascular diseases, strokes, diabetic neuropathies, amputations and more. Consequently, the health expenditures are tremendous. According to the *Global Burden of Desease Study 2015*, high fasting plasma glucose and high Body Mass Index (BMI) rank 3rd and 4th, measured in Disabilty Adjusted Life Years (DALY)s [6, 12–14]. Another major risk factor for developing diabetes type 2, independently from BMI, is physical inactivity [15].
This pandemic has for example lead to the EU project Diabesity and many other research projects about developing new drugs and re-evaluating common therapies for obesity and type 2 diabetes [16, 17], but two of the keystones in diabetes prevention and treatment are medical nutrition therapy and physical activity [15]. Therefore those topics have to be covered in every diabetes self-management training [6, 18]. Although it has been exposed that medical nutrition therapy has a positive effect on patients suffering from diabetes type 2, there is no single diabetes diet that fits for everybody. Quite the contrary is the case, as finding the personalised diet for every patient seems to be very important [19].

1.2. Telemedicine

The current healthcare system faces the situation that in the near future, the number of patients will rise steadily, leading to the challenge of treating more patients with a higher number of comorbidities at the same costs [20]. One approach to overcome those challenges, is an extended use of telehealth services (e.g. telemonitoring), as those are cost effective methods in therapy of chronic diseases [21, 22].

Telemedicine, by definition, is the use of Information and Communication Technology (ICT) in healthcare, whereas the patient and the healthcare provider are not present at the same place [23]. The goal of telemedicine is to deliver information about therapy or diagnosis of a disease independently from physical (decentralised) and temporal (asynchronous) distance.

In general, the fields of application for telemedicine can be separated into telediagnostics, telehomecare, telemonitoring and teleteaching [20, 24].

Telediagnostics is the act of making a diagnosis without the physical attendance of the healthcare professional [24].

Telemonitoring concentrates on the direct and constant exchange of information between the patient and the healthcare professional. Monitoring the patients vital functions allows the healthcare professional to adjust the therapy if necessary. This enables an intervention taking place before the patient gets hospitalised or his/ her health status decreases drastically. Often, the progression of the disease can be influenced positively and long-term complications can be prevented by using this technology [20, 24].

Telehomecare also implicates monitoring a patient's vital functions, but it rather focuses on the support in medical and nursing care at home. It therefore enables patients, including many elderly people, to stay at their homes for a longer period of time [20, 24].

Teleteaching offers multimedia information and advised actions. Ideally those programs are individualised and tailored to a certain audience [20].

Despite the believe that the well designed use of ICT in healthcare can increase its quality, change the experience of care for patients and their families for the better, and actually save lives [21], implementations of telemedicine are quite limited, even in high income countries. Mainly its application is restricted to pilot or informal projects. In 2009 the World Health Association (WHO) examined four field of implementation, namely, telepsychiatry, teledermatology, teleradiology and telepathology. From those fields, the highest rate of established telemedicine projects was found in the field of teleradiology. It was shown, that in this sector over 60% of all responding countries worldwide were offering some service and 33% of countries were having an established service [25].

1.3. Keep in Touch (KIT) Telehealth Solutions

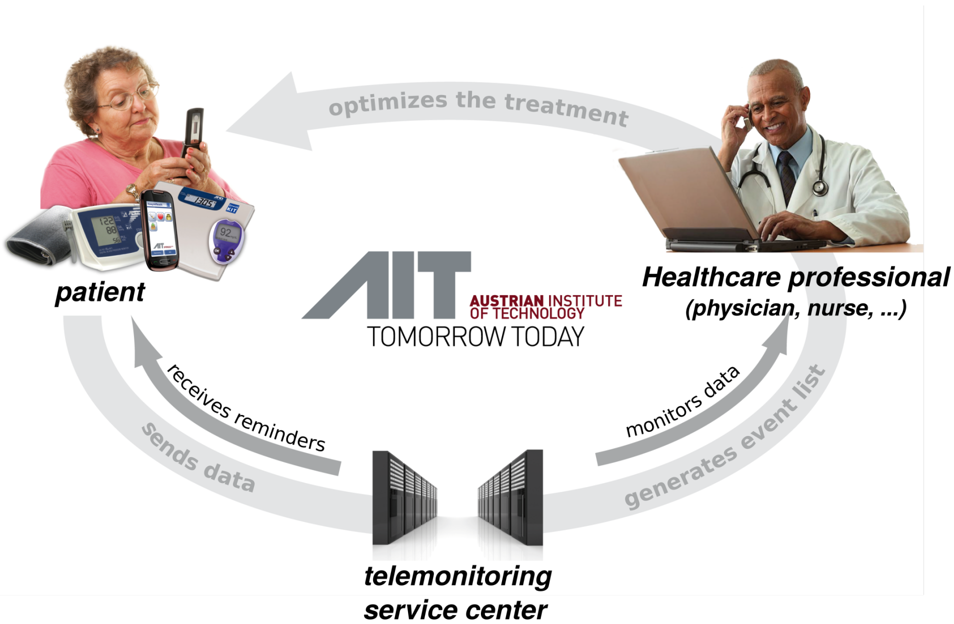


Figure 1.2.: Schematic depiction of the telemonitoring system, modified from [3].

KIT is a telehealth system that was developed by the AIT Austrian Institute of Technologiy GmbH (AIT). It works according to the closed loop healthcare principle, of which a simplification is depicted in figure 1.2. The system allows a safe transfer of information. The patients are able to collect their vital parameters, e.g. blood, pressure,

blood glucose, heart rate, bodyweight, etc., themselves with the help of a mobile application. The transmission is especially simple, as the mobile application uses Near Field Communication (NFC) and Bluetooth Low Energy (BLE) for automatically connecting to, and reading data from measurement devices. Access control, using personal RFID/NFC cards, provides the necessary security. Once the data is stored on the mobile phone, it is synchronized with a health data server so that it can later be accessed by the healthcare professionals via a web application. Instructions from the healthcare professional, as well as adjustments to the therapy are transferred directly to the mobile application via an encrypted connection [4].
Figure 1.3 gives a more detailed overview of the parts, the KIT system consists of. The heart of it is the KIOLA Cares Framework, a server framework which can be accessed by a web client from the patients, as well as the healthcare professionals. Through a HL7 Gateway the data stored in the server framework can also be forwarded to e.g. a Hospital Information System (HIS) or software for Healthcare Professionals (HCP)s. The patients' core instrument for communication with the care network is a mobile application also called KIOLA Mobile Client (KMC), which will be described in more detail later on. In recent research the network has also been connected to consumer products, such as fitness trackers.

1.3.1. Disease Management Program (DMP) solutions

Within the history of healthcare, there have been several definitions of Disease Management and Disease Management Program (DMP). What most of them include is disease management being a systematic approach in treating chronically ill patients. Stock et. al. postulated that a DMP has to include prevention, diagnosis, therapy and care of a patient, and that it has to be maintained across all stages of a disease [26]. The goal of a DMP is to reduce long-term complications and costs while keeping up

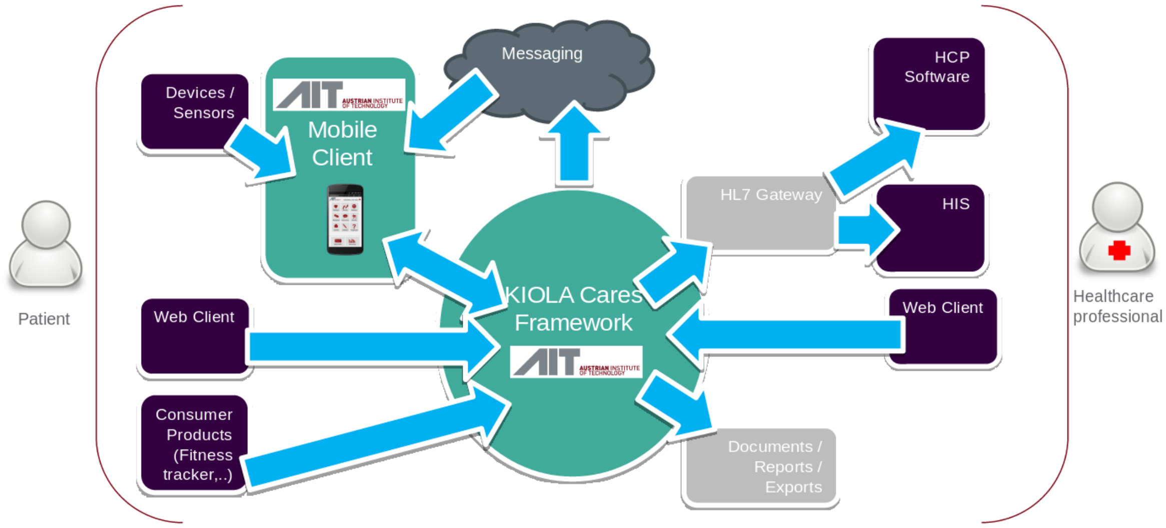


Figure 1.3.: Sketch of all the interacting parts of the KIT system.

or even improving the quality of care. It furthermore tries to enhance communication between stakeholders in the healthcare sector, by defining and using standardised treatment pathways [27].

The KIT technology is already in use in several DMPs. One of them being *Health Dialogue Diabetes Mellitus* (Gesundheitsdialog Diabetes Mellitus [28]) a DMP run by the *Versicherungsanstalt für Eisenbahnen und Bergbau (VAEB)*. Another DMP run by the VAEB, that is using the KIT technology, is *Health Dialogue Hypertension* (Gesundheits-dialog Bluthochdruck [29]).

1.3.2. KIOLA Mobile Client(KMC)

The patients core instrument for communication with the care network is a mobile application called KMC, which is shown in figure 1.4. It enables them to record their vital parameters, respond to questions about their medication and well-being, as well as to add free text comments. Feedback from the healthcare professional and the

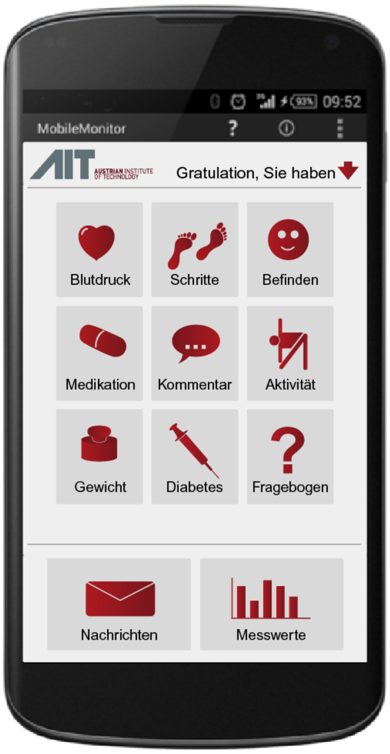


Figure 1.4.: Startup Screen of the DiabMemory App, one version of the KMC [4].

periodically generated automated reports are also presented to the patient by the KMC [4].

The KMC is distributed in different versions depending on the DMP it is used in. All the versions are released as Android applications on the Google Play Store (Google Inc., Mountain View, United States) [30]. Every DMP has its own Application Software (App) that is adjusted to the needs of its patients, but they share a common core Android project. For example, the App for the *Health Dialogue Diabetes mellitus* is the *DiabMemory 2* App (registered trademark by AIT Austrian Institute of Technology GmbH) and the App for the *HerzMobil Tirol network* is called *HerzMobil* [31, 32].

1.4. Dietary assessment

There are several methods for assessing the dietary intake of an individual, altogether called direct methods. Those methods require a direct interaction with the test person. This leads to a more concious perception of the personal food intake and can affect peoples' self-evaluation or can even get them to change their eating behaviour. Common problems are that test subjects underestimate the intake of unhealthy foods (sweets, alcoholic drinks) and overestimate the intake of healthy foods (fruits, vegetables, drinks). In addition, some people actually consume more of what is commonly thought as being healthy and less of what they believe is unhealthy food. These phenomena are called under-/overreporting and under-/overeating respectively [1]. Direct methods for assessment of dietary intake can coarsely be divided into retrospective and prospective methods. An overview of the most common methods can be found in table 1.1.

Retrospective methods share some pros and cons, due to which they are mainly used for epidemiological studies with a high number of participants. On the one hand, the workload for the participants is quite low and the studies are usually not very time-consuming. Therefore, they have a high compliance and large samples of test subjects are possible. On the other hand, those methods require participants to have a good memory. In a 24-hour diet recall the last 24 hours have to be remembered. In a diet history interview and a Food Frequency Questionnaire (FFQ), commonly eaten foods of the last weeks up to several months should be estimated. Another common problem in retrospective methods is under-/overreporting. In general it can, thus, be concluded that retrospective methods are not very accurate [1, 33].

Prospective methods such as dietary records, especially the weighed dietary record, are quite time consuming and expensive. They ask the participant to measure, or at least estimate (estimated dietary record) the portion size of every meal. In the duplicate diet method, a duplicate of each meal, eaten by the test subject, is analysed

Table 1.1.: Overview over direct methods for dietary assessment. Modified from [1].

Retrospective methods	**Prospective methods**
• 24-hour diet recall	• Dietary records: weighed / estimated
• Diet history interview	• Duplicate diet method
• Food frequency questionnaire	• Observation methods: Image assisted dietary records

in a lab. The weighed dietary record and the duplicate diet method are considered to be very precise and are, thus, used for evaluating other methods. As prospective methods actively interfere with the patient's daily life, they are subject to under-/overreporting as well as under-/overeating. They are also expensive, as trained experts are needed to evaluate the participants' dietary intake. As those methods lead patients to consume foods more consciously they are often used in nutritional counselling and therapy.

1.4.1. Image assisted dietary assessment

Image assisted dietary assessment includes all methods using images and videos to assist patients in self-assessing their dietary intake and those that use images as the main source of information. Several different methods have been developed. Active methods require participants to take pictures of their meals before and after eating episodes. Passive methods are based on wearable devices that record meals automatically, usually by a constant documentation of the daily life. Many of the projects still rely on specially trained staff for judging the energy intake from the images. They have to determine the various ingredients of meals and estimate the portion sizes, but there are also methods in development that try to automatically

judge foods and portion sizes. Both methods, often, take advantage of a marker, such as a ruler or a specially designed marker for size comparison and/or colour adjustment [33–38].
It was shown that image assisted dietary assessment increases the estimated energy intake in comparison to standard methods as e.g. estimated dietary records, which shows an improvement of the estimated caloric intake towards the gold standard of weighed dietary records. In order to get accurate values, images should be supported by additional information on, the type of foods a meal consists of, and the cooking methods used [34].

1.4.2. Dietary assessment and DiabMemory

In 2013, a feasibility study on using image assisted dietary assessment within the DiabMemory project was conducted. The simultaneous use of Nutrinaut (registered trademark by Dr. Dietmar Dörrer, Vienna, Austria), a web app for dietary assessment, and the telehealth program DiabMemory was tested.
The intervention group consisted of ten patients that were part of the *Health Dialogue Diabetes* and also participated in the DiabMemory program [39]. Only people suffering from Diabetes type 2 excluding those with insulin therapy were allowed to take part in the study. The control group was a historical one.
The intervention lasted for three months. In the first month the participants had to record at least 3 main meals a day additionally to their usual tasks in DiabMemory, which were:

- Measuring their blood glucose at least three times on one day per week
- Measuring their blood pressure at least one day per week
- Transmitting their body weight at least once a week
- Recording their physical activity, if required

They recorded the meal images with their mobile phones and sent it to an email address from Nutrinaut, so that they were added to their Nutrinaut account automatically. The images of the meals were evaluated by a professional dietician using the Nutrinaut software. Evaluation of the images included choosing the correct food items and estimating the portion size in order to receive the food composition information from Nutrinaut. Once a week the participants received feedback about their nutrition habits and goals for the next week. Feedbacks were given in form of phone calls, emails and short messages.
Although there was no significant change in BMI, between intervention and control group, the study showed that the willingness and motivation of patients to keep an electronic nutrition diary is very high. It was also pointed out, that it would be better if the nutrition diary was integrated into the KIT telehealth system [40].

1.4.3. Apps for Dietary Assessment

Smartphone Apps are likely to have the power to enhance a healthy lifestyle. Especially the amount of physical activity, but also adherence to a healthy diet and weight loss are improved, and all of that at low cost [41–43]. There are several mobile Apps for Android phones, many of them are free to use with the option to upgrade to a premium version, facing costs up to 20 $ per month [44]. Their most common features for adding nutrition information are the following:

- A search function to add foods from a database by name
- A Universal Product Code (UPC)/European Article Numbering (EAN) code scanner
- The possibility to add personal foods and declare favourite meals

One of the upcoming features is automated image analysis. Some Apps even declare to be able to analyse foods by the spectrum of the reflected light [44, 45].
Research showed that users prefer Apps that are easy to use and raise awareness for dietary intake and body weight development [41]. Only few Apps that are openly available offer information about the publishers or even their sources. *Konsument* stated that despite all the advantages, no smartphone App can replace a medical nutrition therapy [46]. It is also indicated that there is a lack of smartphone Apps that are adapted to different cultures and languages and in this regard scientifically tested [41].

1.4.4. Food composition databases

There are several different options for food composition databases including scientific ones, like the Bundeslebensmittelschlüssel (BLS) and those that are developed with the help of users, as, for example, the FatSecret database. Food composition databases are used in different sectors, such as health, trade regulation and legislation, agriculture and the environment [47]. Many European countries have their own food composition database(s). This leads to unreliable, inadequate or incomparable food composition data, as those databases are often designed for one specific purpose. It also encourages the use of old data as curating and updating such a database is expensive [47]. Thus, efforts have been made to develop a collective food composition database applicable for whole Europe, namely, the EuroFIR project [47, 48]. A list of databases available in German, with a short description including information on how the databases are distributed, is presented below:

Bundeslebensmittelschlüssel (BLS) :

The BLS (Max-Rubner-Institut, Karlsruhe, Germany) is a food composition database built for epidemiological studies in the field of nutrition and food consumption in Germany. With its help, changes in the nutritional behaviour should be made traceable. The latest version is the BLS 3.2. It contains 14.814 different foods with information about a total of 131 nutrients. Therefore the BLS is also suited for being used in international studies and provides a good resource for scientific work in the field of nutrition [48–50]. The database is offered for download as a text file. Within Europe, the BLS can (thankfully) be accessed free of charge for use in research projects run by state institutions.

Österreichische Nährwerttabelle (ÖNWT) :

The ÖNWT (Dato Denkwerkzeuge, Vienna, Austria) is not a stand-alone database, but an extension of the BLS. It expands the BLS vertically as well as horizontally. Main advantages are the inclusion of foods that are commercially available in Austria, as well as additional information on allergens and Austrian synonyms for several food items. The ÖNWT is published by *Dato Denkwerkzeuge* in co-operation with the Department of Nutritional Sciences, University of Vienna [51, 52]. On request the ÖNWT can be offered as text file, Extensible Markup Language (XML) file or Structured Query Language (SQL) bulk insert.

European Food Information Resource (EuroFIR) AISBL :

This international, member-based, non-profit association was founded in 2009 to ensure sustained advocacy for food information in Europe. One of its main goals is the harmonisation of standards across Europe, in order to increase quality, access and storage of food composition data. The ultimate goal is a single integrated, comprehensive and validated database, or other food information resource, for Europe [47, 53]. By now, EuroFIR (EuroFIR, Brussels, Belgium) offers access to food composition databases of 25 European countries, the United States of America and Canada via their online tool FoodExplorer [54].

FatSecret :

FatSecret (FatSecret, Melbourne, Australia) offers it's own calorie counter application, also going by the name of FatSecret, which can be downloaded as mobile application, but can also be accessed via web application [55]. Furthermore, they offer their food and nutrition database, which they claim to be the biggest one worldwide, as an Application Programming Interface (API) for other developers. Their API comes with a lot of features, like searching foods by UPC code, brand names or even checking for food items by restaurant name. They offer a Basic version, which is free of charge and includes a limited number of API calls, as well as a Premium Free, which is free for non-profits and start-ups, and a Premium version [56].

MyFitnessPal :

MyFitnessPal (Under Armour, Inc., Baltimore, United States) offers a combined application for fitness tracking and calorie counting. Lately they have also started to offer their own API, which for now is only accessible for approved developers [57].

1.5. Aim of the Master Thesis

The goal of this thesis was the design of a nutrition diary, that allows full integration of dietary assessment into the KIT telehealth system. The minimum requirements for the mobile App were the possibilities to take pictures of the meal and to add the according nutrinitional information. The information had to be downloaded from a food composition database. Furthermore the data needed to be synchronized with the KIOLA health data server, so that it would be accessible for a healthcare professional, via the web application. Additionally, the possibilities of including a UPC/EAN barcode reader and the use of image processing for automated estimation of nutrients were to be examined.

Besides the technical requirements, the inclusion of nutritional counselling into the DMP was to be drafted.

2. Methods

2.1. Extending the DMP

In cooperation with a nutrition expert and health manager, working at the VAEB, and the head of the project DiabMemory, from the AIT, a treatment pathway for nutrition management in a telemonitoring project was discussed. Furthermore, requirements for the extension of the KMC, with regard to patients needs and skills, were outlined. Also, an expansion of the web application to suffice requirements for depicting dietary intake was sketched, which allows the dietitian to check and correct the annotations made by the patient.

2.2. Data structure

The KIT system and the related mobile devices have been developed on the basis of the design guidelines by the Continua Health Alliance (Continua Health Alliance, Beaverton, United States [58]), whose goal it is to ensure medical device interoperability [59]. This guideline is based on the ISO/IEEE 11073 and on established technologies like Bluetooth and NFC [4].

Until now, the ISO/IEEE 11073 does not cover the fields of nutrition or food, therefore the ÖNORM EN 16104 *Food data — Structure and interchange format* was reviewed [60]. It was decided that the currently used data structure was not compatible with the one suggested by the ÖNORM EN 16104. In addition, non of the potential food composition databases where compliant with the ÖNORM EN 16104. Thus, the data structure used to store and transmit the dietary information was, in agreement with experts at the AIT, designed to solely fulfill the requirements of the KIT system and the Continua guidelines, as far as applicable.

2.3. Mobile App KIT-nutrition

The first step in extending the mobile App was to get to know the existing KMC, and in particular the DiabCare Project, one flavour of the KMC, which the extension should be based on. The current version of the DiabCare App (DiabCare Tirol Project, developed in a collaboration between Tirol Kliniken GmbH Innsbruck and AIT Austrian Institute of Technology GmbH, Innsbruck, Austria) was examined and extended, using Android Studio (Android Studio 2.3.3, Google Inc., Mountain View, United States, [5]) in combination with several other software products described in the following section.

2.3.1. Development environment

Android

Androids **Platform Architecture** is a software stack based on a Linux kernel. The most important building blocks are shown in figure 2.1. The hardware abstraction layer is basically the lowest layer that can be called at by an Android App. It offers the

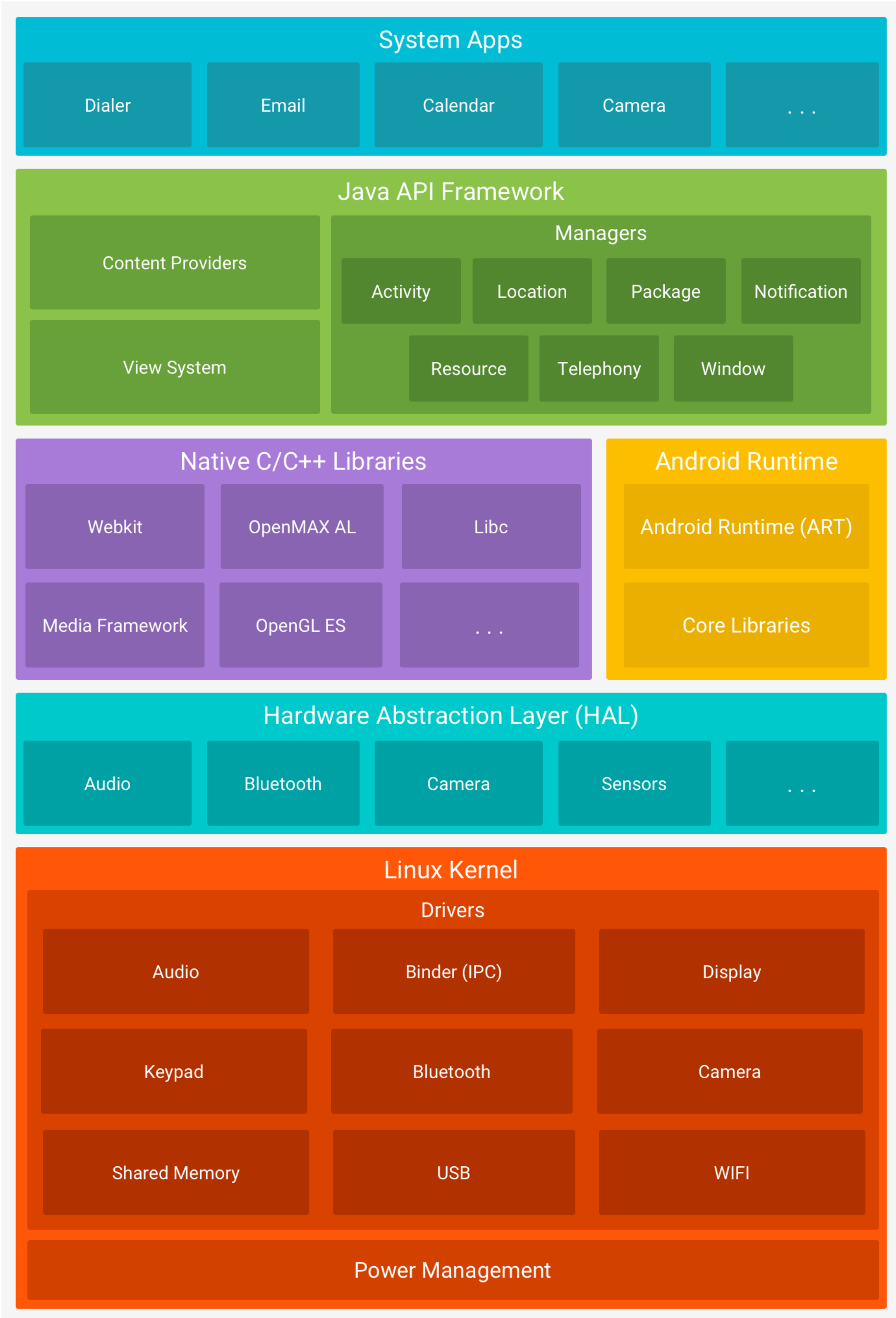


Figure 2.1.: The Android software stack [5].

appropriate APIs for the underlying hardware. On top of it is the Android Runtime, which has formerly been Dalvik. Android Runtime is designed to execute Dalvik Executable (DEX) files on multiple virtual machines on low-memory devices. While Apps written for Android Runtime usually run smoothly on Dalvik, the opposite might not work. The most commonly needed reusable components for building an Android App are offered by the Java API framework. Developers can make use of the same framework API's that Android system Apps use e.g. the Activity Manager, that takes care of the App lifecycle, or Content Providers that allow Apps to access data from foreign Apps. The top layer is built by the Android system Apps. Those native Apps work as Apps for users, but they also offer some key capabilities for developers. So, if a new App needs to send an email, this feature does not have to be implemented again. The App can simply address the systems usual email App and it will send the email instead [5]. One of the main building blocks for Android applications is the **Activity**. Activities are not only responsible for all user interaction, they also determine how a user can navigate through the App. In other words, one could say, that one screen equals one Activity. The communication between Activities is managed by **Intents**.

With the emergence of tablets, the use of **Fragments** became more important. Each Activity can host multiple Fragments, which are each responsible for one part of the User Interface (UI). Fragments are enhancing the user experience, because they can be rearranged depending on the screen size of the Android device. Moreover they are reusable, meaning that multiple Activities can use the same Fragment.

Other important classes are **Loaders**, **Services** and **Content Providers**. Loaders in Combination with Content Providers are used for loading data in the background, may it be from a local or an online resource. Content Providers also allow for sharing contents with other Apps. For other background tasks that do not need a user interface, such as, for example, all kinds of connections like NFC or Bluetooth, Services are used [5].

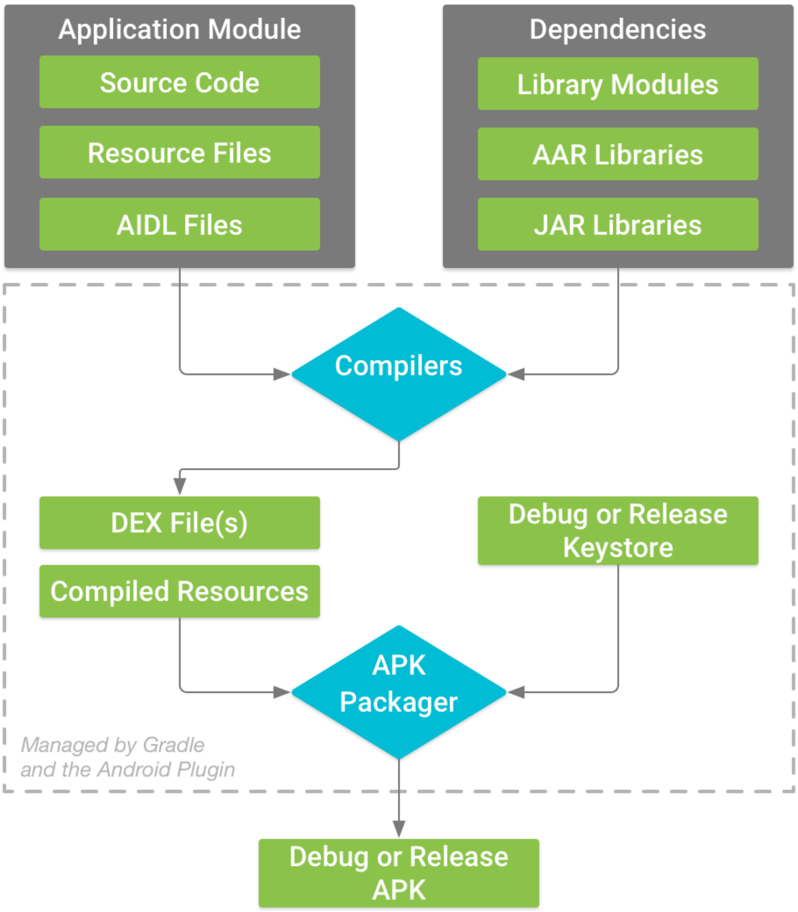


Figure 2.2.: The build process of a typical Android App module [5].

Android Studio

Android Studio is the official Integrated Development Environment (IDE) for developing applications for all kinds of Android devices [5] and comes with a lot of features. It includes an emulator for the different kinds of Android devices and versions, allowing for testing an App without the need of possessing the hardware. In this case, Android Emulator 26.1.4 was used. The instant run option allows for pushing resources or code changes onto the emulator or an external device while the App is running. Androids layout editors allows to generate UIs by defining elements in XML or by simply dragging and dropping elements. Although Android Studio nowadays supports using C++ as a programming language, JAVA is the, by far, more frequently used one.

Gradle

Android Studio uses **Gradle** (Gradle Inc., San Francisco, United States) as its build tool [61]. Gradle enables Android Studio to include external libraries and customize the build configurations. The used version was gradle 3.3. Figure 2.2 shows the build process of a typical Android App module and all the components needed. The first step is to compile the application module and the dependencies into DEX files. Dependencies can be local library modules and libraries, but also external ones, that are downloaded automatically. The next step is to pack the DEX files into an APK and sign it using the keystore. This is done by the APK Packager. The behaviour of this whole process can be changed by different configuration files. It can, for example, be controlled if a debug or a release version of the App should be built. Even building different App flavours is possible. These are used to build the different versions of the KMC out of one project [5].

GitLab & GitHub

GitLab (GitLab B.V. , Utrecht, Netherlands, [62]) and **GitHub** (GitHub Inc., San Francisco, United States, [63]) are both platforms based on the Version Control System (VCS) Git, which was originally programmed by Linus Torvalds. It was designed to handle thousands of developers working on the same project and to still be efficient and quick [64]. GitLab is a web interface for version control which offers several project management and bug tracking tools. It is used for managing the

DiabCare project. The extension of the App was done on a branch of the DiabCare project, which was regularly updated to the latest version of the main branch. GitHub could also be used as a VCS, but is commonly known as an online service, that hosts open source software development projects and was only used for downloading such projects.

Artifactory

Artifactory (JFrog, Netyana, Israel) is an Artifact Repository Manager and can be used for software packages written in several languages. It allows the tracing of artifacts from development to release [65]. In combination with Gradle, Artifactory was used to integrate foreign libraries but also to deploy private ones.

Base64

Base64 is an encoding standard that was first used to encode attachments of emails, as SMTP was only designed to transmit ASCII signs. Nowadays it is also used for encrypting user names and passwords in Hypertext Transfer Protocol (HTTP) basic authentication. In base64, binary files are encoded into a set of 64 ASCII signs and one special character for padding at the end. One character is therefore representing 6 bits of the original file [66].

Mobile phones

The mobile phones used for development of the App where a Fairphone 2 (Fairphone, Amsterdam, Netherlands) running on Android version 6.0.1 and an LG Spirit 4G LTE (LG Corporation, Seoul, South Korea) running on Android version 6.0.

2.3.2. Taking and storing images

The Android file system offers an internal or an external storage for saving files. The key characteristics of both are listed in table 2.1. For reasons of privacy and security it has been decided to use the internal storage for saving the images. As no special features are needed when taking the images, the first attempt was to use the system camera App for doing so. Unfortunately it was discovered that the different system camera Apps behave differently and therefore lead to an unintended behaviour on several phones. To gain better control it has been decided to access the camera at the hardware abstraction layer instead. Since API level 21, the Camera2 API replaces the deprecated Camera class. To ensure functionality on older phones as well, both APIs needed to be included. For this purpose the open source project sandriosCamera (v 1.0.9, sandrios studios, Pune, India) was downloaded from GitHub and modified to match the defined requirements. It was then packed into an .aar library and uploaded to Artifactory to ensure accessibility from different computers.

Table 2.1.: Comparison of the key properties of internal and external storage.

Internal storage	**External storage**
• Available all the time • Files stored here are private and can only be accessed via the corresponding App • When uninstalling the App its internal storage is swiped completely.	• Might not always be accessible, for example if it is currently mounted as a USB storage • Is world readable • Is only in certain cases deleted on deletion of the App

2.3.3. Requesting food information

For the communication with the API, that was developed to access the BLS (section 2.4), the Google Volley library (Version 1.0.0, Google Inc., Mountain View, United States) was used. Volley is an HTTP library that ensures easy and fast networking for Android Apps and is available on GitHub [5, 68].

2.3.4. Calculation of the energy expenditure

In order to calculate the Total Energy Expenditure, the Basal Energy Expenditure (BEE), as well as the energy expenditure during activity, is needed. The BEE was calculated after the Harris-Benedict formula, a simple empirically developed formula taking into account w the weight in kg, h the height in cm, a the age in years and the gender of an individual [69]. The two formulas for men and women are given in equation 2.1 and 2.2 respectively.

$$BEE(kcal/d) = 66.4730 + 13.7516 \cdot w + 5.0033 \cdot h - 6.7550 \cdot a \tag{2.1}$$

$$BEE(kcal/d) = 655.0955 + 9.5634 \cdot w + 1.8496 \cdot h - 4.6756 \cdot a \tag{2.2}$$

The Metabolic Equivalent (MET) is a way to express the degree of energy expenditure reached while exercising. The total caloric cost of an activity can be calculated by a simple formula stated in equation 2.3, where w is the weight in kg and MET is the metabolic equivalent of each activity [70]. The normal range of physical activity level expressed in MET values ranges from 1.0 to 12.0, where one MET equals the caloric expenditure of a person at rest [71–73].

$$AEE(kcal/min) = \frac{MET \cdot 3.5 \cdot w}{200} \tag{2.3}$$

There's a collection of standard MET values published by the Compendium of

Table 2.2.: Chosen activities from the Compendium of Physical Activities and their according standard MET values.

	Activity level		
	low	moderate	vigorous
nordic walking	walking, for exercise, 3.5 to 4 mph, with ski poles, Nordic walking, level, moderate pace MET = 4,8	walking, for exercise, with ski poles, Nordic walking, uphill MET = 6,8	walking, for exercise, 5.0 mph, with ski poles, Nordic walking, level, fast pace MET = 9,5
hiking	climbing hills with 0 to 9 lb load MET = 6,5	climbing hills with 10 to 20 lb load MET = 7,3	climbing hills with 21 to 42 lb load MET = 8,3
running	running, 5 mph (12 min/mile) MET = 8,3	running, 7.5 mph (8 min/mile) MET = 11,8	running, 10 mph (6 min/mile) MET = 14,5
swimming	swimming laps, freestyle, front crawl, slow, light or moderate effort MET = 5,8	swimming, crawl, medium speed, 50 yards/minute, vigorous effort MET = 8,3	swimming, crawl, fast speed, 75 yards/minute, vigorous effort MET = 10,0
tennis	tennis, doubles MET = 6,0	tennis, general MET = 7,3	tennis, singles MET = 8,0
cycling	bicycling, 10-11.9 mph, leisure, slow, light effort MET = 6,8	bicycling, 12-13.9 mph, leisure, moderate effort MET = 8,0	bicycling, 14-15.9 mph, racing or leisure, fast, vigorous effort MET = 10,0

Physical Activities, which includes all common sports as well as household activities [74].

The DiabCare App additionally offers the possibility to enter exercise sessions performed. One can choose between nordic walking, hiking, running, swimming, tennis, cycling and other sports. Furthermore one out of three different activity levels ranging from low to vigorous can be selected. For each combination of type and level of activity there was a MET value chosen from the Compendium of Physical Activities, as shown in table 2.2. For the METs of the activity type *other* the mean of all the other activities was taken.

2.4. Web service for food composition data

For development of the Mobile App, in the beginning, the *FatSecret Platform API* was used. First, the *Basic offer* of the API was applied with the REST API option and later it was upgraded to the *Premium Free* offer. As the support for German language is only included in the *Premium* offer, we decided that using the *FatSecret Platform API* would not be a sustainable solution. Because none of the other food composition databases is offering an API, a new web service based on the BLS was developed.
The web service was implemented according to the Relational State Transfer (REST) architecture. RESTful web services are stateless and implement HTTP methods only. For the transfer of information, XML, JavaScript Object Notation (JSON), or both, can be used. For now the web service accepts only JSON [75–77].
Using cloud services for data storage is an emerging trend throughout the world, for the advantage of scalability and adaptability to the given workload. Hardware is no longer a problem of the developer [78]. Therefore, it was decided to use *Azure Cloud Services* (Microsoft Azure, Microsoft, Redford, USA) for the realization of the food composition data service.

2.4.1. Development environment

Azure

Azure offers services for building, testing, deploying and managing applications. It furthermore supports different operating systems and programming languages, e.g., .NET, Python, NODE.js, PHP and many more. Not only SQL (NoSQL) as well as SQL databases can be integrated. All in all, Azure offers everything needed for a RESTful web API that is connected to a data storage [79].

MySQL Workbench

MySQL is a relational software management system, which is published as open source software. MySQL Workbench (Oracle Corporation and/or its affiliates, Redwood City, USA) is a graphical user interface for handling of MySQL databases, e.g., database design and modelling, database administration and database migration [80, 81]. The used version was MySQL Workbench 6.3.

NODE.js

The web server was programmed in *NODE.js* (Version 6.10.3, NODE.js Foundation, San Francisco, United States), which is server side *JavaScript*. It is asynchronous and event-driven [82]. The *express framework*, which is also a project conducted by the *NODE.js* foundation, was used for the API. The framework offers a lot of HTTP utility methods and takes care of setting up the basic functionalities of the server, granting a robust performance. So developers can concentrate on defining the needed routes and detailed functions [83].

Visual Studio

For developing *Visual Studio Community* (Visual Studio Community 2017, Microsoft, Redford, USA) was used. *Visual Studio Community* is a free IDE that offers a lot of features for developing applications, from Android and Windows up to web applications [84]. The combination of using Azure and Visual Studio allows for deployment of web applications in just a few steps, as those two services work hand in hand. Visual Studio furthermore offers the possibility to start a project as an Express App, so that it automatically sets up the express framework.

Postman

Postman (Version 5.1.3, Postdot Technologies Inc., San Francisco, United States) is a toolchain for support in API development. It enables developers to test APIs automatically by setting up request collections and run the whole collection with the Collection Runner [85].

2.4.2. Web server / API

For communication with the mySQL Database, the *mysql2* package was used. Mysql2 is a mySQL driver for NODE.js which ensures a fast and secure connection to mySQL Databases, using Transport Layer Security (TLS) encryption. We decided to use the OAuth 2.0 protocol for granting the mobile App access to the web server. An authorization by client credentials only seemed to be sufficient for the test server, therefore no further authentication of users took place. The OAuth 2.0 framework is based on using access tokens instead of owner's credentials, for authorization, thus making the storage of user credentials unnecessary. An access token is a string

representing a certain scope, lifetime, and other access attributes [86]. In this case the JSON Web Token (JWT) was used, which holds all the claims of the token inside a JSON object [87]. For building the JWTs the package *jsonwebtoken* was used and for implementing the OAuth workflow the packages *passport* and *oauth2orize* were utilized.
The url package was applied to break down the URL and parse the search terms. All the packages were installed using the node package manager (Version 3.10.10, npm Inc., Oakland, United States [88]).

2.4.3. Database

For research purposes we received a licence for the *Bundeslebensmittelschlüssel (BLS)*. The BLS was downloaded as a plain text file. First, using the Azure Table Storage seemed like being a good idea. It is a NoSQL key-value store, which is highly scalable and allows OData-based queries [79]. But apparently not all the query functionalities included in OData are yet implemented. Thus it was concluded that the query functionality was not sufficient. Finally it was decided to use a MySQL Database for storing and querying the BLS. The downloaded data was transferred to a MySQL Database using MySQL Workbench.

2.5. Web client

Together with a group of dietitians working at the VAEB the necessary features for a web client, allowing a dietitian to perform a dietary intervention, were discussed. Discussions included the representation of the collected data as well as the possibilities to correct the data entered by the patient. Moreover, the need of giving feedback was

analysed. Eventually, a list of necessary features for the back end was developed and a concept for the extension of the web client was drafted.
For testing the system, a minimalist version of the needed tools, was implemented, including the ability to display pictures and the newly developed measurement profiles.

2.6. Beta test & field trial

For the evaluation of the newly developed system, a beta test, with volunteers from work and university, was conducted. The main goals of this test run were to find out about the performance of the App on different phones and to identify technical problems and design flaws. Besides, the goal was to learn about the usability and time consumption for front-end users. For ethical and data security reasons, each volunteer received a pseudonym, which was used for generating an account within the KIT system.

2.6.1. Tasks for participants

The tasks for the participants were defined as follows:

- Download the Kit-nutrition App from the Google Playstore and connect it to the Kit-diabetes staging server.
- Record the food intake for 7 days, by taking pictures of every food and add the necessary annotations, by searching the right foods from the data base.
- Add the annotations as a comment if they could not be found in the database.
- Register the activities if wanted.
- Register the body weight if wanted.

- Answer a feedback questionnaire

2.6.2. Feedback questionnaire

Design

The questionnaire was designed guided by the evaluation of the MyCor system, a telehealth system for patients with coronary disease [89], and further by Delone and McLean's model of information system success [90], which defines six areas, that should be included in the assessment of an information systems quality, namely:

- System quality
- Information quality
- Service quality
- Usage
- User satisfaction
- Net benefit

For the beta test of Kit-nutrition there was no system service running in the background, therefore the sector service quality was not covered in the questionnaire. Also the sector usage was not included in the questionnaire, but judged by the amount of transmitted measurements. The questionnaire consisted of 14 multiple-choice questions about the other 4 sections. The possible answers, according to the four point Likert scale, were *disagree, rather disagree, rather agree, agree* extended by the option *don't know*. Participants were also asked about the time consumption per entry and per day and about the mobile phone and android version they had used. Furthermore the questionnaire included open-ended questions about possible feedback, like problems and suggestions. The full questionnaire can be seen in Appendix A.

Distribution

The questionnaire was sent to the participants per email. It was implemented as an interactive PDF file, constructed in OpenOffice writer (Apache Software Foundation, Forest Hill, United States). The decision of how to return the questionnaire, electronically or by hand, was left to the participants.

Evaluation

The answers to the questionnaire were summarized using Microsoft Excel (Microsoft Excel 2013, Microsoft, Redford, USA) and evaluated using RStudio (Version 1.0.153, RStudio Inc., Boston, United States).
For the multiple-choice questions the answers were graded with points from one to four where *disagree* equals one and *agree* equals four. The answer *don't know* was treated as not available. By calculating the mean of the given answers, there was a grade determined four each of the four sectors covered.
The feedback given in free text format was simplified and grouped by topics.

3. Results

3.1. Disease Management Program (DMP) - Nutrition

The following section describes the concept of nutrition therapy, as a telemonitoring program, that emerged from discussions with nutrition experts. An overview of it can be seen in figure 3.1. Before the admission to the program, patients receive information about a healthy diet and eating behaviour tailored to their special situations. They are also trained in using the needed equipment. This part is already included in the special treatment of people in the program *Health Dialogue Diabetes*.
After the admission, patients will have to keep a nutrition diary for one week, after which they have an appointment with their dietitian to discuss personal goals. This *nutrition profile week*, as it was named, will be repeated after a suitable amount of time. In the meantime, patients will be in a *support & supervision* phase.
During the **nutrition profile** week, patients will have to track their food intake, by images and annotations, in order to create a food record. During this phase, they will be provided with an overview of their own food consumption and feedback on single meals or the corresponding annotations.
In the **support & supervision** phase, patients will only have to track their weight once a week and report their physical activity. It's very important that the personal goals are visible for every patient and that they get regular feedback and reminders about

healthy eating habits. This can be done via semi-automated messages. Furthermore it is recommendable to have some sort of reward system and/or a way to show the personal progress in order to keep the motivation of the patients up. For the health/nutrition expert in charge it is important to get alerted if the patient's weight is rising or if a patient stops doing his records.

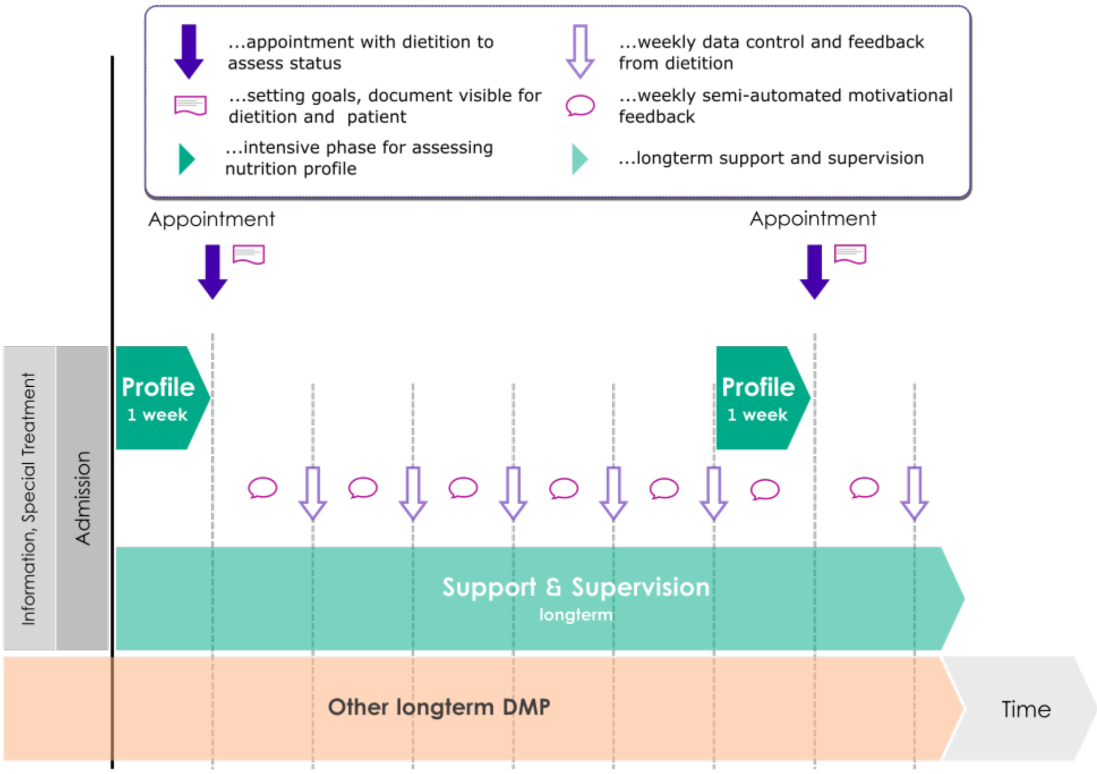


Figure 3.1.: Overview of the treatment pathway of medical nutrition therapy in a telehealth program.

3.2. Data structure

In order to be able to fulfill all the requirements needed, regarding the KIT-nutrition system, three profiles were defined: a **meal**, a **meal part/ food item** and a **meal**

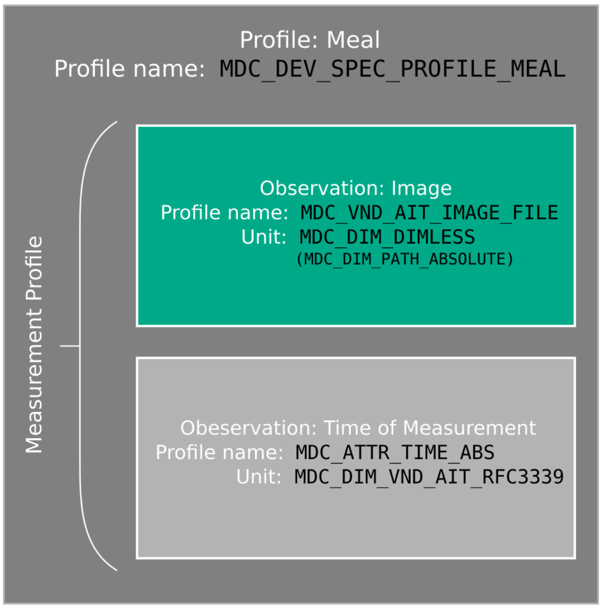


Figure 3.2.: Definition of the profile and the observation profiles for a meal.

summary profile. The meal profile includes an image of the meal and the time of the measurement, as depicted in figure 3.2. A special feature of the meal profile is that the unit of the meal image can either be a path or dimensionless. Within the database of the mobile phone, both of these units are allowed, while within the Kiola database, only the unit dimensionless is allowed. The profile of a meal part/ food item includes the *big eight* of nutrition, energy, carbohydrates, sugar, fibre, proteins, fat, saturated fatty acids and cholester, extended by the measures of bread unit, portion size and average portion size. It furthermore contains the BLS key and the name of the food, as well as a reference of the meal it is part of. It also contains the time of measurement (table 3.1). The meal summary profile is needed to be able to set daily goals for caloric intake or a maximum number of bread units per day. It summarizes all the food items of one day and therefore consists of almost the same measurement profiles as the meal part profile. It is illustrated detail in table 3.2.

Table 3.1.: Definition of the profile and all the observation profiles for a meal part/ food item.

Profile: Meal part Profilename: MDC_DEV_SPEC_PROFILE_VND_AIT_MEAL_PART			
Observation	Profile name	Unit	Occurences
BLS key	MDC_VND_AIT_FOOD_SBLS	MDC_DIM_DIMLESS	1
Name	MDC_VND_AIT_FOOD_NAME	MDC_DIM_DIMLESS	1
Carbohydrates	MDC_VND_AIT_FOOD_CARBS	MDC_DIM_MG	1
Sugar	MDC_VND_AIT_FOOD_SUGAR	MDC_DIM_MG	0-1
Fibres	MDC_VND_AIT_FOOD_FIBRE	MDC_DIM_MG	0-1
Proteines	MDC_VND_AIT_FOOD_PROTEIN	MDC_DIM_MG	1
Fat	MDC_VND_AIT_FOOD_FAT	MDC_DIM_MG	1
Saturated fat	MDC_VND_AIT_FOOD_FAT_SATURATED	MDC_DIM_MG	0-1
Cholesterol	MDC_VND_AIT_FOOD_CHOL	MDC_DIM_MG	0-1
Energy	MDC_VND_AIT_FOOD_ENERGY	MDC_DIM_X_CAL	1
Bread Units	MDC_VND_AIT_FOOD_BU	MDC_DIM_BE	0-1
Portion size	MDC_VND_AIT_FOOD_WEIGHT	MDC_DIM_X_G	1
Average portion size	MDC_VND_AIT_FOOD_WEIGHT_AVERAGE	MDC_DIM_X_G	0-1
Time of measurement	MDC_ATTR_TIME_ABS	MDC_DIM_VND_AIT_RFC3339	1
Reference	MDC_VND_AIT_OBS_REF	MDC_DIM_DIMLESS	1

Table 3.2.: Definition of the profile and all the observation profiles for a meal summary.

Profile: Meal summary Profilename: MDC_DEV_SPEC_PROFILE_VND_AIT_MEAL_SUMMARY			
Observation	Profile name	Unit	Occurences
Carbohydrates	MDC_VND_AIT_FOOD_CARBS	MDC_DIM_MG	1
Sugar	MDC_VND_AIT_FOOD_SUGAR	MDC_DIM_MG	0-1
Fibres	MDC_VND_AIT_FOOD_FIBRE	MDC_DIM_MG	0-1
Proteines	MDC_VND_AIT_FOOD_PROTEIN	MDC_DIM_MG	1
Fat	MDC_VND_AIT_FOOD_FAT	MDC_DIM_MG	1
Saturated fat	MDC_VND_AIT_FOOD_FAT_SATURATED	MDC_DIM_MG	0-1
Cholesterol	MDC_VND_AIT_FOOD_CHOL	MDC_DIM_MG	0-1
Energy	MDC_VND_AIT_FOOD_ENERGY	MDC_DIM_X_CAL	1
Bread Units	MDC_VND_AIT_FOOD_BU	MDC_DIM_BE	0-1
Time of measurement	MDC_ATTR_TIME_ABS	MDC_DIM_VND_AIT_RFC3339	1

3.3. Mobile App KIT-nutrition

The Kit-nutrition App extends the KMC, by the functionality to track the food intake. As shown in figure 3.3 the button nutrition was added to the main menu. Unlike the other measurements, for example blood glucose or personal well-being, the sector nutrition needs more than just one activity.

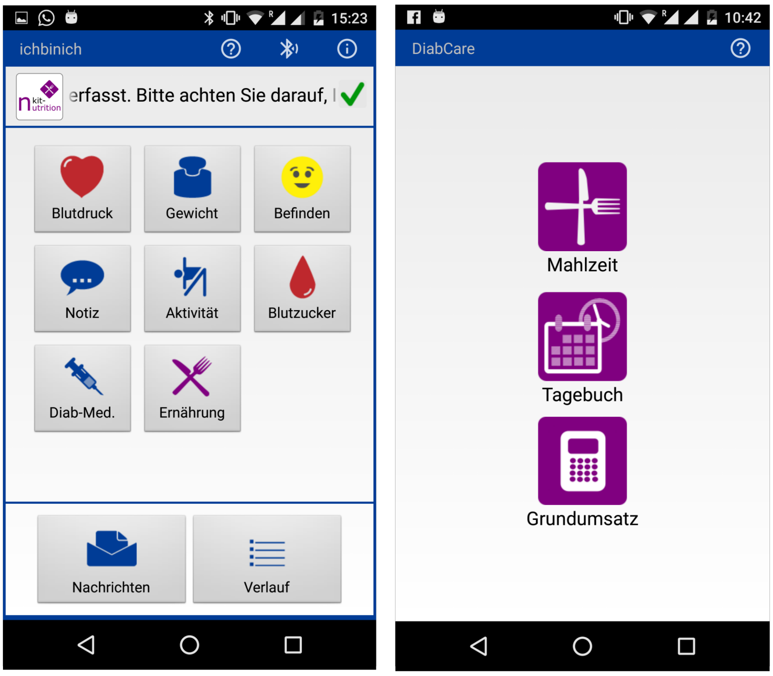


Figure 3.3.: Screenshots of the main activity of the Kit-nutrition App (left) and the main menu of the nutrition diary (right).

As indicated in figure 3.3, the developed App extension consists of three main functionalities, the possibility to add a new meal to the diary, a BEE calculator and the nutrition diary. In figure 3.4 the workflow of the new part of the App is depicted. It shows all the Activities, Fragments, Services and Loaders, the nutrition part consists of. Moreover, it depicts where data is read from and written to.

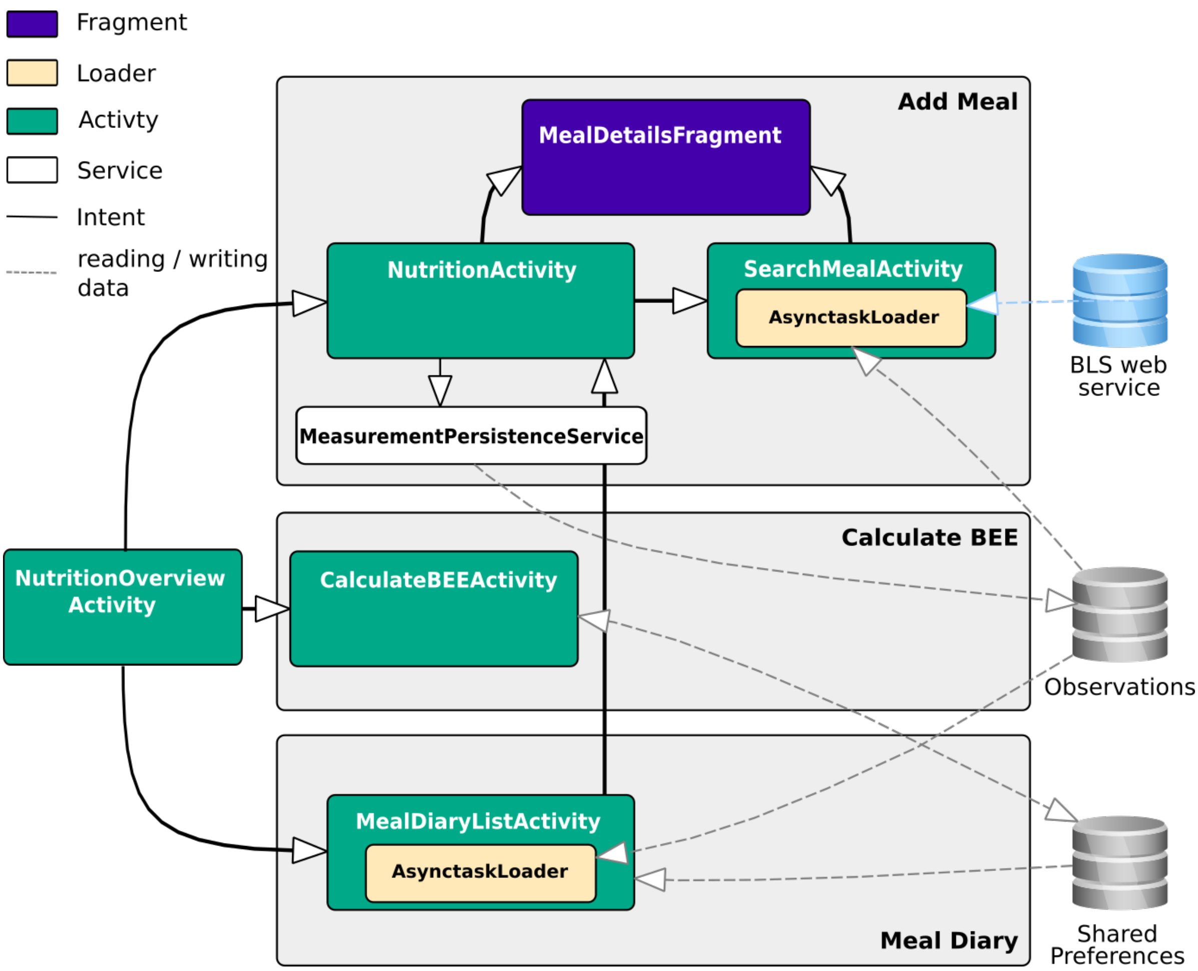


Figure 3.4.: Workflow of the nutrition sector of the Kit-nutrition App.

3.3.1. Adding meals

User interface

The first step for adding a meal is to choose if it is a breakfast, lunch, dinner or a snack. The view of that activity can be seen in figure 3.5. The next task, in the intended use of the App, is adding a picture of the meal. This can be done by either taking a picture, with the integrated camera activity, or choosing one from the gallery. The annotation of the image is done by searching for appropriate entries in the database.

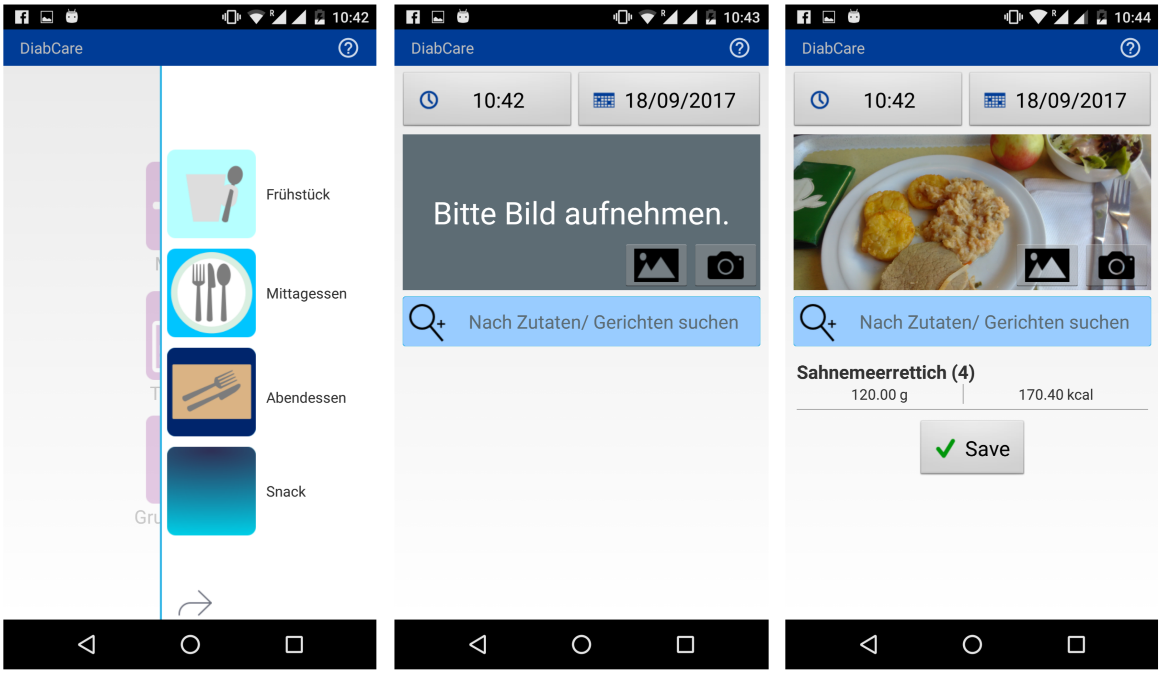


Figure 3.5.: Screenshots of the view for choosing the mealtype (left) and the activity for addig a meal with (right) and without (middle) entered information.

A list of already entered food items is shown as a suggestion (figure 3.6) and is filtered while typing. If a specific food item has not been entered before, the online search is started by pressing the go button. In case there were no foods found that match the entered query string or if there was a connection error, an information is shown that can also be found in figure 3.6. After having successfully added the respective food items to a listview, another window opens on a single click on one of the items. It enables the user to enter the consumed amount of the chosen food and then save it.

BLS server requests

Before the request is started, the internet connection is checked automatically. If there is no internet connection, a toast, which shows this fact, appears to the user.

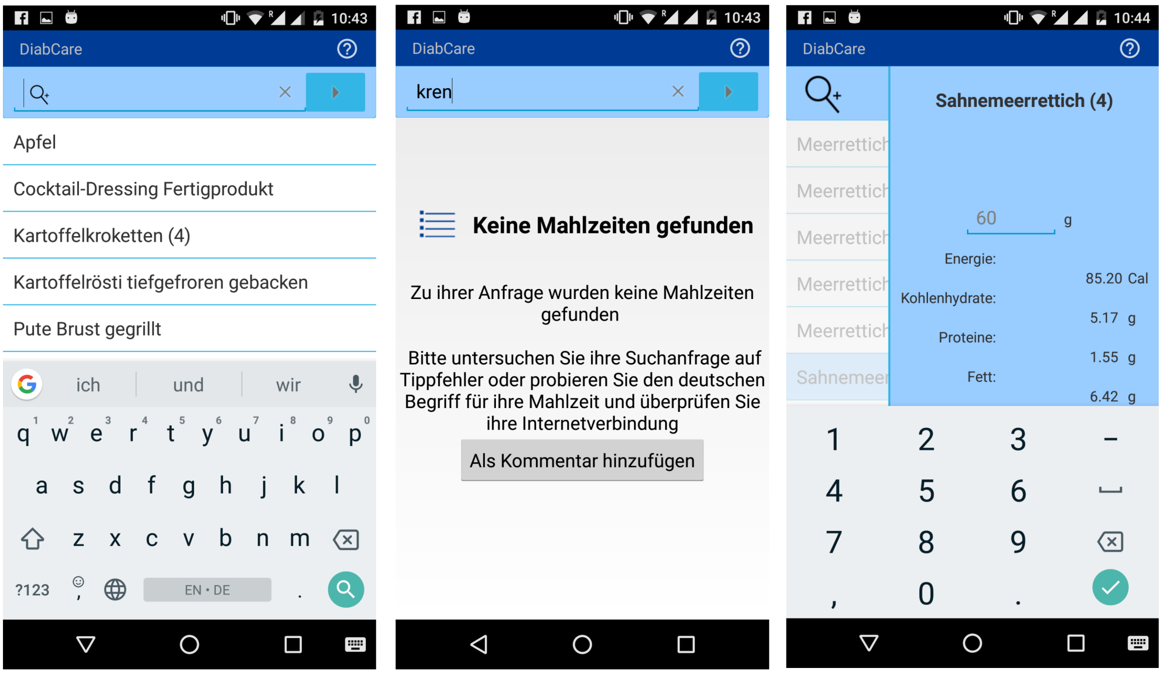


Figure 3.6.: Screenshots of the meal search activity while typing (left) and the information given if there was no result found (middle), as well as the view while entering the portion size (right).

The online search is implemented as a GET request to the *BLS web service*. If there is an authentication token stored, it is loaded and added to the GET request, which is initiated via *HTTPS*. On success, the server answers with a JSON array of foods, including the name and the key, which is then fed to the activities listview. On error, three different cases are distinguished.

Unauthorized: This means, that either there was no token sent with the request or that the token was invalid or expired. Therefore, this error is handled by requesting a new token. On successful retrieval of a new token, it is stored in the shared preferences.

Timeout: A timeout error may occur if the phone has a bad connection to the internet. In this case the request is repeated.

Other: All other errors are handled by showing an error message.

On choice of a food from the list, another GET request is started to load the details of the food in question. Errors are handled the same way as before.

Storage of measurements

Pressing the save button in the nutrition activity, starts a background task, which saves the entered measurements in the internal *observations* database. Values are stored as measurements and the observations they consist of. For images, the absolute path of it is stored in the database. The image itself is saved in the default image folder of the internal storage.

3.3.2. Calculating the BEE

User interface

The activity for calculating the BEE is a simple form that needs to be filled in. After informations on the height, weight, age and gender have been entered, the BEE is calculated by hitting the button. The corresponding user interface is depicted in figure 3.7.

Storage of values

All the entered values are stored in the shared preferences. If the BEE has been calculated before, those values are loaded on start of the activity and shown in the respective fields

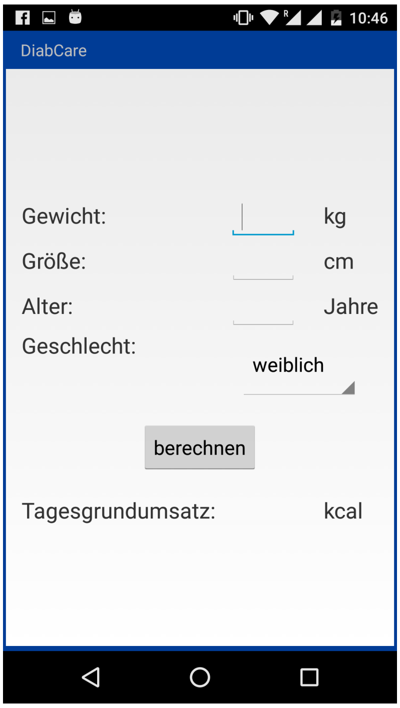


Figure 3.7.: Screenshot of the activity for calculating the BEE.

3.3.3. Nutrition diary

User interface

The nutrition diary is a list of entries being relevant in the context of nutrition. It shows meals, as well as activities and weight entries. Moreover, a daily overview is added, which summarises a user's caloric intake and consumption of energy by sports and the basal metabolic rate. It also illustrates the distribution of the macronutrients for the whole day (figure 3.8).

On Click of one of the entries, more detailed information is shown (figure 3.9). For the daily summary, the detail view, further includes the values of saturated fatty acids, cholesterol, sugar and fibres. For a meal entry, the details view shows the picture of the meal as well as all the annotations and its summarised calories.

On long click of an entry, a dialogue opens, which provides the user with the

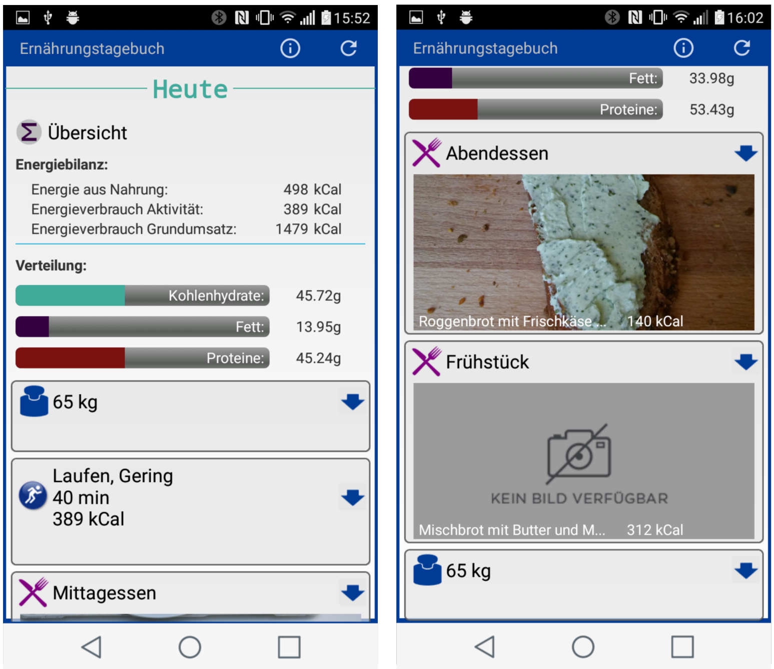


Figure 3.8.: Overview of the diary showing the summary of the day, a weight and an activity entry (left) as well as two meal entries, where one doesn't have a picture (right).

opportunity to add additional information, if applicable. To a meal entry, comments and food items can be added (figure 3.10).

3.3.4. Synchronisation of measurements with KIOLA

Synchronisation with KIOLA, is provided by the so called KiolaASAPNetworkService, a service that is running in the background and is up-/downsyncing measurements and observations to/from the KIOLA server as soon as possible. This happens via HTTP commands. If the observation is an image, only the path to the picture is stored in the *observations* database on the phone. Thus, before uploading an image observation to the KIOLA server, the image is read and base64 encoded. The resulting string is uploaded afterwards.

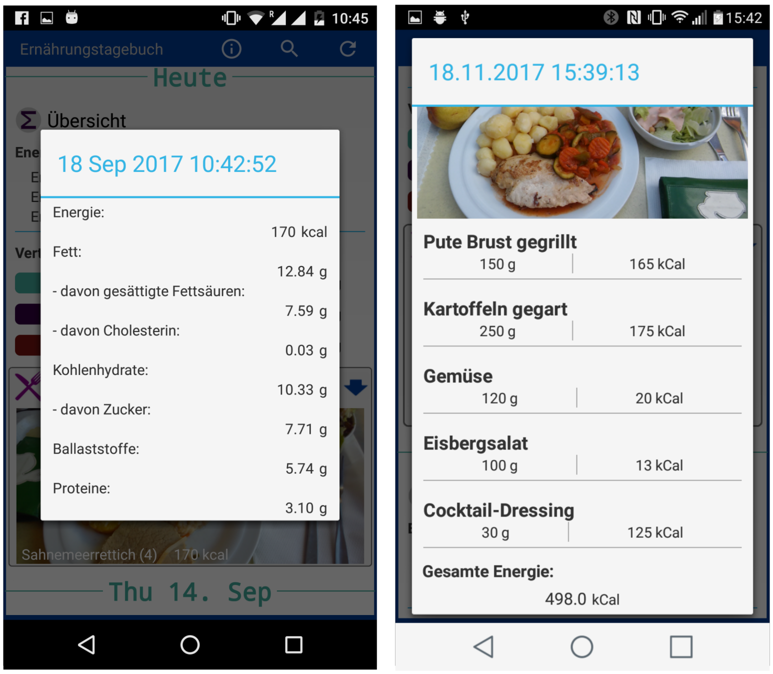


Figure 3.9.: Detailed views of daily summary (left) and one meal (right).

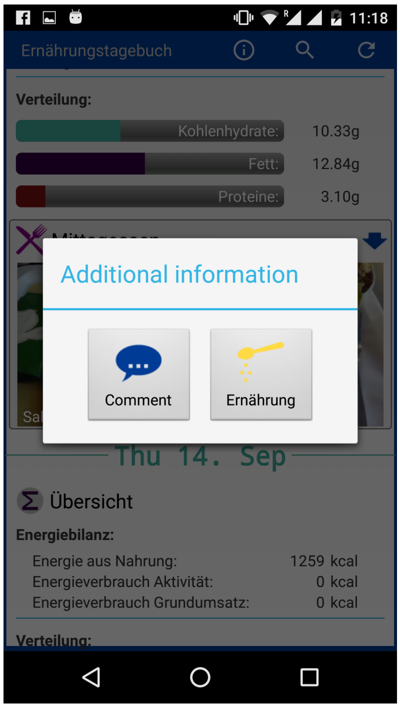


Figure 3.10.: Dialogue for adding information to a meal.

3.4. Web service for food composition data

The resulting web service is a combination of a web server and a MySQL database, both hosted by Azure. It is presented on `https://bls-dev-service.azurewebsites.net`. An overview of the web service can be seen in figure 3.11. It shows the main parts of the service, namely the authorization framework and the resource server, which queries the MySQL database, holding the BLS data.

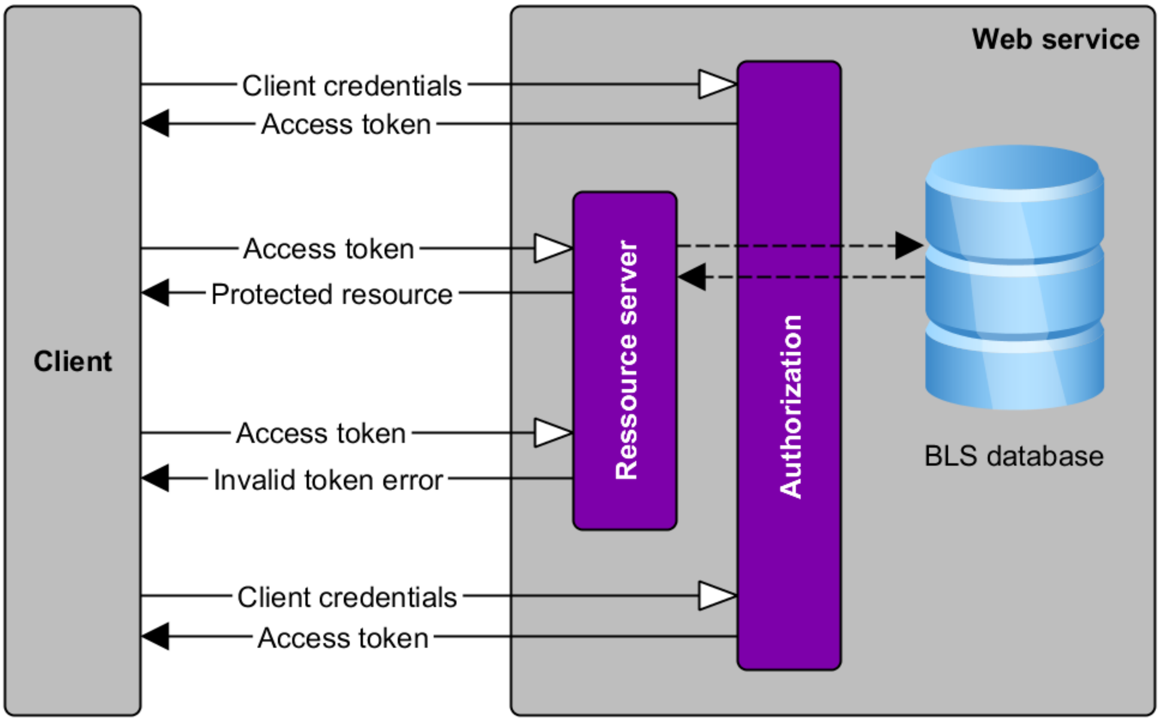


Figure 3.11.: Overview of the interactions of the BLS web service, guided by [86]

Authorization framework

The authorization framework can be accessed via the route `/oauth/token`. Requests, that are directed to the authorization framework, are checked for client credentials. These need to be stored in the header of the incoming HTTP request, base64 encoded into a string. If the client credentials are correct, a client credentials grant will be passed to the client in form of a JWT.

Resource server

The resource server is built to search the BLS for items containing a certain string or access single items by their id. Those routes are protected by the passport framework, which only grants access to them if the request includes a valid token. The request has to comply with the following syntax.
To search the BLS for foods the query needs to follow the pattern `/api/items?name=[string]`. The string can include multiple search terms, separated by the character '+'. On such a request an SQL query directed to the BLS database is started. For a string containing up to three parts, all the possible permutations of the parts are built, leading to an SQL query for an array of strings. The query uses the *SELECT* and the *LIKE* operator, to only retrieve the columns, name and id, of items with a name containing the query string. The result of such a query, consists of a JSON array of food items. Each item being made out of the name and the id of the food. The array is sorted by the length of the item names and a JSON array, including the first 50 entries, is sent back to the client.
A call to the route `/api/items/[id]` returns the item with the stated id. The server again starts an SQL query, by searching for an item with the wanted id and selecting the information: id, name, carbohydrates, proteins, fat, sugar, fibre, cholesterol, mono saturated fatty acids, bi saturated fatty acids, calories, bread units and average portion size. If an item with the requested id is found, it is sent back to the client, as a single JSON object.

BLS database server

The database server can be accessed via `bls-dev-service-mysqldbserver.mysql.database.azure.com`. It consists of a single database called *mysqldatabase58831*, which includes the table *bls_values*. The table *bls_values* contains all the data from the BLS 3.2. The server can only be accessed by using an SSL/TLS encrypted connection. This adds another layer of security.

3.5. Web client

3.5.1. Implemented features

The web client was modified in order to be able to depict the newly defined profiles, including the food images. So far, only the measurement list was adapted and no other new views were generated. The measurement list now displays every meal, as shown in figure 3.12. The view expands on hovering over it or clicking on it and presents the meal image as well as all the meal parts, it consists of.

3.5.2. Required features

The required features for the back end, as discussed with dietitians and nutrition experts are listed below:

- An overview of the nutrition profile, including a timeline of images and total calories of a meal
- A detailed view for each meal, showing all the nutrients and other information

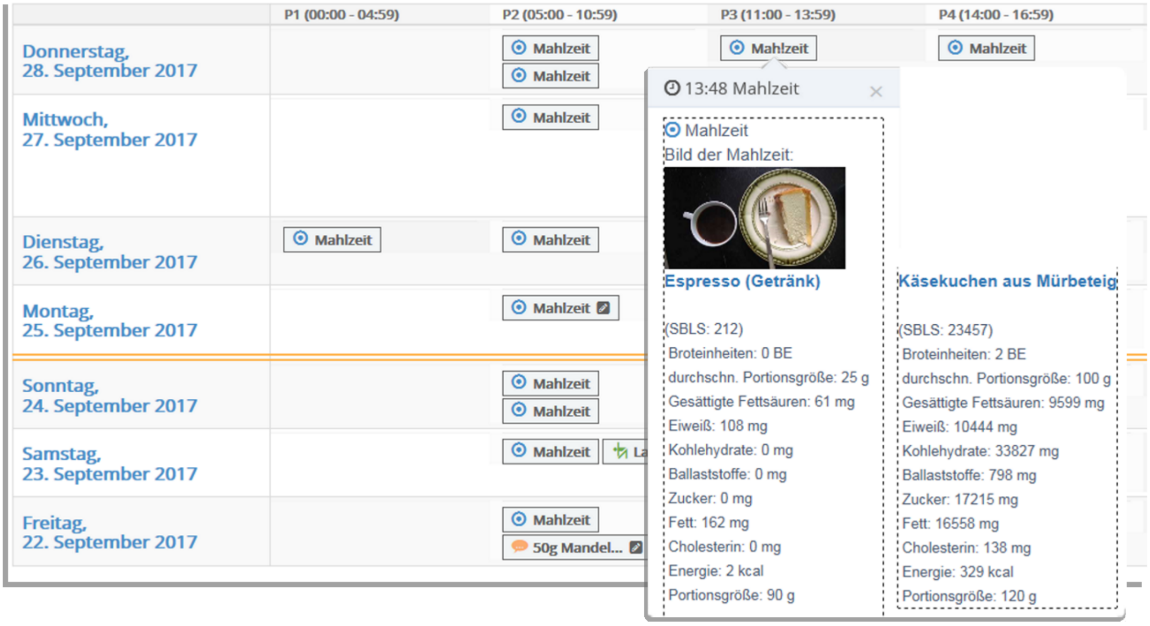


Figure 3.12.: The measurement list view of the Kiola web client, showing an expanded view of a meal.

- For patients with insulin medication:
  - An overview of the blood glucose development
  - A clear depiction of the relation between blood glucose level, insulin dosage and nutrition
- The possibility to give feedback, especially for single meals or meal parts
- A tool to set target values, for example, the maximum of Bread Units (BU)s or calories per day

3.6. Beta test & Field trial

The test run was conducted with volunteers from work and university. 15 people signed up for the beta test of the KIT-nutrition system. One of them was excluded, because he did not have an Android phone and therefore could not use the App. The

remaining 14 participants included 3 women and 11 men. Participants were quite young with a median of 26 years (minimum: 24 years, maximum: 53 years). The level of education was high, with the majority of people having at least a masters degree (minimum: school leaving examination, maximum: PhD.) and all of them were using their smartphone on a regular basis.
The test run started on September 26th and ended on October 6th, 2017. Within those two weeks the participants had to track their nutrition for 7 days.

Usage

3 of the 14 participants took pictures of less than three meals, one participant took down about 14 meals, the other 10 volunteers transmitted at least 21 pictures of their meals. In total the participants uploaded 407 meals, 1181 meal parts and 50 activity entries.
9 of the 14 volunteers reached the goal of tracking their nutrition for 7 days, one of them for 6 days, one for 4 days and the remaining 3 tried it for one day. This concludes to a usage of 77.55 % of the intended 84 days. The histogram is presented in detail in figure 3.13.

3.6.1. Questionnaire

The response rate of the questionnaire was 12 out of 14. The given answers to the multiple choice questions, split up into the different areas, are indicated in the figures 3.14 - 3.17. The charts show which answer was given, for each question and how often. Furthermore, the grades for each area are given next to the title of each figure. They concluded to *2.9* for *system quality*, *3.4* for *information quality*, *3.1* for *user satisfaction* and *2.9* for *net benefit*.

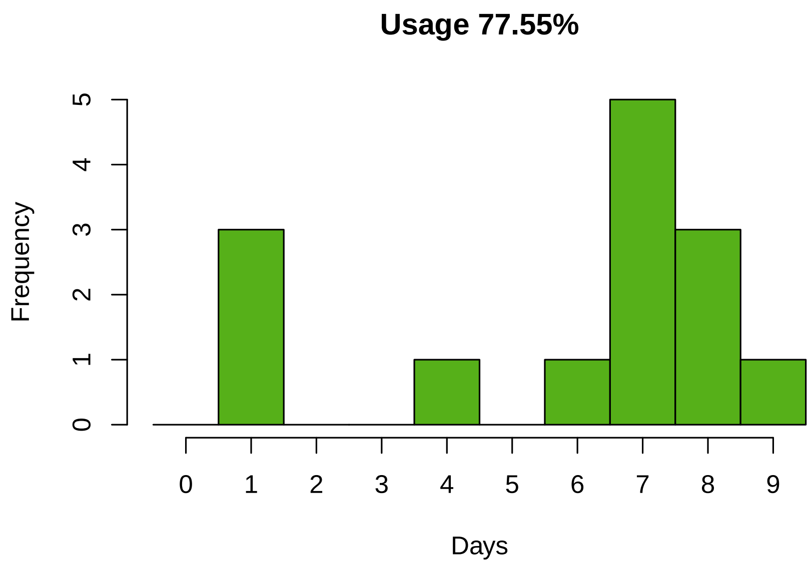


Figure 3.13.: Histogram of the usage of the App for each person, measured by the number of active days.

System quality

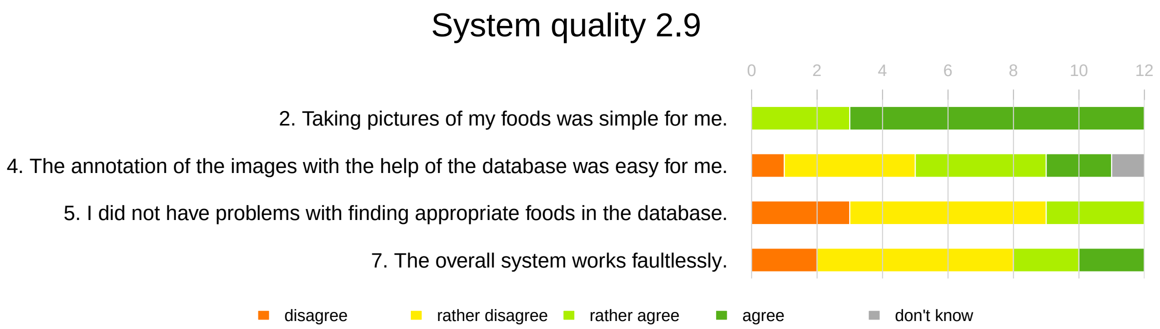


Figure 3.14.: Assessment of questions about system quality.

None of the participants had problems taking pictures of their food. The annotation of the pictures with the help of the database was troublesome for 5 people and one person could not remember. Nine people stated that they had difficulties finding matching food items in the database and four people indicated that the system worked without errors.

Information quality

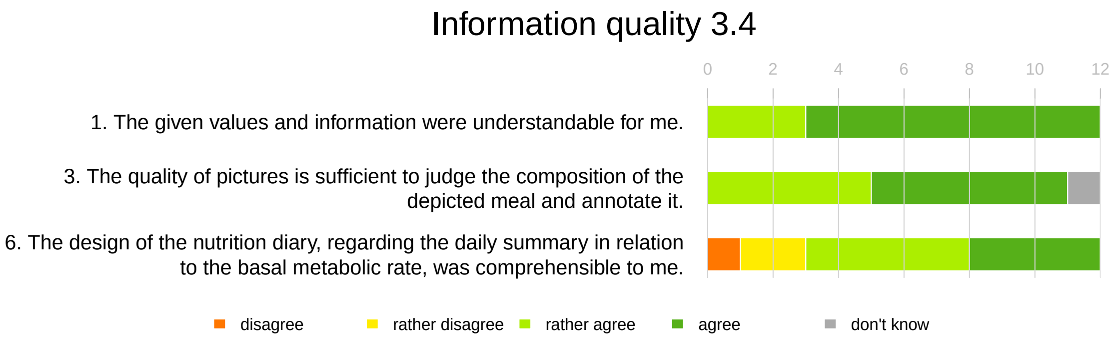


Figure 3.15.: Assessment of questions about information quality.

All the subscribers found the given values and information at least rather understandable and found the image quality sufficient for the given purpose. Only one participant made no indication on this matter. Three of the participants had problems in understanding the daily summary in relation to the basal metabolic rate, which is shown in the nutrition diary.

User satisfaction

Nine people were of the opinion that the overall system is user friendly and all of them thought that the inclusion of nutrition and sports into this DMP is a good idea. Eight of the volunteers answered they would recommend using the nutrition App to friends. Eight people thought that keeping a nutrition diary can be done rather quickly, whereas two people answered in the negative.

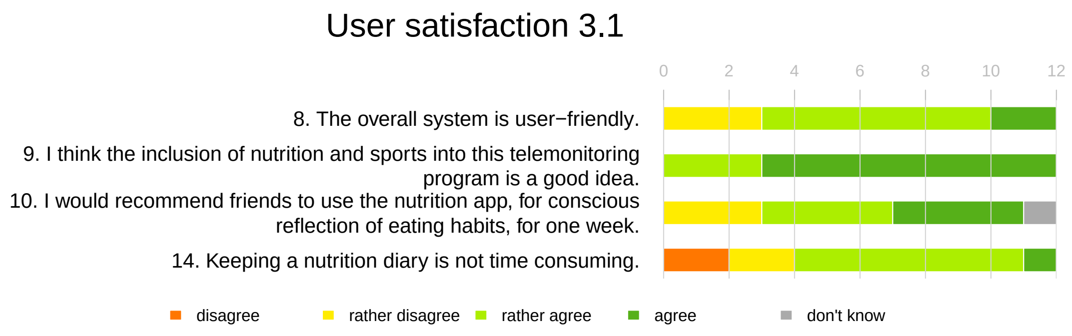


Figure 3.16.: Assessment of questions about user satisfaction.

Net benefit

Only one participant thought that the App did not help him to observe his dietary intake more consciously, whereas four people at least rather disagreed with the statement that the system helped them taking better care of their health. Seven people made the resolution to mind a more healthy lifestyle and eating habits in the next weeks.

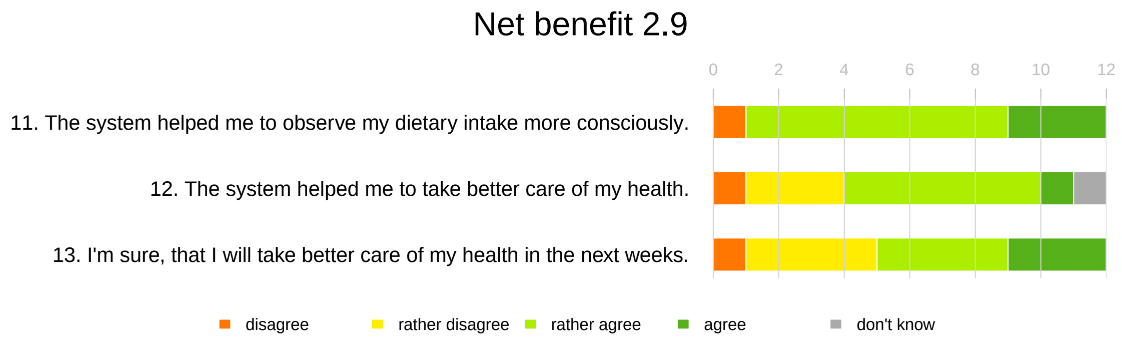


Figure 3.17.: Assessment of questions about the net benefit.

3.6.2. Problems & Suggestions

Every person that returned the questionnaire had at least one suggestion or problem to report. The most common areas of interest are depicted in the figures 3.18 and 3.19.

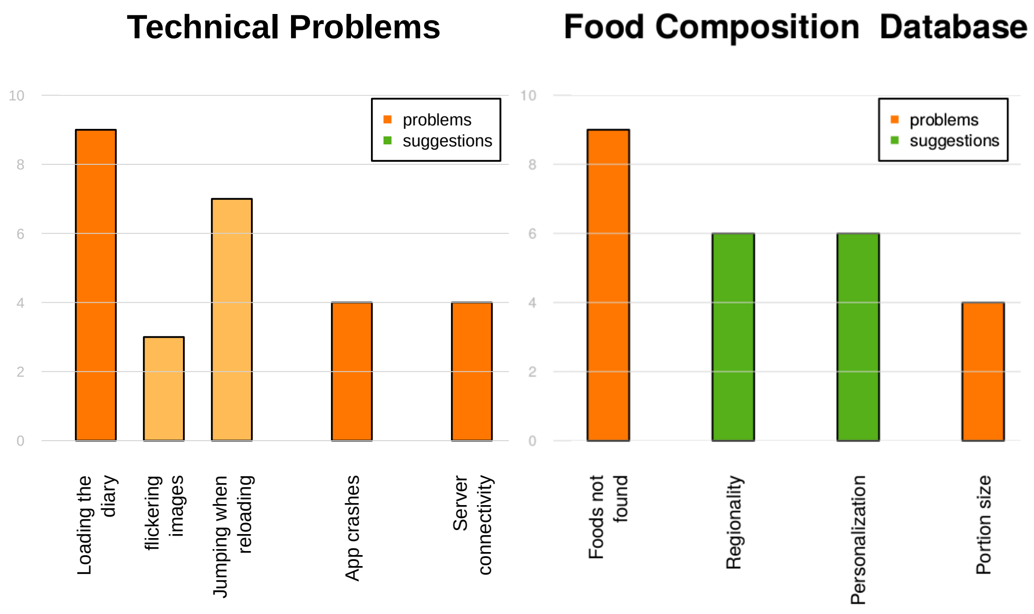
There were four positive remarks about the idea and the system that could not be sorted into one of the categories. Furthermore, there were 14 more statements, given by 7 different people, that did not correspond to the categories below of which the only one being mentioned twice was the suggestion of using a weighing scale in order to measure the weight of the food items more accurately.

Technical problems

Four people had the problem that the App stopped working, whereas one of them could not enter the diary at all anymore. The others encountered this problem only occasionally, e.g., after returning from using another App. The people that stated problems in synchronising entries with the Kiola server were also four in number. The most frequently reported technical problem, with altogether nine people mentioning it, were phones that had problems loading the nutrition diary smoothly. Three out of those nine noticed that the images were flickering due to slow loading/rendering and seven faced the problem that the diary's view was jumping back to the first entry unintendedly. There were four more technical problems reported by only one person.

Food composition database

The most frequently noted problem (9 times) with the food composition database, were that people could not find the foods they were searching for. Six participants



(a) Summary of technical problems

(b) Problems and suggestions about the database

Figure 3.18.: Summary of the most common problems and suggestions.

suggested the use of a regional database to avoid problems due to cultural and language based differences. The wish for a way to personalize the food composition database, based on personal routines, was expressed by six people. Four people voiced concerns about the accuracy of the suggested portion size. Four more statements, about the food composition database, were only mentioned once and are therefore not stated here.

Nutrition diary

The wish of making meals editable after saving them was uttered by seven people. Two subscribers criticised the representation of the meal images, because parts of the image were cut off and three participants thought that the nutrition information, especially the distribution of the macronutrients, was not depicted in an understandable way. The suggestion that the summarized calories should be shown for every meal was mentioned by two individuals. Five people proposed a different handling of drinks within the diary, of which some suggested to make drinks a separate class of food and some thought it was unnecessary to track all of their drinks. There were 15 more one-time comments written by two people. Most of them are concerning personal preferences in App handling or design and are thus not dealt with in more detail.

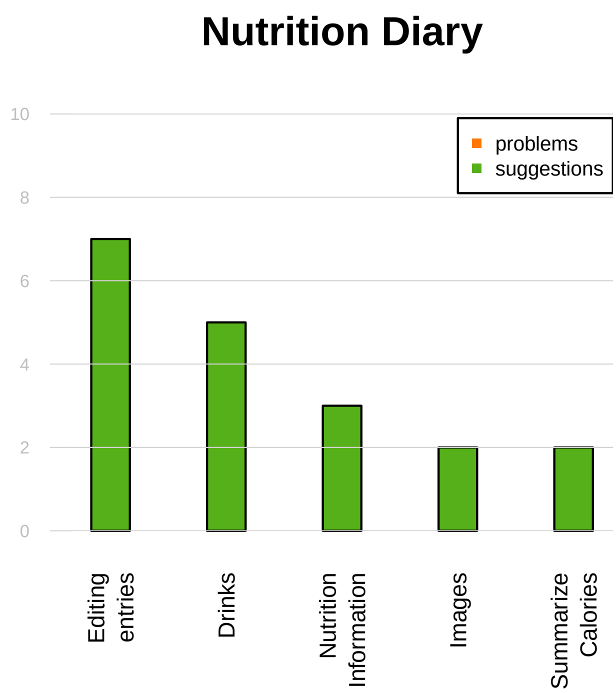


Figure 3.19.: Overview over the most common problems and suggestions about the nutrition diary.

3.6.3. Time consumption & Used phones

The median of time consumption per entry was 5 min (min: 2 min, max: 7 min). The median of the time consumed by using the App for a whole day was 18 min (min: 8 min, max: 60 min) per day.

A list of the used phones is shown in table 3.3. The only phone that was used by two participants was the Motorola G4. Both phones had the same Android version installed.

Table 3.3.: Table listing the different phones and Android versions used by the participants of the beta test.

Phone	Android version
Blackberry A100-2	6.0.1
Blackberry DTEC50	6.0.1
Blackberry PRIV STV100-4	6.0.1
Huawei P9 lite	7.0
HTC One Mini 2	4.4.2
Fairphone 2	6.0.1
Motorola G4	7.0
Samsung Galaxy A3 (2017), SM-A320FL	6.0.1
Samsung Galaxy S5 mini	6.0.1
Sony Xperia XZ	7.1.1
Sony Xperia Z1 compact	5.1.1

4. Discussion

The assessment of the newly developed KIT-nutrition system resulted in mainly positive feedback, therefore, showing that the inclusion of an electronic nutrition diary is technically feasible. The usage of over 75% proved, that an intensive use of the system for a whole week in a real life setting is manageable. For application in nutrition counselling, even a diary of about 4 to 5 days could be of great value, as long as it includes weekdays as well as weekends. However, the App still showed minor technical problems. The deficits and suggestions on how to overcome them are further addressed in section 4.1.1.
All in all, it can be summarized that the performance of the App was stable on the majority of the different phones in use. This was not certain, as during development several problems have been encountered, due to differing Android distributions and system Apps used by phone manufacturers. Those especially caused problems regarding the handling of the camera and the storage management. Apparently those difficulties have been solved successfully.
The system architecture, including the newly developed profiles, proved to be applicable. By having two separate profiles for meals and food items, the setup is flexible enough to allow for an adaptation to the different needs. For some target groups, keeping a meal diary by taking pictures only might be sufficient. So, for them the possibility to enter food items could be removed remotely, by their dietitian.
Most of the given information was understandable to the users, and people in general

thought that this program was a good idea, although it could be a little more user friendly. About half of the test users believed that the system actually helped them to become healthier. From preceding research it is known that actual diabetics judged the health they gained from keeping an electronic nutrition diary a lot more positively [40]. Therefore, it can be assumed, that a trial within one of the DMPs will show even better results in the sector of net benefit.
Also the feedback from the nutrition experts was very affirmative. For them, the use of such a system would open a wide range of new possibilities. Primarily, an image assisted approach would help them overcome some of the limitations they are facing, so far, in nutrition management, as they would have a tool to re-evaluate the patients' self-assessment. The potential areas of application are discussed in more detail in section 4.2.1.

4.1. Problems & Suggestions

4.1.1. Technical problems

There have been several technical problems encountered by the test users, as for instance, issues with the synchronisation of measurements with the back end. Those were actually caused by the database that was used within the staging server. The database was partly unavailable, due to recurring tasks, like securing the data. The problem was solved by manually synchronising the measurements, that were uploaded to the server, with the database.
The bugs while loading the diary actually have different causes. While scrolling through the diary, the images are loaded in the background to enable smooth scrolling. As the images need a long time to load, compared to the rest of the data, they appear a little later. One way to speed up the loading process would be to save thumbnails

of the images.
The bugs of the diary's list view should be sorted out by calling the right method after having finished the loading process. Some of the jumpy behaviour could also be due to the quite different Android distributions in use, as, for example, Blackberry phones had not been tested before.
The fact, that the App crashes after coming back from another App is probably connected to Android pausing Apps that run in the background, if there is not enough processing power left. On pause, the variables of an activity are deleted and can cause a Null pointer exception on return from another Activity. Why exactly the diary activity broke down completely for one of the participants, has not been solved yet, but it is most probably connected to the fact that the Android version of the phone (Android 4.4.2) was beneath the target version of the KIT-nutrition App (Android 5).

4.1.2. Food composition database

The choice of the right food composition database is crucial in such a project, as user satisfaction, but also the accuracy of information is highly depending on it. The crux of the matter is to find the best cost-benefit ratio. For now, we used the BLS, as it was offered free of charge for scientific purposes. Another advantage of the BLS is, that all the stored values are measured or calculated using scientific means and are therefore very accurate [48]. One of the shortcomings, that got confirmed during the beta test, is that the BLS does not include brand names or Austrian synonyms for foods. Although, this might not be a problem for experts working in this field, it definitely is for amateurs. The inclusion of the ÖNWT could solve some of these problems, while still being as accurate as the BLS.
During the development process, we also used another food composition database,

namely, the FatSecret database. It has the huge advantage that users can add foods to the database themselves and therefore they have a lot more information available, such as different suggested portion sizes, brand names and UPC/EAN barcodes. Unfortunately the Premium Version, which would be needed for this project, as it is the only version offered in German, is too cost expensive (3000 $ per month). It was also discovered that the data sometimes misses important values, like the portion size in grams or any other scientific weight measure. This also deepens the suspicion that some of the nutrition information in the FatSecret database might be inexact.
As diet tracking is a quickly emerging sector, it will for sure be of interest to follow upcoming projects and look out for other database options, as for example the food composition database by MyFitnessPal, which might soon be available for the public.
Another reason, that complicated searching foods, was the fact that there was no information available on which foods are the most common ones. Therefore, sorting search requests was done solely based on the length of food names. If such a system is used for a longer period of time it would make sense to collect information about which foods are eaten more often, so that the usability improves over time.
The suggestion mentioned above could be expanded to also consider the personal preferences of each user, as wished for by some test users.

4.1.3. Nutrition diary

Editing or deleting entries, which was asked for by seven participants, is so far not possible within the KIT system. This was decided in order to prevent patients from cheating about their vital parameters. Mostly, patients transfer those measurements to their phone from their measurement devices, using NFC, leaving almost no space for human error. When entering a meal by hand, this is something very different. The most common mistakes were that people forgot to change the time or mistyped the portion size. In those cases it would of course make sense to enable the editing of entries. To do so, a new status would have to be implemented for changed measurements in order to assure the correct upload to the server. Anyways, it would be smart to keep the initial measurements to inhibit the misuse of this feature.

4.2. Outlook

4.2.1. Areas of application

Commonly used methods in medical nutrition therapy are the 24-hour diet recall, FFQs and pen and paper dietary records. Those methods are prone to under-reporting and human error. Using an image assisted dietary record allows the attending dietitian to get a better picture of the patients diet as he/she can estimate the portion sizes himself/herself. The possibility to give immediate feedback enables the use of the system in teaching of patients. Therefore the KIT-nutrition App could be of great help in several of the DMPs that are already using the KIT system. The areas of application are listed below.

- **Lifestyle intervention**
  This area especially applies for diabetes type 2 patients, but also for overweight patients in order to prevent diabetes and cardiovascular diseases. It would also help in treatment of patients with high blood pressure. For those patients, the most prominent goal is to change unhealthy eating habits, therefore, a detailed analysis of all the meals might be unnecessary. Keeping an electronic nutrition diary by taking pictures only could be sufficient for this group of patients.

- **Diabetes treatment**
  Diabetes patients that have to use insulin happen to have problems with the right dosage of their medication, which in the worst case can lead to hypoglycaemia. In this case, the nutrition diary could be used to supplement the glucose curves. A combined view of dietary intake, used insulin and blood glucose levels could help the patient, as well as the attending healthcare professional, to better estimate the insulin dosage.
- **Training of diabetics**
  For people suffering from type 1 diabetes, it is inevitable to learn how to estimate the amount of carbohydrates, often measured in BUs, in their meals. By using the KIT-nutrition App they could calculate the BUs of their meals. In this case, it would be recommendable to not only estimate the portion sizes of the consumed food items but actually measure them using a weighing scale.

4.2.2. System requirements & Extension possibilities

As described, the areas of application for an integrated nutrition diary are manifold. Consequently, the flexibility of such a system is very important. First of all, the recommended diet has to be tailored to every patients personal needs [19]. Recent projects go as far as basing the perfect diet on the DNA of a patient [91].
Not only the diet, but also the system has to be adaptable in order to enable its use in the different areas of application. As mentioned, in a lifestyle intervention the exact annotation of meal images might not be necessary. Therefore it should be possible, for the attending dietitian, to disable that feature on the patients' device. In the training and teaching of type 1 diabetes patients, on the other hand, the information from the food composition database is crucial. For them, also the display of the consumed BUs in the meal diary is necessary, whereas it would play a minor role in diabetes

prevention.
For the purpose of reducing patients' workload and therefore enhancing their motivation and adherence, modern technologies to annotate images and food intake could be used. One technology that could improve usability are UPC/EAN code readers. This is a quite common feature in nutrition Apps and would not be complicated to implement as there are already a couple of Apps and libraries that could be used for reading the barcodes with the camera of mobile phones. Again, the bigger problem is, that a database that connects the barcodes to the corresponding foods would be needed.
Another interesting approach is automated image analysis, as already done in some Apps and scientific projects [33–38]. The first Austrian project trying to implement this is called SNICS (360factory GMBH, Vienna, Austria, [92]). This might be worth looking at in more detail, as regional differences, in supply and choice of foods, seem to essentially influence those systems.

4.2.3. Future work

In order to integrate the sector nutrition into the KIT system, the next steps will be to further discuss and specify the details, on how to improve the system, and, consequently, implement the features needed.
After that, a pilot study in one of the running DMPs will have to be conducted and evaluated in order to validate the usability of the system within the actual target group, which is in average older and less technically experienced than the test users of the trial run. After that, an actual rollout can be planned.

Appendix

Appendix A.

Questionnaire for the evaluation of Kit-Nutrition

Fragebogen zur Evaluierung von KIT-Nutrition:

Liebe Testerin, lieber Tester!

Vielen Dank für die Teilnahme am Test der KIT Nutrition App in der aktuellen Beta-Release-Version. Fokus der Befragung liegt auf der Zusatzfunktion, die über den Button „Ernährung “ zugänglich ist.

Unser Ziel ist es, die App möglichst selbsterklärend zu gestalten und die Funktionen und Handhabung auf die Bedürfnisse der Anwender abzustimmen. Damit wir bei der Weiterentwicklungen die Anforderungen der Benutzer möglichst gut berücksichtigen können, ist Ihr Feedback besonders wichtig. Dieser Fragebogen soll uns dabei helfen.

Bitte lesen Sie die Fragen aufmerksam durch und beantworten Sie alle Fragen **ehrlich**. Die Auswertung erfolgt anonym, bitte daher keine Identifikationsdaten auf dem Fragebogen hinterlassen.

Versuchen Sie die nachstehenden Fragen zu beantworten ohne lange zu überlegen, sondern entscheiden Sie sich möglichst spontan für eine Antwortmöglichkeit.

		trifft nicht zu	trifft eher nicht zu	trifft eher zu	trifft zu	weiß nicht
1.	Die angegebenen Werte und Informationen im Ernährungstagebuch sind für mich verständlich.	○	○	○	○	○
2.	Das Aufnehmen von Fotos meiner Ernährung ist für mich einfach.	○	○	○	○	○
3.	Die Qualität der Fotos ist ausreichend gut, um die Menge und Zusammenstellung eines Menüfotos nachvollziehen und annotieren zu können.	○	○	○	○	○
4.	Das annotieren der Bilder mit Hilfe der Datenbank ist für mich einfach.	○	○	○	○	○
5.	Ich habe keine Probleme passende Einträge (Zutat, Gericht) in der Datenbank zu finden.	○	○	○	○	○
6.	Die Gestaltung des Ernährungstagebuches mit der Tageszusammenfassung und dem Bezug zum Grundumsatz ist für mich übersichtlich.	○	○	○	○	○
7.	Das Gesamtsystem arbeitet fehlerfrei.	○	○	○	○	○
8.	Das Gesamtsystem ist benutzerfreundlich.	○	○	○	○	○
9.	Ich finde die Einbeziehung von Ernährung und Sport in diesem Telemonitoring-Programm eine gute Idee.	○	○	○	○	○
10.	Ich würde Bekannten empfehlen, die Ernährungs-App für die bewusste Befassung mit dem eigenen Ernährungsverhalten eine Woche lang zu verwenden.	○	○	○	○	○
11.	Das System hat mir geholfen, mich bewusster mit meiner Ernährung zu befassen.	○	○	○	○	○
12.	Das System hat mir geholfen, mehr auf meine Gesundheit zu achten.	○	○	○	○	○
13.	Ich werde sicher auch in den nächsten Wochen mehr auf meine Ernährung achten.	○	○	○	○	○
14.	Das führen des Ernährungstagebuchs kann rasch erfolgen.	○	○	○	○	○

15. Um meine Ernährung aufzuzeichnen benötige ich geschätzt,

pro Aufzeichnung: ______ min

pro Tag: ______ min

16. Anmerkungen oder Verbesserungsvorschläge:

Allgemein:

Technische Umsetzung:

(Verbindungsprobleme, Ladedauer (Tagebuch, Zutatensuche), Auftretende Fehler...)

Information zur Ernährung:

(Vollständigkeit der Datenbank und der angezeigten Nährstoffe, Übersichtlichkeit des Ernährungstagebuchs...)

17. Ich habe folgendes Gerät mit folgender Android Version verwendet:

(einzusehen unter Einstellungen, Über das Telefon)

Gerät (z.B.: LG G6) : ______

Android-Version (z.B.: 6.0.1): ______

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