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Development of a dental diet-tracking mobile app for improved caries-related dietary behaviours: Key features and pilot evaluation of quality

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Abstract

Objective: Diet significantly contributes to dental decay (caries) yet monitoring and modifying patients' diets is a challenge for many dental practitioners. While many oral health and diet-tracking mHealth apps are available, few focus on the dietary risk factors for caries. This study aims to present the development and key features of a dental-specific mobile app for diet monitoring and dietary behaviour change to prevent caries, and pilot data from initial user evaluation.

Methods: A mobile app incorporating a novel photo recognition algorithm and a localised database of 208,718 images for food item identification was developed. The design and development process were iterative and incorporated several behaviour change techniques commonly used in mHealth. Pilot evaluation of app quality was assessed using the end-user version of the Mobile Application Rating Scale (uMARS).

Results: User feedback from the beta-testing of the prototype app spurred the improvement of the photo recognition algorithm and addition of more user-centric features. Other key features of the final app include real-time prompts to drive actionable behaviour change, goal setting, comprehensive oral health education modules, and visual metrics for caries-related dietary factors (sugar intake, meal frequency, etc.). The final app scored an overall mean (standard deviation) of 3.6 (0.5) out of 5 on the uMARS scale.

Conclusion: We developed a novel diet-tracking mobile app tailored for oral health, addressing a gap in the mHealth landscape. Pilot user evaluations indicated good app quality, suggesting its potential as a useful clinical tool for dentists and empowering patients for self-monitoring and behavioural management.

Keywords

mHealth, mobile applications, dental caries, oral health, diet, behaviour change techniques

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Introduction

Dental caries, otherwise known as dental decay, is the most prevalent disease in the world, affecting 2.5 billion people globally, and causing substantial negative impacts on quality of life and economic costs.[1–3] A major aetiological factor for dental caries is the diet, in particular the consumption of fermentable carbohydrates such as sugar, which is essential in the caries process.[4] Behavioural modification

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of the diet is often recommended in textbooks and clinical guidelines for the management of high caries risk patients.[5–7] However, while many dental practitioners acknowledge the value of dietary counselling, few provide it to their patients.[8–10] In addition, dietary advice when given was often brief and general, and not based on detailed dietary records.[8–10]

Detailed dietary assessments, i.e. diet diaries, are records of the time, type, and amount of food and drinks consumed over 3–5 days, and are important as the factors influencing the cariogenicity of the diet are complex, and diet diaries can help clinicians create tailored dietary advice that resonates with the patient and increases the likelihood of behavioural change.[11] However, despite UK clinical guidelines for oral health prevention recommending the use of diet diaries, a recent study found only about 27% of general dental practitioners reported using diet diaries in their practice.[12]

A commonly cited reason for not using diet diaries in clinical practice is the perception of poor patient compliance to diet monitoring, especially with traditional methods such as paper diary templates, which can be burdensome, time-consuming, and more prone to reporting bias.[12,13] Mobile apps and the use of mHealth (defined as 'the use of mobile technologies to track and improve health outcomes'[14]) offer a potential solution by increasing the convenience of diet logging, for example through photo recognition of food items, and can even automatically populate nutritional info, enhancing the fidelity and richness of the diet data. Some evidence suggests that the use of mHealth is effective for promoting healthier diets[15] and changing nutrition behaviours, as well as nutrition-related health outcomes such as obesity and blood lipids.[16] Furthermore, mHealth has the capacity to incorporate behaviour change techniques (BCTs) such as self-monitoring, improving knowledge, and building self-efficacy, which can empower and motivate the patient for behaviour change to improve health outcomes.[17] For example, a recent systematic review in oral health including 15 randomised clinical trials using mHealth interventions to improve oral hygiene, incorporated a variety of BCTs and found significant improvement in plaque and gingivitis outcomes.[18]

While there are many apps for general diet tracking in relation to weight loss and diabetes management,[19] emphasising various aspects of the diet (e.g. saturated fat, total calories intake, etc.), very few apps focus on free sugars intake and the goal of improving oral health through dietary change in adults. A review of 33 popular oral health promotion apps found only one-third included some brief or partial discussion of diet, with only two apps providing comprehensive dietary information.[20] To the best of our knowledge, only one app – FoodForTeeth – that addresses dietary assessment from a dental perspective is currently available for download on app stores.[21] While this app provides dentally relevant information for several common foods in Western diets and allows input of a diet diary through text or photos which can be sent to the dental professional for review, it lacks features for self-monitoring and relies on the dental professional to identify harmful dietary patterns.

Therefore, there is a need for a dental-specific diet-tracking app that can assist the dentist in obtaining a detailed snapshot of their patient's diet for the tailoring of dietary counselling and at the same time empower the patient to recognise potential harmful patterns in their diet and support their behaviour change through persuasive content and features. In this paper, we describe the development of a mobile app that aims at preventing dental caries through improving dietary patterns. We discuss the key features of the app which were developed incorporating evidence from prior literature and BCTs from mHealth, together with data from an initial evaluation of the app quality and qualitative feedback collected from user-testing.

Methods

Overview of the development of the app

The app was developed collaboratively by the National University of Singapore (NUS) Faculty of Dentistry, NUS School of Computing, and NUS Smart Systems Institute. We reviewed recent systematic reviews on mobile apps for oral health to identify the key features and limitations of the currently available dental-specific diet-tracking apps.[20,21] The design of the features was further informed by the 10 heuristics (e.g. usable and aesthetically appealing design, educate users, visibility of the user's status, etc.) recommended for improving the usability of persuasive health technologies[22] and guided by the evidence where possible. For example, the WHO sugar guidelines were used to determine the cut-offs for the traffic light system colouring of the total sugar consumed in the day.[23] Common BCTs used in mHealth were also incorporated where possible.[17,24,25]

Reference food database, photo recognition model, and app system architecture

The variety of foods in cosmopolitan Singapore is uniquely diverse. Thus, we used the Health Promotion Board food database created specifically for Singapore, which curates the nutritional information of 3531 food items.[26] We further supplemented this database with the AUSNUT[27] to improve the range of foods included.

A localised Singaporean food dataset was used as the image database for photo recognition as previously described.[28] Briefly, 231 popular Singaporean food dishes were selected from the Health Promotion Board food database created specifically for Singapore,[26] and candidate

images crawled from the Internet. In addition, following the first round of feedback, categories specific to dental decay (e.g. sugar-sweetened beverages, bakery items, biscuits, etc.), and categories based on food appearance (e.g. packaged, bottle drinks, freshly prepared coffee and tea) were added and the images collected and curated as above. The final dataset contains 241 food categories, a total of 208,718 images with a minimum size of 50 pixels × 50 pixels to guarantee the quality of retrieved images, and comprised 47.6 GB of data.

Food recognition was performed using state-of-the-art deep learning models to automatically identify the items in photos taken based on the collected image database and provide nutritional information from the reference nutritional databases. In particular, the Xception model was employed, as it yields superior accuracy and achieves moderate training time yet competitive inference time compared with its counterparts.[29] The system architecture of eDental is a progressive web app deployed on a cloud server, with its frontend developed via Angular and Ionic frameworks, and the backend developed by node.js with Redis deployed for caching, and the backend server using PostgreSQL as the database system.[30] Further technical details on the system architecture of the app, data collection and curation pipeline in the creation of the image dataset, and evaluation of the food recognition deep learning model, are available elsewhere.[28,30]

Evaluation using the Mobile Application Rating Scale (MARS) and qualitative feedback: beta-testing of the prototype app and pilot evaluation of the final app

User-testing for the app was conducted among first-year undergraduate dental students (aged 19–21 years) at the NUS Faculty of Dentistry. As part of the Cariology module, students are tasked with completing a 5-day diet diary and reflecting on the experience. The choice of 5 days was made based on dental clinical guidelines recommending diet diaries to be kept for a minimum of at least 3 consecutive days.[31] No restriction on the method used to log their diet was given, and the app was offered as a potential method. Students were then invited to provide anonymous quantitative and qualitative feedback on the app quality using a self-administered survey questionnaire.

Participants assessed app quality using the widely used and validated Mobile Application Rating Scale (MARS) assessment tool.[32–34] MARS is 23-item questionnaire consisting of four objective quality subscales – Engagement (5 items), Functionality (4 items), Aesthetics (3 items) and Information quality (4 items) (Appendix), and an optional subjective quality section which evaluates the user's overall satisfaction (4 items). All items are scored on a 5-point Likert scale (1-inadequate, 2-poor, 3-acceptable, 4-good, and 5-excellent). A score of 3.0 or more was deemed to be of high quality.[21] The original MARS requires training and expertise in mHealth and the relevant health field to administer, but as our goal was to obtain feedback on the quality of the app from the user's perspective, the simpler, end-user version of the MARS (uMARS) was used in this study.[33] uMARS has similar questions to MARS but with improved readability, and an additional subscale that evaluates the users' perceived impact of the evaluated app (6 items) (Appendix). Qualitative feedback was obtained at the same time through the free-text questions in the self-administered survey questionnaire. The specific questions asked were 'What did you like / not like about the app?', 'What challenges did you face in using the app?', 'Do you have suggestions for improvement?', and 'Any other feedback?'.

User-rated evaluation of app quality at two cross-sectional time points using two separate cohorts (2020 and 2022) of first-year dental students at each time point was collected; first, during the beta-testing phase of the prototype app (n = 37), and a second round on the final app (n = 23) after implementing refinements and new features based on the first round of user-testing and feedback. The NUS institutional review board approved the study protocol (NUS-IRB-2020-500) as exempt along with a waiver of documentation of informed consent as the research involves no more than minimal risk to subjects and involves no procedures for which written consent is normally required outside the research context.

Data analysis

Mean values and standard deviations (SD) were calculated for each uMARS item. Section scores were derived by averaging the item scores within each section, and the overall uMARS quality score calculated by averaging the scores of the Engagement, Functionality, Aesthetics, and Information Quality sections. Information Quality was not assessed in the first round of evaluations, as the initial focus was primarily on beta-testing and troubleshooting the functionality of the prototype app but was included in the second round of pilot user-testing on the final revised app. Data analysis was conducted in SAS Version 9.4. A single examiner (CG) categorised the qualitative feedback obtained from the two rounds for descriptive purposes, without employing formal qualitative methodology, and used quotes to illustrate the main themes.

Results

Qualitative results from the first round of evaluation

In general, students found the app easy to use and had individual preferences for how to log their diet (Table 1). The dental-specific visual reports were also found to be

Table 1. Descriptive themes and illustrative quotes from qualitative feedback from the first round of evaluation: Beta-testing of the prototype app.

	Quotes
Benefits of the app	
Different methods of logging	'I like the camera feature!! Super efficient way to log in my diet'. 'The text entry feature as there were pre-uploaded food options that I could select for the food entry'. 'The gallery allows uploading of previous meals'. 'I like that there was a wide range of foods and that each food had its nutritional information for it. You can also adjust the food portions according to what you ate'.
Informative visual reports	'I like that they provided nutritional information and graphical representations of your meal intakes and that when you upload from gallery, they automatically adjust the timing based on the time the photo was taken' '(I liked) The meter telling us our sugar consumption. It's a good visual reminder for me'.
Challenges faced while using the app	
Tedious data entry and inadequate food items to choose from	'The inability to add food items quickly, the variety of food items available' 'This list of food to choose from is limited and sometime, it does not truly reflect what we ate'. 'The auto food recognition feature. It was mostly inaccurate' '(The app) was confusing to use'
Suggestions for improvement	
More instructions needed	'Usability - I find it a bit confusing as I'm not sure how I should fill out certain parts of the log'.
Reduction of visual clutter and improve the specificity for dentistry	'I think the food information on fats/ sugars/ carbs can be minimised or not displayed on the main screen to avoid cluttering of information, which can overwhelm the user... minimise the irrelevant columns to make this app more tailored to oral health' 'Too many options, visual clutter' 'Additionally, labelling the foods according to their cariogenicity is more relevant and important. (i.e. high sugar foods has a red dot next to it)'.
Increase user engagement	'To increase user engagement (i.e. more than 5 min), there need to be more components under the directory - perhaps a link to a blog which gives more information on caries so that people can have a better understanding of the concepts of 'host/ time/sugar'/ Stephens curve because I think this concept is important for the understanding of caries. A FAQ section can also help' 'It might be nice to have a reminder function in the app as well. For example, patients can set a timing for when they would like to be reminded to record their meals (e.g. If they usually eat lunch at 12pm and dinner at 6pm, they can set a reminder for that timing in the app)'
Increase food items in database or allow customisation	'I think the app should be contain more varieties for the food selection or maybe allow an input of OTHERS, thus allowing users to input their meals if it cannot be found'. 'Ability to change the nutritional values of food – benefit home cooked food suited for personal taste which might not contain typical ingredients and condiments'.

especially informative for understanding their dietary patterns. Users reported frustration with the limited list of food items in the database that made data entry tedious. Comments on the photo recognition function were polarised; while some viewed it as novel and convenient, others found it inaccurate and listed it as their least-liked feature of the app. Suggestions for improvement centred around the need for instructions on how to use the app, and the reduction of visual clutter, and the many options to fill that made data entry time-consuming. To address the most common challenge of not having a food item that best represented their consumption in the database, the most suggested improvement was to expand the number of food items in the database or allow customisable nutritional information for items not in the database. Additionally, suggestions for increased content for engagement and education, and app reminders to log meals to improve compliance were provided.

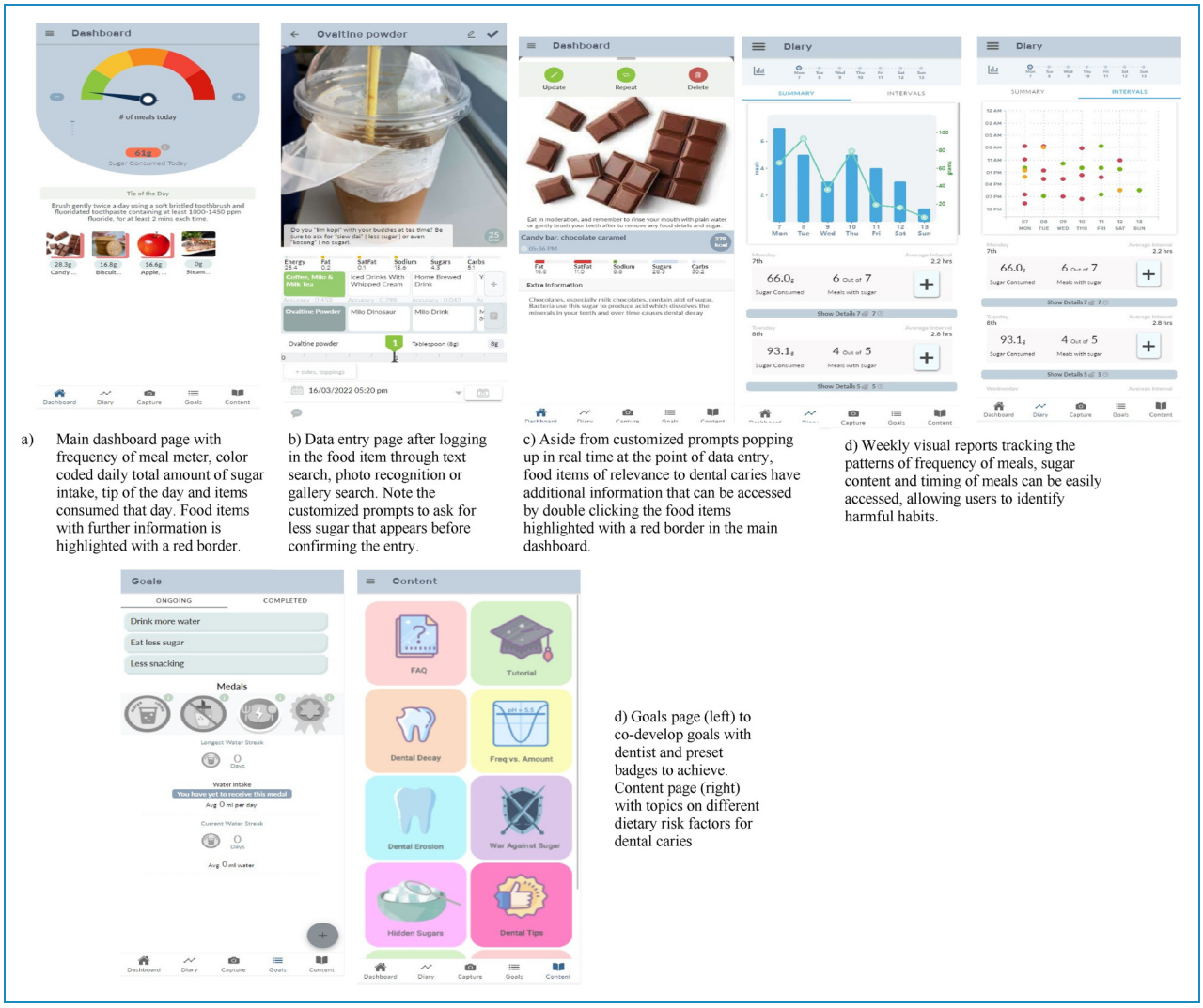
Refinements and features added following beta-testing of the prototype app

Based on the beta-testing of the prototype app, substantial refinements were made to improve its utility, knowledge content, and user experience. The following changes were made.

1. *Reduction of visual clutter* – e.g. Macronutrient information was removed and visible only when the item was double clicked.
2. *Clearer UX (user experience) design* – e.g. Simplification of data entry through less taps and ability to repeat food entries.
3. *Increased oral health educational content* – e.g. Creation of a section with oral health education on the dietary risk factors for caries and custom prompts tagged to food items, empowering users to understand and interpret the weekly reports, and appreciate the science behind the goals and metrics within the app.
4. *Improved photo recognition for food items specific to dental caries* – e.g. sugar-sweetened beverages can be better identified by using the typical shape of the cup and colour of liquid.

Key features of the final app

A brief overview of the key features and technical computing aspects of the app have been presented, and Figure 1 shows screenshots of the final key features of this dental-specific diet-tracking app.[30] In this report, we delve into the rationale and evidence behind the features. Several effective BCTs commonly used in mHealth and oral health promotion were incorporated.[24,25] For example, self-



a) Main dashboard page with frequency of meal meter, color coded daily total amount of sugar intake, tip of the day and items consumed that day. Food items with further information is highlighted with a red border.

b) Data entry page after logging in the food item through text search, photo recognition or gallery search. Note the customized prompts to ask for less sugar that appears before confirming the entry.

c) Aside from customized prompts popping up in real time at the point of data entry, food items of relevance to dental caries have additional information that can be accessed by double clicking the food items highlighted with a red border in the main dashboard.

d) Weekly visual reports tracking the patterns of frequency of meals, sugar content and timing of meals can be easily accessed, allowing users to identify harmful habits.

d) Goals page (left) to co-develop goals with dentist and preset badges to achieve. Content page (right) with topics on different dietary risk factors for dental caries

Figure 1. Screenshots* of the final app showing the key features of this dental-specific diet-tracking app.
*Images have been previously presented in conference proceedings https://dl.acm.org/doi/10.1145/3511808.3557215.

monitoring enables users to evaluate and reflect on their progression towards set goals and has been shown to be an effective BCT for a variety of behaviours ranging from dietary change leading to weight loss and the control and reduction of blood pressure.[35,36] Dental caries, being a disease that is largely preventable, is amenable to self-monitoring as the controllability of the disease and the willingness of patients to engage in self-monitoring has been previously observed.[37] BCT taxonomies coded using the 'BCT Taxonomy (v1)' by Michie et al. (2013) which contains 93 BCT techniques clustered into 16 groups,[24] and the newly proposed additional BCT techniques specific to mHealth by Dugas et al. (2020)[17] are identified for each key feature where relevant. We also describe another novel feature of our app – the creation of the real-time advice prompts, in addition to the photo recognition feature.

1. *Image recognition and multiple methods of logging*: A key feature of this app is the ability to use photo recognition to identify the food item, thus simplifying diet logging and increasing user compliance. Food entries can also be logged by text search of the food reference database, or from a gallery of previous entries.
2. *Daily and weekly visual reports on total amount of sugar consumed, frequency of meals, as well as sugar intake per meal*: Both total amount and frequency of sugar intake is associated with caries risk.[4,38,39] A traffic light colour system was employed to visually represent key metrics in an intuitive manner. Daily total amount of sugar consumed was categorised (<25 g (green); 25–50 g (yellow); and >50 g (red)) based on the WHO guidelines of reducing sugar intake to 10% (~50 g), or even 5% of total energy intake.[23] Number of meals per day was categorised (0–3 meals (green); 4 meals (yellow); 5 meals (orange); 6 meals (red); and 7 meals (dark red)) taking reference from the Cariogram diet frequency categories.[40] Weekly reports visualise sugar content per meal (< 5 g (green); 5–10 g (yellow); > 10 g (red)), and the cumulative frequency of meals. This allows users to not only assess their average number of meals per day but also identify their meals with the highest sugar content. Across weeks, they may also recognise patterns in their consumption; for example, a tendency to consume sweetened drinks at tea-time, which can then be targeted for modification. This corresponds to the BCT 2.2 'Feedback on behaviour' and BCT 2.3 'Self-monitoring of behaviour'.
3. *Goal setting and badges*: Users can set customised goals, or preset goals (e.g. 7 days streak with intake of sugars <50 g) are available in the form of badges, which remain greyed out until achieved. This corresponds to the BCT 1.1 'Goal setting of behaviour', and the obtaining of badges corresponds to the newly proposed BCT category of 'Gamification' in particular BCT 18.2 'Earn badges/levels'.[17] In a previous systematic review, 40% of effective RCTs were to use some form of goal setting.[17]
4. *Educational content page and real-time prompts:* o increase engagement and retention, educational content in the app is delivered through different several touchpoints. Food items from the Health Promotion Board's list of popular Singaporean food dishes[26] with oral health relevance were identified and categorised into food groups such as instant drinks, fruit juices, cookies, and chocolates. Customised pieces of advice were written for each group to be randomly triggered when that item was logged. The concise (<30 words) actionable advice, such as 'avoid sipping sugary drinks over long periods of time', is displayed in real-time on the data entry page for immediate user visibility. This feature is a novel feature of our app and corresponds to the BCT 7.1 'Prompts and cues'. Prompts and cues were found to be the most common BCTs used in effective trials.[17] In our app, a potentially cariogenic food item instantly triggers an advice prompt which has been customised to that food item and provides information how to minimise that risk. For example, logging 'Fruit juice' prompts the following advice: 'Instead of drinking fruit juices, try eating the whole fruit instead as it retains all the vitamins and dietary fibre in the fruit, makes you feel fuller, and lowers the amount of sugar consumed'. As the prompt is specific to the food item and triggered by an individual's unique dietary intake, the relevance and perceived importance of the advice is increased, making it more likely to be accepted and acted upon.[11,36]

   For interested users seeking more detailed information, group-specific longer form explanations on why a particular food item is relevant to caries risk can be accessed by double-clicking the item on the main dashboard. These items will be highlighted with a red border, enhancing user engagement, and promoting further knowledge acquisition.

   The dashboard includes a 'Tip of the Day' feature that randomly cycles through 13 oral health tips, improving user engagement. Additionally, a comprehensive Content section is available, offering modules on dietary risk factors for dental caries, such as 'Frequency vs. Amount' and 'War on Sugars'. These modules can be assigned by the dentist to reiterate advice given during clinic visits, providing a valuable resource for patients. The different types of educational content features cover a variety of topics ranging from the consequences of tooth decay, toothbrushing techniques, and how to reduce sugar consumption by seeking less sweet beverage alternatives, tapping o BCT 4.1 'Instruction on how to perform the behaviour' and BCT 5.1 'Information about health consequences'.[24]

uMARS results from beta-testing of the prototype app and pilot user-testing of the final app

In the first round of evaluation using the prototype app, 37 students completed the uMARS survey form. The overall uMARS app quality mean (SD) score was 3.4 (0.4) out of 5. The app rated most highly on the Aesthetics section [3.6 (0.6)], but lowest on the Engagement section [3.1 (0.5)] (Table 2). The performance of the individual items is presented in Figure 2.

Following the improvements to the app described above, the overall mean uMARS user score was slightly improved with a mean score of 3.6 (0.5) (Table 2), though direct comparisons with the scores of the first round should not be made, as the second round included the Information section, had a smaller sample size (n = 23), and the main purpose of the evaluation was not to show an improvement but rather to provide pilot data on the app quality of the final app. The Information section was rated most highly [3.8 (0.6)], with Aesthetics and Functionality close behind [3.6 (0.5), 3.6 (0.6)]. When examining the individual items (Figure 2), the items 'Credibility of the source' and 'Visual Info' scored the highest, as well as several items from the Aesthetics section such as 'Layout' and 'Graphics', whereas Customisation and Interactivity from the Engagement section performed the worst.

Subjective Quality items which are not part of the overall performed poorly in both rounds of evaluation (Figure 2).

Table 2. User Mobile Application Rating Scale (uMARS) quality rating for the first and second round of app quality evaluations.

	1st round (n = 37) Mean (SD)	2nd round (n = 23) Mean (SD)
Engagement	3.1 (0.5)	3.2 (0.6)
Functionality	3.5 (0.5)	3.6 (0.6)
Aesthetics	3.6 (0.6)	3.6 (0.5)
Information[a]	-	3.8 (0.6)
Overall MARS score[b]	**3.4 (0.4)**	**3.6 (0.5)**
Subjective	2.5 (0.5)	2.7 (0.5)

Note. The bold represent the overall score which is the average of the above sections.
aIn the first round of evaluation, the Information section was not assessed as the focus of that evaluation was beta-testing and troubleshooting the functionality of the prototype app.
bThe overall uMARS score is determined from the of the 4 objective subscales: engagement, functionality, aesthetics, and information.
SD: standard deviation.

In general, while participants reported that they would recommend the app to those who might benefit from it, they would not pay for the app. Nevertheless, on average they gave the app a rating of 3.5 (0.6) stars. Finally, the Perceived Impact items assessed in the second round of evaluation and revealed some increase in user's awareness, knowledge, and attitudes towards caries-related dietary habits (Table 3). However, the participants expressed a certain level of ambivalence regarding whether the app had effectively increased their motivation for behaviour change, encouraged help-seeking, or resulted in actual behaviour change.

Qualitative results from the second round of evaluation on the final app

Additional feedback and suggestions for improvement following the second round of evaluation are collected and summarised in Table 4. Many participants found the app well-designed and easy to use. Notably, there were no more complaints regarding visual clutter. Instead, participants praised the 'nice' and 'simple interface'. Another improvement was that none of the users reported finding the app confusing to use or needed more instructions. Less negative feedback regarding the inaccuracy of the photo recognition was observed, and several participants reported that the 'moderately accurate identification of food' was convenient. As before, participants appreciated the visual summaries of sugar intake and frequency of intake, but additionally noted that educational content such as the 'several fun facts and advice' and tip of the day feature helped improved their knowledge. The main suggestions for improvement centred around improving the photo algorithm identification of foods and improving the food database. In terms of usability and functionality, a common suggestion was to make the app, which is currently a web-based application, available for download in the app store, and the creation of reminders/notifications to log the diet to improve adherence to diet logging. Integration with other health apps and public health incentive schemes was also suggested. Other suggestions included differentiating between intrinsic sugars (e.g. in fruits) versus the more detrimental free sugars (e.g. in fruit juices), or providing sugar intake as a % of energy intake amount as per WHO guidelines.

Discussion

We developed a mobile app that facilitates caries-related dietary monitoring and identification of harmful dietary patterns, and incorporates BCTs to motivate patients to change their diet. The design process of this app was iterative, and user feedback obtained early in development spurred the improvement of the photo recognition algorithm and

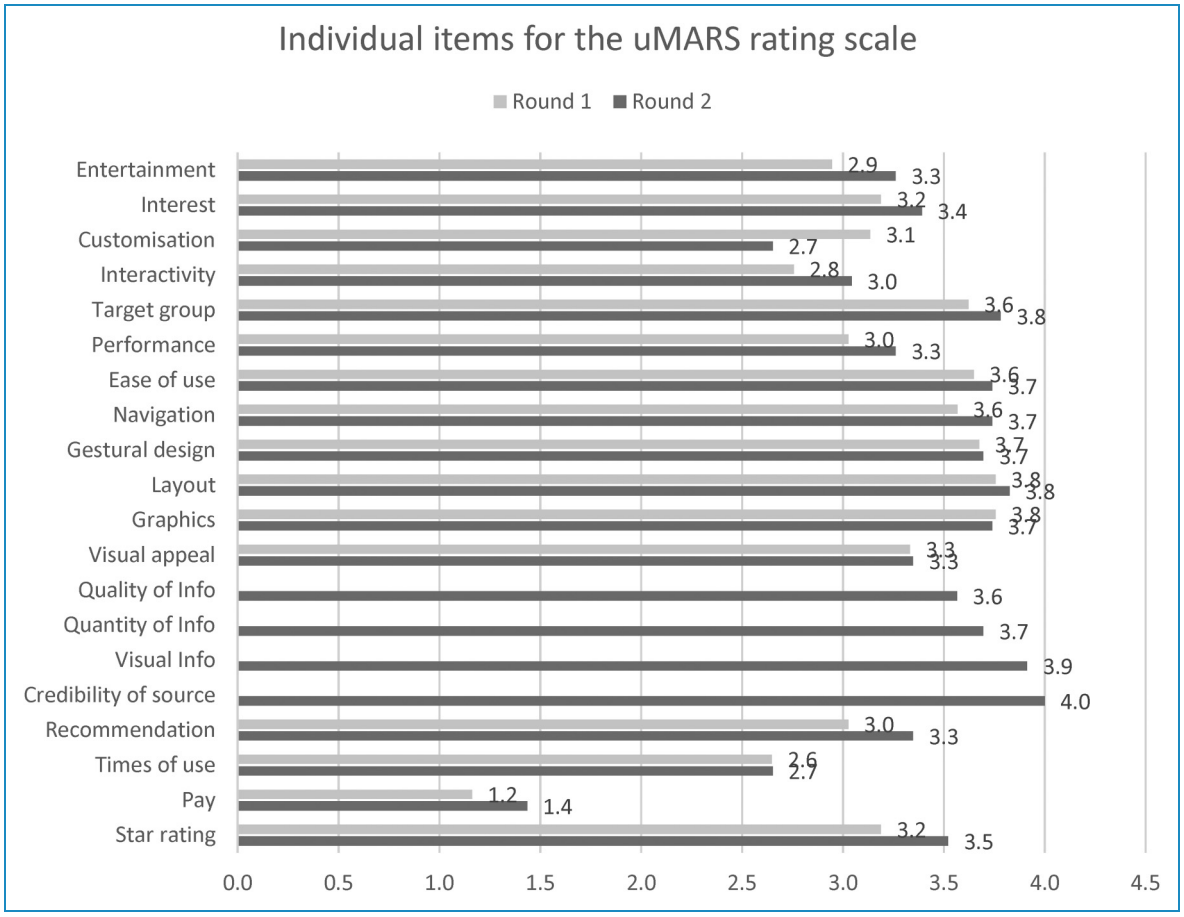


Figure 2. User Mobile Application Rating Scale (uMARS) quality rating for the first and second round of evaluations.
*uMARS is 23-item questionnaire consisting of four objective quality subscales –Engagement (Entertainment, Interest, Customisation, Interactivity), Functionality (Target group, Performance, Ease of use, Navigation), Aesthetics (Gestural design, Layout, Graphics,) and Information quality (Quality of info, Quantity of info, Visual info, Credibility of source), and an optional subjective quality section which evaluates the user's overall satisfaction (Recommendation, Times of use, Pay, Star rating). All items are scored on a 5-point Likert scale (1-inadequate, 2-poor, 3-acceptable, 4-good, and 5-excellent).

addition of more user-centric features such as real-time advice prompts. The app was assessed to be of high quality with an overall mean (SD) score of 3.6 (0.5) out of 5 on the uMARS quality scale in the pilot user-testing evaluation of the final app quality, with all sections scoring above 3.0, and the Aesthetics, Functionality, and Information Quality sections scoring above 3.5 each.

Recent reviews of mobile apps for oral health and caries prevention find limited coverage of dietary risk factors for oral health and poor information quality,[20] and very few apps focused on targeting the dietary risk factors of caries.[21] Our app addresses the existing gap in the field by demonstrating a notably higher overall app quality score than most of the apps evaluated in previous reviews. For example, only 10 out of 40 apps achieved a mean score above 3.0 in all four subscales of MARS, and apps focused on diet only received an overall MARS score of 2.7 (0.6).[21] While our app quality ratings assessed by users are not directly comparable with the app quality ratings assessed by trained professionals in previous research,[21] our results provide some support that the app meets a certain quality threshold in terms of content, user interface, and functionality, which are necessary for it to be a potentially effective mHealth intervention for behaviour change.[20]

The objective of our app is twofold. We aim to provide a useful tool for dental professionals to obtain detailed diet records from their patients in order to tailor dietary advice and prompt patient-dentist discussions to co-develop goals.[41] Oral health professionals often cite a perceived lack of time in the clinical setting and inadequate renumeration for the time spent as barriers to conducting dietary assessments and providing dietary counselling.[9,10,12] mHealth tools such as our app may be used as a time-efficient complementary clinical tool for dental professionals in modifying dietary behaviours, and our extensive content section used to elaborate on and reinforce the dietary advice given by the dentist outside of clinical time.

Table 3. User Mobile Application Rating Scale (uMARS) perceived impact items (n = 23)

Survey item	Mean (SD)	Disagree[a] %	Neither agree nor disagree %	Agree %	Strongly agree %
Awareness This app has increased my awareness of the importance of addressing the health behaviour	3.7 (0.90)	9%	30%	43%	17%
Knowledge This app has increased my knowledge/understanding of the health behaviour	3.7 (0.8)	9%	30%	48%	13%
Attitudes The app has changed my attitudes toward improving this health behaviour	3.7 (0.9)	9%	35%	39%	17%
Intention to change The app has increased my intentions/motivation to address this health behaviour	3.5 (0.8)	9%	39%	43%	9%
Help-seeking This app would encourage me to seek further help to address the health behaviour (if I needed it)	3.4 (0.7)	9%	48%	39%	4%
Behaviour change Use of this app will increase/decrease the health behaviour	3.5 (0.8)	13%	30%	48%	9%

aNone of the participants responded 'Strongly Disagree' for any of the six perceived impact items.
SD: standard deviation.

The other aim of our app is to equip users with the skills to identify and manage their caries-related dietary behaviours. It does so through several of the key features which correspond with effective BCTs used in mHealth.[24,25] For example, our app facilitates self-monitoring by enabling users to track the trends in dietary sugar intake over various time frames, including days, weeks, and even months, through the summary reports which were a well-liked feature as reported in the qualitative feedback. Likewise, the BCT of prompts and cues were facilitated by through the use of real-life prompts.

Some limitations of the app itself remain as highlighted in the qualitative feedback from the pilot user-testing of the final app. Although the current database from the HPB Singapore contains many localised food items, some participants struggled to find the exact food item consumed. Likewise, despite improvements to the photo recognition algorithm and creation of specialised training datasets to further classify types of sugar-sweetened beverages, the photo recognition was only moderately accurate. As many Asian cultures practice communal eating – where multiple food items in family portions are shared – some participants also struggled with the effort of logging the different foods. Ease of data entry is an important factor affecting the adherence to diet tracking, and these limitations may potentially influence user compliance.[19,42] Nevertheless, a systematic review showed image-based methods are well received by users and preferred over traditional methods,[43,44] and active research to address these known challenges of image-based sensing monitoring of the diet is underway.[13] For example, image segmentation of mixed meals, or ingredient recognition, has been suggested to improve the accuracy of the automated photo recognition.[42] Additional methods of diet logging relevant to specific target groups to improve the ease of data entry may also be considered. For example, the rise of sophisticated of natural language chatbots, like ChatGPT, offers new possibilities. These chatbots can be embedded within popular messaging apps and parse the user's natural language description through text or voice messages to a machine-data format which is automatically linked to a nutrition database. Follow-up chatbot messages can further gather precise details like portion sizes and timing of consumption. This approach may be particularly suitable for certain populations, such as those with lower mobile specifications or older adults who are already familiar with basic text messaging but may be hesitant to learn a new app. In addition, ChatGPT linguistic strengths can be tapped on to generate creative, natural-sounding advice and nudges which are personalised to the user.

Table 4. Descriptive themes and illustrative quotes from qualitative feedback from the second round of evaluation: pilot evaluation of the final app

	Quotes from reflections
Well-liked features of the app	
Simple, aesthetic, ease to use interface	• 'It has good user interface so it may be suitable to introduce to people who may not be as good at using mobile devices'. • 'App is well written and designed in general. Can see the effort placed in making the app as user-friendly as possible'.
Engaging content and fun facts	• 'There were several fun facts and advice relating to teeth'. • 'The fact of the day was useful'. • 'The app allowed me to track my sugar intake and the sugar meter helped to ensure that I did not exceed the healthy amount of sugar to consume'. • '(I liked the) Reminders to brush my teeth and rinse my mouth upon eating sugary foods'.
Convenience, utility of the photo recognition, and informative visual reports	• '…moderately accurate identification of food from pictures'. • 'The scanning feature of the app makes it a quick way to record the food I ate'. • 'It was very convenient'. • 'The food was very localised to our local cuisine, very detailed too'. • '(I liked the) summaries of sugar intake and frequency of intake'.
Suggestions for improvement and next steps	
Wrapping into an app downloadable from the App store/Google Play Store	• 'Make into an app on app store/play store'
Integration with other health apps, reminders, and incentives for behaviour change	• 'I think for now the functions and idea behind it is great. The achievements are a great way to encourage good dental practices as well, perhaps some sort of incentives like LumiHealth[a] can be considered?' • 'Make it downloadable on app store or function in one of the hospital apps'. • 'Possibly reminding users to track their food consumption e.g. via notifications'
Improve photo recognition and food database	• The recognition of the food through photos can be further improved • 'Complicated to log home cooked food or food with many components'. • It was very hard to find some food entries. For example, the wordings of some foods are inconsistent. e.g. A pork pao was listed as 'Pow, pork' but the chicken pao was listed as 'chicken pau'
Other suggestions for increased relevance	• 'It did not differentiate between sugars and free sugars. e.g. fruits • 'The app only gave a sum of sugars. It would be nice to have it calculate the % of sugar intake based on total caloric intake (as per the WHO free sugar guidelines)'.

aLumiHealth is a free personalised health programme using the Apple Watch designed by Singapore's Health Promotion Board (HPB in partnership with Apple to encourage healthy behaviours. https://www.lumihealth.sg/

The functionality of the app was limited by the base architecture of the app version being web browser-based rather than a native app downloadable from the app store. This format was chosen during the development phase to enable quick reiterative changes based on testing and feedback and for its ability to work across different mobile operating systems. However, this prevented us from providing notifications and reminders for logging food intake as suggested by several users, and the customisation of sound, content, and notification preferences which requires integration with the operating system. As the app has now received positive feedback and quality ratings, we hope to obtain funding for recoding/repackaging the app for release on the different app stores.

As suggested by some participants, there is potential in integrating this dental-specific diet-tracking app with the larger ecosystem of health apps and health promotion incentive schemes to improve its impact. For example, integration

with Singapore's Health Promotion Board mobile app 'Healthy 365' which has successfully implemented nationwide multi-behavioural health promotion and incentive programmes such as the 'National Steps Challenge'[45] and the 'Eat Drink Shop Healthy Challenge' would enable the extension of mHealth financial incentives shown to be effective for physical activity and dietary behaviour change.[46–48] In addition, integration with healthcare system apps, such as NUHS My Health Map, would enable the linking of rich information on diet with electronic medical health records, allowing healthcare providers across disciplines to provide tailored feedback to patients, and through machine learning and AI of the data, contribute to further understanding of the links between oral health and systemic diseases and yield new insights for personalised interventions.

There are some limitations of this study. The main aim of this study was to describe the development and key features of the app, and assess pilot user evaluation of app quality. Thus, we are unable to make any statements regarding the effectiveness of our app in modifying the dietary behaviours of patients, and this remains to be tested in future studies using pre-post evaluation studies or randomised controlled trials. Furthermore, while several evidence-based BCTs were incorporated, it is unclear which, if any, of these techniques will be effective for changing dietary behaviours for oral health. Another limitation is that the participants in our quality evaluation were young, first-year dental students, who likely differ from the target audience of the app (possibly older, less digitally native individuals, who are at moderate to high risk of caries), and their perspectives may not be generalisable. With their increased dental knowledge, our participants may overestimate the usability of the app, in particular, whether the app is interesting and entertaining to use, and the clarity of instructions and educational information. Similarly, the relatively small sample size of users may limit the generalisability of the user perceptions. Finally, the acceptability of this app to dentists as a tool for assessing poor dietary behaviours and as a clinical aid in behavioural change remains to be examined. Therefore, future research could involve clinical evaluations and trials, as well as focus groups to investigate the perceived impact, usability, and acceptability of this app in dental patients, as well as the dentists. Nevertheless, this study presents an important first step, as it addresses a critical gap in the field of mHealth for oral health, by specifically addressing the dietary risk factors of dental caries.

Conclusion

In conclusion, we developed a dental-specific diet-tracking mobile app that fills a previous gap in the mHealth landscape and may potentially enable detailed dietary assessments for dentist-patient discussions as well as patient-centred self-monitoring and management. The app introduces a novel image recognition function of data entry which has specific capabilities for the identification and categorisation of sugar-sweetened beverages, real-time dietary advice prompts, and the use of visual reports to highlight dietary patterns. While the app was evaluated as being of high quality by users and has the potential to be an effective clinical tool for dentists and self-monitoring tool for patients in the management of dietary risk factors for caries, this remains to be tested in future evaluations.

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