Exploring Opportunities for Multimodality and Multiple Devices in Food Journaling

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Digital food journaling can support personal goals, such as weight loss and developing healthy eating behaviors. However, traditional manual tracking demands great effort, often leading to lapses or abandonment. We explore opportunities for journaling with multiple input modalities and devices, leveraging people's daily interactions with a range of technologies. We report on an extended analysis of 15 participants' experiences with ModEat, a prototype supporting journaling with several input modalities on phone, computer, and voice assistants. Participants' modality and device preferences were largely influenced by their goals, but they frequently deviated from those preferences depending on device availability, perceived affordances, and characteristics of foods eaten. Participants rarely combined input modalities in entries, but some described that doing so allowed for more detailed journaling or serve as a placeholder for later. We discuss advantages and drawbacks of multimodal tracking and potential strategies for improving interactions.

CCS Concepts: • **Human-centered computing** → **Ubiquitous and mobile computing**; *Mobile devices*; *User studies.*

Additional Key Words and Phrases: Personal Informatics; Multimodality; Multi-device; Food Tracking; Voice Assistants

ACM Reference Format:
Lucas M. Silva, Elizabeth A. Ankrah, Yuqi Huai, and Daniel A. Epstein. 2023. Exploring Opportunities for Multimodality and Multiple Devices in Food Journaling. *Proc. ACM Hum.-Comput. Interact.* 7, MHCI, Article 209 (September 2023), 27 pages. https://doi.org/10.1145/3604256

1 INTRODUCTION

Technology support for food journaling has been widely researched for the past two decades (e.g., [34, 67, 68, 91, 97]). It is among the most popular forms of personal tracking, with 42% of U.S. adults having used a mobile app to keep track of their diet or nutrition as of 2017 [52], and over 165 million people worldwide using MyFitnessPal to journal their food intake as of 2016 [44]. Food journaling can effectively assist with a variety of eating related goals, such as weight loss [13, 39, 75, 97], managing chronic diseases (e.g., diabetes) [19, 26, 38, 69], identifying intolerances [46, 88], and mindful eating to make healthier food choices [35, 58, 78].

Despite the benefits of food journaling and the assistance of technology, fitting food journaling into everyday practice is notoriously burdensome and challenging [20, 22, 31, 32, 54]. Many of the challenges people face are circumstantial to the foods they eat or the situations in which they are eating. For example, homemade foods with many ingredients often do not appear in food databases

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2573-0142/2023/9-ART209
https://doi.org/10.1145/3604256

and lack barcodes [23]. Social circumstances can additionally make journaling uncomfortable or awkward [23], and devices may not be present or accessible when a person is eating [22]. Because of these difficulties, people often forget or are unable to log their foods. Eventually, these challenges can result in abandoning food journaling without reaching their desired benefits [20, 23, 30, 33, 54].

One opportunity for reducing journaling burden is to make the practice more convenient and flexible to better align with people's journaling needs and situational constraints. Researchers have leveraged a range of modalities, or methods of input [56], when designing tools for manual capture of foods, including photo-based capture [22, 31], barcode scanning [91], voice logging [67, 91], and database lookups [2, 97] on both mobile phones and personal computers. Other devices, such as smart speakers, provide opportunity for supporting journaling behavior through quick interactions [61, 65, 81]. The increased availability of mobile, wearable, and intelligent personal devices, like smart speakers, offer opportunity for multimodal and multi-device wellbeing interventions [56]. Apps and platforms typically support one or a few modalities for journaling food and usually on a single device. Research on self-tracking has increasingly suggested supporting flexibility and customizability in tracking, such as enabling people to identify what they are interested in tracking [24, 89] or select and configure the frequency and fidelity of data entry [4, 49].

Despite the potential benefits of supporting food journaling with multiple devices and modalities, little is known about people's device and modality interests and preferences or how they are influenced by the different circumstances under which they journal. Understanding people's preferred use of multimodal journaling systems can inform what modalities to prioritize, describe how everyday circumstances impact device or modality choice, and offer suggestions for improving future multimodal ecosystems beyond food journaling. In this work, we explore multimodality specifically in the collection (e.g., entry) stage of food journaling [33, 57], seeking to understand participants' preferences when not as limited by recognition capability (e.g., database, barcode, photos) of current technology [23, 66].

To understand people's experiences and perceptions of multimodality and multi-device use for journaling foods, we extend our previous analysis of the deployment of ModEat [66], a mid-fidelity prototype supporting journaling with a range of devices (mobile phone, computer, voice assistant) and input modalities (database search, text description, voice log, photo, barcode scan, URL). Fifteen participants used ModEat to food journal for two weeks each, choosing whichever device and modality was most preferable whenever they journaled. Our previous analysis focused on participant's food description preferences and contribute recommendations for designing systems to account for variance in details and ways to support automatic food interpretation (e.g., language processing and image classification). Through a deeper look at participant's interviews, we now contribute new understanding of how context and goals influence device and modality preferences and choices for journaling foods. Overall, we found that participants typically had a default device and method of input for journaling that was heavily reliant on their food goals and technology preferences, but frequently deviated from those choices based on what, when, where, and with whom they ate. Participant's interviews combined with daily surveys and food logs point to the value of multimodal and multi-device journaling in everyday life for flexibility and varied goals. We specifically contribute:

- An understanding of how people's journaling goals, affinities, and aversions influence their default modality and device choices. Participants with food awareness goals were open to use any convenient device and preferred descriptive modalities (e.g., picture, text, and voice description) while participants with quantitative goals focused on modalities which would provide nutritional information (e.g., database search, barcode scan). Participant's prior familiarity with or aversions to platforms also guided modality and device choices.

- An understanding of how everyday circumstances influence people to deviate from their preferred devices or modalities, leading to journaling in ways which did not always align with their eating goals. Participant's choices varied depending on what device(s) were available, whether speed or efficiency needed to be a priority, presence of other people, properties of the foods being journaled, or emotions and cognition in the moment.
- Considerations and opportunities for future multimodal and multidevice systems, including strategies for simultaneous device usage for entry composition, open questions for supporting collaborative journaling between different family members, and challenges promoting reflection in multimodal food journals.

2 BACKGROUND

Multimodal food journaling builds on previous work investigating the use of different devices and interactions based on people's activities and contexts. Specific to food journaling, past work has mainly focused on use of phone apps and highlight how challenging it is for people to sustain tracking and achieve better eating goals. We build on this work to explore whether and how multimodal and multidevice ecologies support people's food goals in everyday life.

2.1 Ecology of Use with Multi-Device and Multimodal Systems

Lee et al. define a modality as *"a single independent channel of sensory input or output between a computer and a person"* [56]. Modality can denote both the interaction itself (e.g., visual, listening) and the type of information represented by a particular sensory stimulus (e.g., image, audio). People often have access to an array of devices supporting multiple modalities including mobile phones, voice assistants, and desktops. Multimodal toolkits often focus on supporting browsing and searching, using devices collaboratively in real-time or in rapid succession [15, 72, 73]. In O'Leary et al.'s characterization of device roles in multi-device systems, journaling is a task where devices play the role of a collector of data [77]. Relative to other multimodal tasks, such as glancing at an email notification on a phone and opening it on computer, it is not clear whether people desire combining devices to journal in real-time, minutes or hours later, or not at all. It is also not clear how personal goals and contexts might influence the use of multimodal journaling systems.

People often desire to use multiple devices and modalities simultaneously or in combination. Research on designing multi device-ecologies emphasizes that systems should support task continuity, allowing for easy synchronization of data and the ability to transition from one device to the next to complete an activity [28, 43]. This work suggests the importance of leveraging the strengths of different devices, such as convenience or physical affordances [43, 47]. Though people may have a preference for a specific device depending on context, habit, and current task [43, 47], they often find support for multi-device interactions and simultaneous use lacking, in part due to limited design toolkits and platform standards [29, 77, 79].

Although most journaling and tracking technology to date has leveraged mobile and desktop/laptop apps, researchers are increasingly exploring the utility of other technology for supporting health and wellbeing practices, such as self-tracking. For example, conversational agents, such as via smart speakers, SMS, or voice are increasingly being designed to promote health care [51, 53]. Luo et al. explore multidevice tracking in TandemTrack, combining a smart speaker and mobile app to provide complimentary visual and voice feedback to enrich people's experience with physical exercise [65]. Similarly, in Data@Hand, Kim et al. combine voice and touch input modalities in a mobile app to enable visual exploration of personal health data [50]. Pina et al.'s DreamCatcher [79] and Saksono et al.'s Spaceship Launch [87] designs have combined wristbands and a shared display to collect and visualize sleep and physical activity data. However, their designs primarily used the wristbands for passive input, with the primary interaction being on the single shared display. Less

work has developed understanding of how devices and modalities can be combined for collecting self-tracking data, leveraging different device data format capabilities and interaction sensibilities.

2.2 Personal Informatics and Food Journaling

Personal informatics systems are technologies that aid people with monitoring, managing and reflecting on various aspects of their health, activities or routines [57]. Food journaling, or keeping track of the food one eats, is among the most popular tracking domains [34]. Journaling in any domain is typically viewed as a high-burden form of tracking. Choe et al. describe a continuum from fully manual (e.g., journaling) to fully automated tracking (e.g., passive sensing), suggesting that fully manual tracking requires substantial effort [16]. Journaling requires the person to remember to log, disengage from other activities, and match their experiences with available options [16].

Although burdensome, tracking food intake can allow people to be more aware of their food choices and change their behaviors [39]. Clinicians often utilize food journals in their care practices, recommending that patients utilize it as part of their health management [41, 84, 95]. Research continues to examine technology-driven strategies for food journaling, supporting weight loss [39], diabetes management [26], irritable bowel management [90], allergies [38], and more. Digital food journaling enables patients to monitor their diet while being mindful and engaging through recording and reflection. Digital journals hold much the same benefits as paper journaling, with studies showing that they demonstrate higher adherence and weight loss outcomes than traditional paper journals [13, 14].

Motivations for tracking include curiosity, having a record, and behavior change [86]. Within behavior change for healthy eating, goals range from quantitative and specific to more hedonic [74]. In food journaling, this range is often classified into metrics-driven goals like calorie counting [2, 45, 71, 82, 97] and mindfulness or awareness-driven goals [6, 22, 31]. Prior research has indicated that breadth and flexibility for data collection may better support individual tracking needs [4, 49]. Although people often consider their personal goals and needs when identifying tracking tools, they are often influenced by the popularity of apps, recommendations, aesthetics, and presence of other features (e.g., social features, privacy preservation) [17, 33, 37, 48]. Our work therefore aimed to understand how or whether people's goals influence how they perceive and use multimodal systems, alongside situational contexts, to understand whether and how systems designed to support different goals should ideally incorporate multimodality.

2.3 Food Journaling Modalities and Devices

Digital food journaling has been supported with a variety of techniques in commercial systems and in research, including on desktops/laptops and mobile devices and with entry styles including database lookups, barcode scanning, voice logs, and photos. Table 1 summarizes devices and modalities supported by some prominent research and commercial systems.

Database lookups enable people to search through a food database. This method closely aligns with how experts approach making sense of paper food journals [41, 88] by looking up the food item within large data sets, such as the Nutrition Data System for Research (NSDR) [76]. Database lookups require that people find the correct description of the food they are looking up with in the database and estimate the portion size they consumed [45], but may face challenges with finding foods from non-Western cultures [23], or being susceptible to entry errors, such as confusing multiple similar types of a product [45].

Scanning of barcodes allows people to scan packaged foods such as frozen, canned, or prepared foods. They have been implemented in research tools such as Barcode Ed [91] and are widely used in commercial apps to facilitate food lookups [91]. However, Cordeiro et al. [23] highlight that

Table 1. Devices and modalities supported by some prominent research and commercial systems for food journaling. List not intended to be exhaustive, instead intended to illustrate variance in device and modality support. Commercial app capabilities as of April 2023.

System	Devices Supported	Modalities Supported					
		Database Lookup	Barcode Scanning	Voice Log	Photos	URL	Text Description
Barcode Ed [91](2006)	PDA		✓	✓			
PmEB [97](2007)	Mobile	✓					
MAHI [67](2008)	Mobile/Desktop			✓	✓		
VERA [6](2012)	Mobile				✓		
DECAF [22](2015)	Mobile				✓		✓
MyBehavior [82](2015)	Mobile	✓(1.0)			✓(2.0)		
Food4Thought [31](2016)	Mobile				✓		✓
INTAKE24 [93](2017)	Desktop	✓					✓
TableChat [62] (2018)	Mobile				✓		✓
FoodPrint [19](2019)	Mobile				✓		✓
GlucOracle [27](2019)	Mobile				✓		
EaT [45](2020)	Mobile	✓					
FoodScrap [64](2021)	Mobile			✓	✓		
GlucoGoalie [36](2021)	Mobile				✓		✓
MiranaBot [83](2022)	Mobile			✓			
MyFitnessPal [71](Commercial)	Mobile/Desktop	✓	✓			✓	
Ate [3](Commercial)	Mobile				✓		✓
Recovery Record [85](Commercial)	Mobile				✓		✓

barcode-based journaling can nudge people away from eating fresh foods like fruits and vegetables, which are less likely to have barcodes, in favor of store-bought or packaged foods.

Photo capture and voice logs allow for more descriptive food monitoring and have recently become available in some commercial apps, such as Ate [3] and Recovery Record [85]. Evaluations of food journaling systems suggest that photo and voice-based journals can help support mindful goals and normalize some burden of journaling foods that might not have barcodes or be present in food databases [10, 23, 63, 67, 83]. Also, Luo et al. found that the speech input modality in FoodScrap allowed for quick and flexible detailed food descriptions [63]. Unlike other modalities, photo-based entries typically require in-the-moment entry to capture what the person has consumed, which may not be possible or preferable if eating while socializing or when photo capture is unavailable [22, 23]. Text input enables open-ended and flexible food description, and has typically been incorporated in conjunction with photo-based food entries [19, 22, 31, 36]. Research has also examined using natural language processing to mine nutrient information from websites [70, 96].

Researchers continue to examine how sensors can passively detect eating moments [8, 9, 18, 60, 94], identify what and how much a person has eaten [45], and improve the accuracy of approaches. Passive collection reduces the manual burden of tracking, but presents other challenges such as accuracy, physical, and privacy concerns. Choe et al. also argue that passive data collection removes opportunity for reflection, which is integral to people understanding their habits (e.g., being mindful of their food choices) and potentially changing them [16].

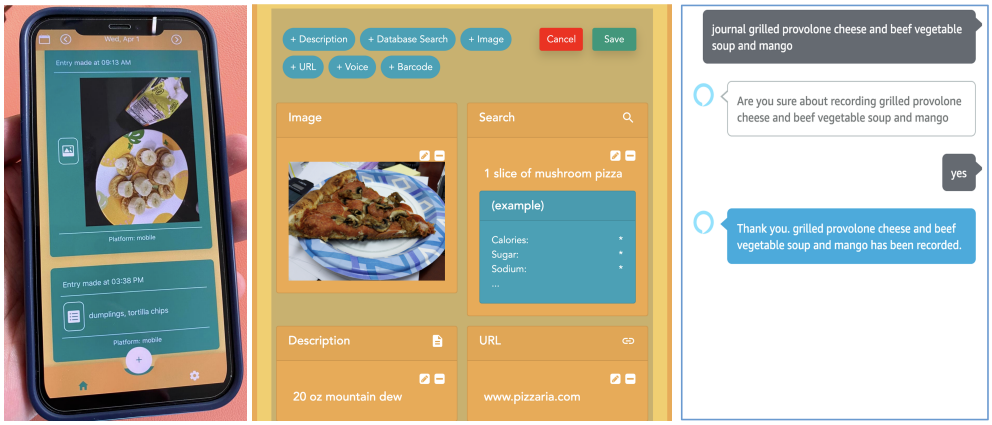
Most food journaling research systems have been designed or developed exclusively for mobile devices, though some commercial mobile apps additionally allow journaling through a website. Devices such as desktop/laptop, and voice assistants also present potentially useful food journaling opportunities. For instance, computers might be situationally more available when being used for another task while eating (i.e., desktop dining [40]), and voice assistants allow for multitasking while preparing food or doing other activities [61, 81]. We therefore explored in this work whether and how the ubiquity of these devices and their modality affordances might better support people's food journaling than a solely mobile experience.

3 METHODS

To understand how people perceive and experience multimodal and multi-device support for food journaling, we extend our previous analysis of the deployment of ModEat [66] to better understand what influences participant's preferred devices and modalities when journaling. Fifteen participants used the system for two weeks, and we briefly describe ModEat's supported modalities and study participant demographics to explain the context.

3.1 ModEat Design and Implementation

ModEat is a multimodal and multi-device journaling prototype designed to capture people's desired strategies for food description practices [66]. ModEat is available on phone, computer, Amazon Alexa, and Google Assistant. ModEat's input modalities are informed by features in commercial apps and previous research on journaling food. It is intentionally flexible and does not incorporate suggestions for what or how to journal. The deployment focused on the collection stage of journaling [33, 57] and de-emphasized the feedback that an app might provide. Therefore, database searches and barcode lookups are simulated, with participants being instructed to suspend belief about feedback and journal as if receiving expected results ([66], see Figure 1b for an example). Each device and modality have unique interaction characteristics and with varying affordances, effort of use, and sensory stimuli. For example, photos might be quick and provide visual nuances, whereas a text or voice input might take longer but offer flexible description. Likewise, the database search could provide detailed nutritional information, but might require effort in describing the right search items. See Section 2.3 for more detailed considerations about modalities and devices for food journaling. Table 2 summarizes input modalities supported on ModEat.



(a) Phone. (b) Computer. (c) Voice Assistant.

Fig. 1. ModEat supported food journaling across modalities and devices, including (a) mobile, (b) computer, and (c) Amazon Alexa. ModEat's mobile and computer apps allow multiple modality inputs in an entry, such as photos and text descriptions. The VAs support open-ended voice description.

ModEat mobile supports six different input modalities including open-ended text description and simulated database lookup, with a person able to choose what input modality or modalities to include with no limit on how many (e.g., Figure 1a). The computer version of ModEat is designed to support any device larger than a phone (e.g., desktop, laptop, tablet), and supports creating new entries with multiple modalities (Figure 1b). ModEat on the VAs Google Assistant and Amazon Alexa support open-ended voice input with the command "journal [food]" (Figure 1c).

Table 2. ModEat's Supported Modalities Per Platform (* indicates simulated results)

ModEat Platform	Database Lookup*	Barcode*	Voice Log	Photos	URL	Text Description
Mobile	✓	✓	✓	✓	✓	✓
Computer	✓	✓	✓	✓	✓	✓
Voice Assistant			✓			

3.2 Participants & Study Procedures

We recruited 15 participants who had various food journaling experiences and goals. Participants used ModEat for two weeks (mean 14.7 days, min 14 max 16), similar to deployments of other food journaling systems, which typically last between one and three weeks [31, 42, 43, 64, 98–100]. Table 3 describes participant demographics. Participant's food journaling goals were distinct, but can be classified under two general categories, quantitative or awareness. Some participants' goals related to maintaining daily calorie budget, or making sure they were eating a set amount protein or certain macro or micronutrients, thus focusing on the quantitative information. Others had goals related to general eating habits (e.g., amount of snacking, eating more plant-based meals, general healthy eating), and focused on awareness of their food consumption. Participants' life stages and routines also varied, with some being married living with partner and kids, and others living with their parents or housemate; and some in collage while others had established careers. To ensure participants had access to a range of devices, they were required to own a smartphone, own a smart speaker device supporting Amazon Alexa or Google Assistant, and have access to a computer. 4 participants who did not own a smart speaker were lent a Google Home Mini or an Amazon Echo Dot via contactless drop-off [92].

Table 3. Summary of Participant Information.

ID	Gender	Occupation	Age	Journaling Experience	Prior Journaling Tools	Journaling Goal
P1	Female	Designer	36	4 years	Calendar	Awareness
P2	Female	Massage Therapist	35	2.5 years	Paper, LoseIt, MyFitnessPal	Quantitative
P3	Male	Civil Engineer	33	2.5 months	Spreadsheet	Awareness
P4	Male	Engineering Manager	38	1 month	Paper	Awareness
P5	Female	Student	28	3 years	MyFitnessPal, Self-made app	Quantitative
P6	Female	Student	25	10 months	Cronometer	Quantitative
P7	Female	Retail	30	3 months	Paper	Awareness
P8	Female	Accounting Clerk	27	1 month	Spreadsheet	Awareness
P9	Male	Engineer	31	None	None	Awareness
P10	Male	Student	28	2 years	MyFitnessPal	Quantitative
P11	Female	Researcher	50	2 months	FitDay	Awareness
P12	Male	Engineer	43	"On and off"	MyFitnessPal	Quantitative
P13	Female	Academic Librarian	44	2 years	MyFitnessPal	Awareness
P14	Woman	Student	33	3 years	MyFitnessPal	Quantitative
P15	Male	Drafting Design	31	2 months	MyFitnessPal	Quantitative

We introduced ModEat to participants as a tool to help researchers reflect on benefits, shortcomings, and possible future designs for journaling with multiple modalities and devices, and positioned the participants as valuable collaborators in exploring ways for facilitating food tracking and lowering burden. Participants were instructed to journal with whatever modality and device they preferred and made sense for their personal goals and daily lived situations, and to think critically about these choices.

At the end of each day, participants answered a short survey to describe the journaling context of each of their food entries. The survey included questions about time of journaling relative to eating moment, presence of others, classification of eating occasions (e.g., meal, snack, other), why they chose the a particular modality and device, and an open field to provide any further details, suggestions, or critiques. After the deployment, participants were interviewed about their modality choices and what about their situations and contexts influenced those choices, if at all. Participants were also asked to reflect on their experience with ModEat and envision ideal features and interactions that would better support them. Participants were compensated $30.

3.3 Data Analysis

Our previous analysis [66] focused on understanding how participants preferred to describe the food they ate by thematically coding the content of each food log saved to ModEat (e.g., text descriptions, database search queries, images taken) and analyzing interview transcripts to *"understand participant's reasons for how they described their foods"* [66]. We extend this analysis of the interviews to better understand what influences participant's preferred devices and modalities when journaling. More specifically, our new analysis focuses on interview sections where participants where asked questions like *"Please explain how you would typically choose device and modality when journaling your foods."* and *"Do you wish that the voice assistant was capable of doing more or something else?"*

We analyzed transcriptions of interviews following Braun & Clarke's reflexive thematic analysis [11, 12]. Our analysis approach was primarily inductive, but employed a semantic analysis of participants underlying goals, beliefs, and motivations for food journaling. A critical realist approach was also used to understand how participants made choices about food journaling in light of contextual everyday life situations and constraints. Following Braun & Clarke's six phases of thematic analysis, we first sought to familiarize with the data by reviewing each participant's journaling goals, and more deeply discussing two interview transcripts. Then, each author independently coded two transcripts. The team met weekly to discuss codes and patterns in the data to iterate on a codebook. After reaching a final codebook, the first two authors recoded all interviews. The first author used the codebook and coded data to build a thematic map to visually highlight the main themes and subthemes, their interconnections, and associated representative quotes. The resulting thematic map had three higher-level themes related to modality and device choices and preferences: factors which motivated default device and modality choice, factors which motivated deviation from defaults, and combining modalities. These had 12 sub-themes, that in turn had 68 sub-items in total. For example, the parent theme *"combining modalities"* had three sub-themes: *complementing information, one is enough, and increased effort*; and a sub-theme *"device choice"* had 13 items, such as *portability, familiarity, multitasking or hands-free, presence of others*. The thematic map became the basis of our findings here reported. We quote participants with PXX.

We also quantitatively analyzed the metadata of journal entry logs and associated survey answers to evaluate how device and modality engagement differed by journaling goal and surveyed contextual factors. Metadata consisted of the modality, device, and eating context (e.g., eating with others, journaling before eating) associated with each ModEat entry. We used logistic regression models, treating each metadata as binary responses. We treated participant IDs as random effects to account for personal device and modality preferences. We corrected for multiple comparisons in post-hoc tests with Tukey corrections.

3.4 Limitations

Most participants' deployment period intersected with stay-at-home orders due to COVID-19. This impacted people's general routines, movements, and, to some extent, foods eaten and journaled. For example, participants who would often eat at a variety of different places (e.g., at work, at

restaurants) overwhelmingly ate at home, which likely influenced their device and modality choices. Despite this limitation, our data represents people's use of journaling tools in everyday situations that can include challenging life events. We further discuss implications on modality and device choice.

While the sample size is similar to past deployments of food journaling systems [42, 46, 73, 97, 99, 100], a larger and more representative sample is likely to uncover further influences on modality and device preferences. Although the sample is relatively diverse in participant's gender and occupation, the findings might not generalize to older or younger participants, complex family settings, and different communities and countries. For example, cultural differences might influence social norms and personal goals around journaling preferences [59]. Also, while P4 mentioned previously journaling food to identify intolerances, none of the participants had a disease diagnosis or management goal, although it is a commonly-studied motivation for food journaling [38, 41, 46, 88]. We suspect people with diagnosis or disease management goals likely have similar preferences to people with quantitative goals, but further research is needed to understand or confirm.

4 FINDINGS

Participants made a total of 659 entries using ModEat, averaging 2.98 entries per day (min 1.07, max 4.26). Participants utilized a range of modalities (average 3.80, min 1, max 6) and devices (average 2.47, min 1, max 3) for their entries. All participants but one explored using two or more modalities (Figure 2a), and all but two used two or more devices for their journaling (Figure 2b; P12 used voice input on the phone app for all entries, P14 used only database and voice descriptions on phone). Most participants opted to use phones for most of their entries (40.6%-100% of entries per person, 62.5% of entries in total). However, participants frequently differed between choosing the computer interface, the voice assistant, or both. 5/15 participants (33%) chose to not use the voice assistant at all, while 4/15 (27%) used it for a third of entries or more. Similarly, 3/15 (20%) participants did not use the computer interface, while 4/15 (27%) used it for at least a third of their entries.

Although participants could combine modalities into entries if they desired, most entries they created (92.2%) consisted of a single modality. Most single-modality entries were either voice description (35.8%) or text description (32.9%), while participants used URL (0.9%) and barcode (3.6%) infrequently. Figure 2 shows (a) modality and (b) device breakdown by participant.

While participants chose to use the phone version of ModEat most often, circumstances often led participants to choose different devices and use different modalities. We found that participants often had a default device and modality preference, motivated by their food journaling goals, prior experiences, and personal affinities. Nonetheless, circumstantial factors frequently led them to deviate from default preferences when faced with situations and contexts which influenced availability, efficiency, and emotion. We also report on participants' thoughts on combining modalities.

4.1 Default Motivational Factors

Participant's default motivations for choosing modalities and devices were based on their personal goals and influenced by how they might have previously journaled their foods. Participants expressed two default motivations for defining their primary strategies for journaling: (1) journaling goal, and (2) affinities for or aversions to specific devices or modalities. Participants with quantitative goals often preferred modalities which supported lookup of nutritional information, while participants with awareness goals varied more in modality use. Participant's choices were often also influenced by their familiarity and prior experiences with each device. Nonetheless, goals can fluctuate over time, and changes can influence default preferences for modalities.

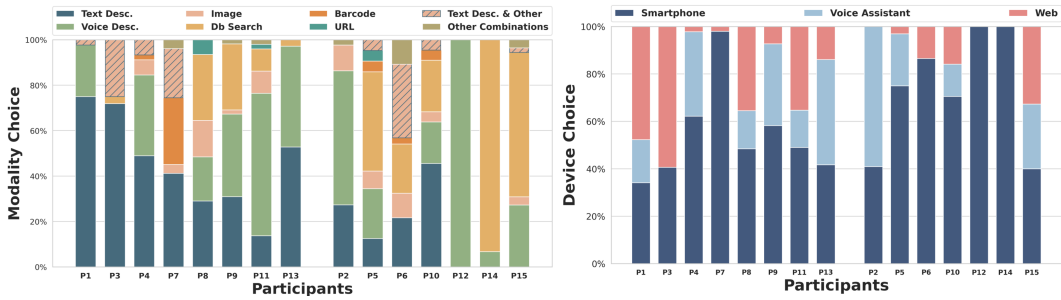


Fig. 2. Distribution of (a) modality and (b) device choice. In each graph, participants on the left group had food awareness goals, while the right had quantitative nutritional goals. Participants with awareness goals used text and descriptions at a higher rate, while those with quantitative goals used database searches at a marginally higher rate. The phone was used for the majority of food entries and participants varied in using the computer or voice assistant.

4.1.1 Journaling Goal Drives Preferences and Choices. Participants described their journaling goal as being most influential in deciding what modalities to use. Participants with quantitative goals typically preferred database search and barcode modalities because they would support learning nutritional information. Participants with quantitative goals used database searches at a marginally higher rate (Z=1.78, p=0.07, 95% CI 0.38x lower – 4.45x higher), though we observed no statistical difference in their rate of using barcodes (p=0.551). For instance, P14 explained that she mostly chose to create entries with database searches because *"at the end of the day, calorie count is the most important thing."* P14 elaborated that if she used more descriptive modalities like taking a picture, *"[I] wouldn't be getting the information I want out of it, which is the calories."* Some participants with quantitative goals imagined that the voice modality would implicitly run a database search. For example, P2 described, *"I would imagine with the voice command of being able to tell it, '32 grams grilled chicken breast,' like it would just populate it onto the software 'This is, according to the Internet, x many fats and proteins and whatever are in grilled chicken breast'"*. P12 added, *"if MyFitnessPal had the ability for me to speak into it and it knew from my frequent foods database or whatever and it would accurately pull nutrition up, I would use that all the time. They don't have that feature, and I assumed that your application did."* These examples illustrate that perspectives on a modality's usefulness were influenced by food journaling motivation, with people desiring support in monitoring and measuring progress towards specific goals.

Having food awareness goals may make using multiple modalities more appealing due to having less requirements for nutritional information. All participants with awareness goals tried at least three modalities during the study. P8 described her preferences as *"I just like having the different options."* Participants with awareness goals tended to prefer the text and voice description modalities, using text description at a higher rate than participants with quantitative goals (Z=2.51, p<0.05, 95% CI 0.46-4.42x higher) though no noticeable difference in use of voice description (p=0.54).

Some participants reported that their journaling goals might change in the future and reflected on how their modality preferences might change if that were to occur. P3 said he liked using ModEat to journal with description and images but considered that if he wanted to lose weight he would need to *"get even more serious about it, it would be more quantitative."* P13 currently wished to be mindful of her eating but had previously focused on nutrient information: *"If I'm just trying to be more cognizant of what I'm eating or how much, then likely I would be fine with the simpler*

[tracking] version. If I'm actually going to be doing my weight training, then I'm going to want the more granular," she also pondered that this goal shift was related to the current pandemic situation: *"if it was a better time, I would be doing a much better job of keeping track of my carbs, but the fact that we are in this [pandemic] situation, means that you shop for groceries differently, healthier attitudes or healthier beliefs are out of the window."* Other participants with quantitative goals mentioned they might shift to an awareness style of tracking after they learned the nutrient information of foods they commonly ate. For instance, P10 said, *"I would use the database search in the beginning when I was less aware of the protein content and then as I got a good sense of how much protein was in particular meals, then I would start using descriptive [modalities] so it was easier to reconstruct."* Despite participants having clear food goals during the study deployment, they indicated that life events or new perspectives could lead to new goals and modify how they journaled.

4.1.2 Affinities and Aversions. People may prioritize journaling with devices with which they have more prior experience. When participants journaled their foods with ModEat, they often preferred devices they used more frequently for other purposes, and perhaps avoided others with which they were less comfortable or experienced. Also, prior experience with journaling on mobile apps may influence people to continue to journal on mobile. P3 described journaling on the ModEat phone app as *"really similar to what I'm used to."* P8 agreed, *"the phone is just easier and through apps, I just think I'm so used to using apps."* Participant's familiarity with their phones enabled easy use and maintenance, suggesting that extensive experience with devices and designs can influence user's journaling affinities and choices.

A few participants explained that they chose not to use some devices due to some level of aversion for the platform, at least for food tracking. P12 considered using his Google Home to make journal entries but described it as *"a prime example of just a complete break in intent"* and *"just so jarring a juxtaposition between where you're at mentally, where you have to go to be talking to a robot."* Instead, he made all of his entries as voice inputs on his phone because it takes *"just three seconds and I'm done,"* not requiring the conversational steps to interact with the VA. P15 said that using VA *"was kind of too slow"* and P9 agreed that it required *"a lot of care"* and *"patience"* because *"[you] run through the three or four verbal steps to kind of make that entry."* Even participants who frequently used VAs for journaling reported concern that VAs would misunderstand or not interpret what they said. Misunderstandings could be due to some amount of accent – e.g., *"it doesn't understand me because of my accent"* (P5) – but *"even in English, she [VA] has a hard time understanding some words"* (P15). Similarly, P3 did not use his VA because he did not feel comfortable with it, but considered that this might change in the future: *"I'm really not comfortable. Just, I'm not really used to using it [VA] to the point where it's second nature to me. I think I would only use it when I'm more comfortable using it, if using the voice assistant was more integrated into my daily life."* Therefore, perceptions of a platform's characteristics and a lack of experience with it can create an aversion to the device. For some participants, these elements combined with a need to learn and manage a new technology can deter from choosing them as default journaling options.

Similar to VAs, perceptions on the tasks computers intend to support may make them less appropriate for food journaling. While most participants enjoyed the practicality of tracking on their computers when already using it for other activities (e.g., while working), other participants disregarded this platform. For P2 the computer was exclusively for school activities: *"[The computer is] not a preference at all. Once I'm done with schoolwork, the computer's closed down."* P7 described only minimally using her computer, and therefore tended not to consider it for journaling: *"I do have a Chromebook, but I don't use it all, especially since I'm not a student anymore. So, I don't really see the need for it [to journal]."* People may not want to use a particular device for food journaling

due to general beliefs about other tasks some technology were originally intended for, even if they own and regularly use it.

4.2 Factors Which Motivated Deviation from Defaults

Situational factors such as what, where, when, how, and with whom a person eats can influence them to deviate from their preferred journaling devices and modalities, in much the same way that context has been shown to influence other interaction modality choices (e.g., using voice and audio for interacting with recipes while cooking [1]). In analyzing participant's experiences with ModEat, we identified six situational factors that may lead to deviations: (1) availability of devices and information, (2) efficiency and speed, (3) device affordances, (4) modality's perceived affordances, (5) presence of others, and (6) emotions and cognition. Participants described their locations and food choices as influencing which devices and modalities were most present or practical. Likewise, they described certain circumstances as leading to quicker and less detailed entries. Participant's choices were sometimes influenced by device capabilities and the data types that modalities provided, and participants had varied perspectives of how to approach journaling in social contexts.

Although participants generally appreciated having multiple device and modality options to accommodate their circumstantial preferences, some felt that having to choose between options increased the mental workload of journaling some. For example, P2 mentioned that *"it was a little overwhelming having all the options. There was just a lot of different ways of doing it."* Likewise, P6 said, *"I am not good with choices, because if I can't figure out what is both efficient and perfect, it just drives me nuts. And having all those options is just like 'which one works best for me right now?' I could take the photo, but also the barcode, I could do that. I was just like, 'what do I do?'"* Still, participants reported that with time and practice this decision effort might lower as *"you learn the app after a while"* (P13). As described below, having multiple options was often useful to circumvent situational constraints or better journal in the moment.

4.2.1 Availability of Devices and Information. Participants found that the physical location of where they ate influenced whether different devices were available for journaling at all. Some physical locations introduced clear constraints, such as eating outdoors typically limiting participants to journaling on their phones, their only available device. In contrast, VAs were used only at home. P2 described that sometimes the VA was the only available option for journaling because she was in the kitchen and the *"phone is charging on a different docking station in a different part of the house."* Participants recorded nearly all entries from home (91%) due to the pandemic, with a few journaled while at work (3%) or other locations such as in a car, at a restaurant, or somewhere else outdoors (6%). Unsurprisingly, mobile devices were used for journaling while not at home more often than other devices ($Z=3.29$, $p<0.01$, 95% CI 0.26-1.66x higher) and VAs were used while at home marginally more often than other devices ($Z=2.09$, $p=0.06$ 95% CI 0.14x lower – 2.01x higher).

Participants described the phone's portability as a factor for journaling a majority of entries this device. P14 said that *"I've got my phone with me constantly. It's with me all the time."* Likewise, P1 pondered, *"Alexa is not always nearby me and my computer is not always nearby, and the phone is in my pocket. It travels nice and it would be something that will be more dependable upon."* The positioning of devices in respect to the body is thus an important factor for availability, such as a phone in the pocket or a VA available "everywhere" in the room.

Participants also considered what device they perceived as most available, even if multiple options were nearby. P5 considered her computer available when *"studying, doing something on my PC and I want something to eat, so I might as well just start logging it."* Likewise, P13 associated her workplace with journaling on computer, although being at home for most of the study due

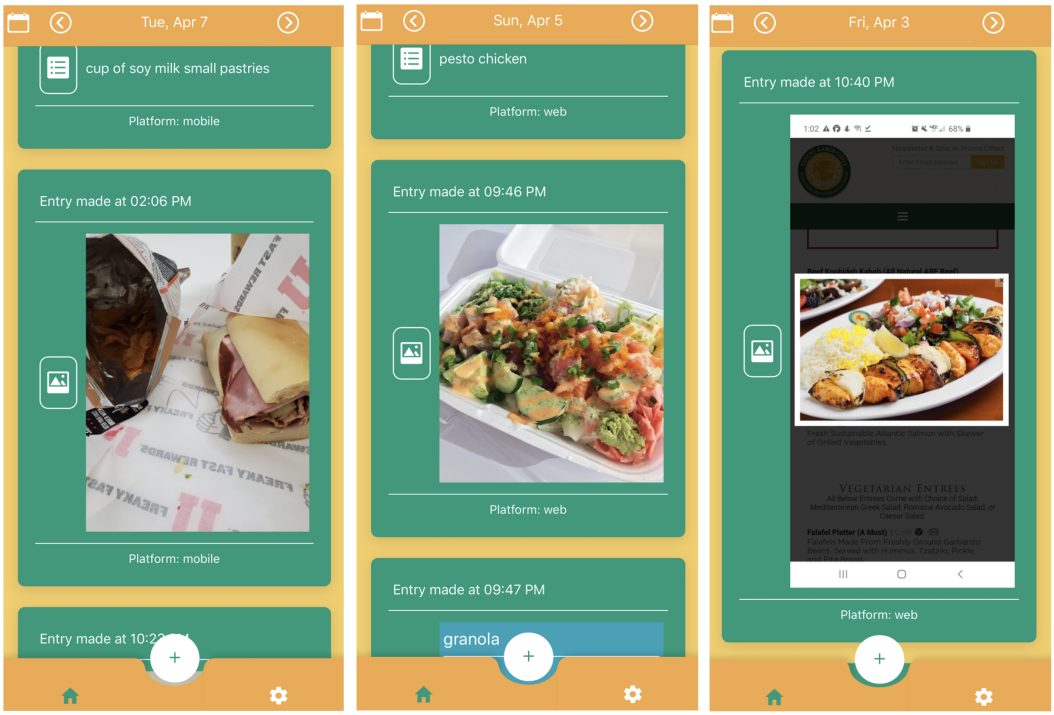
to COVID-19: *"I'm working away in my office and I need to log something, then more than likely I would use the [ModEat] web version. I could also use the mobile, but sometimes when I'm at work, I'm trying to stay off my phone."* Participants generally considered computers as stationary devices, only considering them for journaling when they were nearby. For instance, P12 said *"I'm not going to run all the way upstairs to get on my laptop, type it all in, that's obviously a huge interruption and inconvenience. It's not like I have my laptop next to me."* In general, the multi-device nature of ModEat often led participants to ponder in-the-moment options and consider which one was more practically available.

Participant's modality choices were also influenced by the availability of what they ate relative to when they journaled, sometimes dependent on journaling before or long after they ate. For example, barcode scanning required that foods be packaged, and particularly that the package still be easily accessible. As P13 put it, she would *"not particularly go digging through my trash to go find the particular item that I had eaten three hours before."* Participants described similar logic when taking pictures, needing to input the entry before the meal is over. They were more likely to include images when journaling before or while eating than after eating (Z=4.15, p<0.001, 95% CI 0.92x-2.52x more likely). P8 creatively leveraged the image modality by searching online for pictures similar to her meal, especially when it was from a restaurant (e.g., Figure 3c). P6 described difficulty journaling a food she was unsure of: *"I had no idea what was in the Ube pudding. I couldn't look up Ube pudding on a nutrition database and feel comfortable putting that information in because it probably wouldn't even be accurate."* P6's experience echoes prior work in highlighting that database search can be a challenging modality when facing foods with uncertain ingredients [23].

4.2.2 Efficiency and Speed. Participants generally wanted to be able to journal quickly, and sometimes found themselves in situations where they wanted to prioritize speed when journaling, choosing whatever entry mechanism *"is most convenient or whatever would be quickest"* (P5). For example, P8 had a limited lunchtime at work, and she *"didn't want to spend that much time with just journaling. I wanted something really quick so just [journaled by] typing description."* For five participants (P2, P3, P10, P11, P15), hurriedness meant preferring to journal by taking a picture: *"I was working late, I didn't want to take a break to open the new tab and have the different entries. So, the picture is going to be the fastest way"* (P15). P10 similarly suggested that *"the other methods would require additional concentration and attention,"* indicating that situational needs for quickness could influence device and modality as well as level of detail provided in the food description.

Perception of each modality's efficiency influenced which one they used when in need to make quick entries. We found that participants saw database searches as detailed but not speedy, requiring careful description of foods eaten. When under time pressure, P4 described wanting to reduce the burden of using database searches by not recording some noncaloric items such as onions. He said, *"looking at every single ingredient of a meal is a huge pain in the butt. So, we'll often end up skipping things like vegetables, onions. The effort of looking it up is not worth it."* Despite some participants' perception of VAs requiring a lot of time, others considered that using VA was timely because *"it goes quickly to speak with [it]"* (P5) and being able to simultaneously do other activities. Overall, participants evaluated the balance between amount of time it would take to make an entry and the utility of that entry for later reflection or other needs.

4.2.3 Device Capabilities. Journaling may be better enabled by particular device features at particular times, such as using the voice assistant for handsfree journaling or the ability to multitask. For example, P10 had an Amazon Echo Dot in his room and enjoyed journaling with the VA *"while conducting my morning routine."* Compared to other modalities, VAs were more often used for journaling entries before or while eating than after (Z=3.67, p<0.001, 95% CI 0.26x-1.24x more often). About half of the participants (P1, P2, P4, P5, P9, P11, P13) had their voice assistant located in the



(a) (b) (c)

Fig. 3. Different ways P8 used image to journal food. (a) use of picture captured by phone camera. (b) use of stock food image. (c) use of screenshot of restaurant's menu.

kitchen and found it useful to track while eating or preparing meals. P1 said, *"I would use it when I want to multitask. If it's available right there and I'm prepping or if I'm cooking, so I'll be like, 'Alexa, journal blah blah blah'."* P5 considered that using the VA to make an entry while preparing food would also improve accuracy and avoid the risk of forgetting if done at a later moment:

> P5: *"for accurate tracking [of] your food, if you want to have a specific calorie limit to stay with them, then you have to actually remember everything you eat. If you forget something then you're going to fail your goal. So, using the voice assistant while you're doing the food [preparation] and while you're actually weighing it out, you can tell the voice assistant how much of this, so that way you don't forget."*

Participants mentioned leveraging the computer platform when their foods would be easier to journal through a mouse and keyboard (P3, P4, P5, P6, P9, P10, P11, P15). For example, P15 said, *"it's easier to type on the computer than on the phone. So, if I just have the phone and my computer open, and if I'm eating right there, I would just use my computer, because I don't like texting [on phone] that much."* This was particularly useful when journaling while doing meal planning and/or following online recipes *"because if you browse the recipes online, you could easily import that, copy-paste it"* (P5) and because on phone *"It's too small to see"* (P2). Compared to other devices, participants used the computer to journal after they ate more often ($Z=2.87$, $p<0.01$, 95% CI 0.09x-1.02x more often).

4.2.4 Modality's Value for Future Reflection. Participants evaluated and compared modality's usefulness for later recollection and reflecting on their food choices when deciding which one(s) to

use. However, they also considered the characteristics of the food(s) and what modality would be more appropriate to record it.

A modality may not effectively support some reflection goals, but can still capture information about foods that are circumstantially relevant. For example, participants expressed that images would have limited support for quantitative goals, like calorie counting, by themselves, because they are *"not a searchable method"* (P9) or could not return the desired nutritional information – e.g. *"I wouldn't be getting the information I want out of it [image], which is the calories"* (P14). P10 considered using the image modality as a last resort *"if it was difficult for me to get information on nutritional content of foods not commonly identified to a database [and not packaged], I would prefer to use description or took the photo."* Overall, participants reported thinking about the limitations and advantages of using images in respect to how it might or not be valuable to capture certain foods in comparison with other modalities.

Open-ended modalities like voice or text input can support flexible aspects of record-keeping, like social circumstances or memos, alongside journaling because "because it's basically a blank sheet" (P9). For instance, P4 used text description because *"I wanted to have a description of what I ate that included a general description. I mostly want to record what I ate. I'm not terribly concerned about the quantity or having it be exact."* Interviewees also considered this modality's open-endedness as useful to journal meal contexts and related information about specific situations. For example, P13 said she could use text description to *"make yourself a note that says, 'Never buy this again"'* and P5 made a text entry with a contextual note *"dinner at friend's house."* Participants were more likely to include text descriptions when journaling after they ate ($Z=2.02$, $p<0.05$, 95% CI 0.02x-1.08x more likely). The unstructured nature of open-ended modalities allowed for adaptation that might be useful for future reflection or reminiscence.

4.2.5 Presence of Others. Eating with family members or guests at home or in social contexts had various impacts on how participants decided to journal food. Most participants inevitably chose to journal long after such situations, with the risk of forgetting or having less detailed entries due to relying on memory. Participants had several reasons for postponing journaling in these situations, such as not wanting to interrupt *"other stuff going on"* (P3), *"stop listening to something others said"* (P10), *"trigger unwanted thoughts for those who struggled in the past with eating disorders"* (P14), or taking care of their kids during meal time (e.g., *"kids are demanding, I need to work around their needs"*, P11). This also meant that some modalities would not be available, such as scanning a barcode or taking a picture of the food. Nonetheless, five participants (P1, P4, P6, P10, P13) pondered that in some social situations they would evaluate picking the phone for a modality that was quick enough (e.g., a picture) to not hinder social interactions: *"I don't want to interrupt social activities so in order to minimize that, I would pick a modality that would be very quick to capture what I ate"* (P10). Some people feel journaling is stigmatized and avoid doing it around others [23]. Our findings suggest that fast interactions may avoid these feelings, but people often instead postpone journaling for later.

Although participants were generally comfortable journaling around others who lived with them, the presence of housemates occasionally had implications for device and modality choices. Participants found journaling with VA to be sensitive to the noise of others around or potentially disrupting other's activities. P2 said, *"[when my boyfriend] does telemedicine or he's listening to lectures from his program, the Alexa just wasn't a good fit,"* while P11 added, *"late at night, I don't want to disturb other people by using [the] voice assistant."* Participants also occasionally described privacy concerns around journaling with a VA. P6 decided not to use her VA to journal because she considered that her *"family is a bunch of eavesdroppers and control freaks and I don't want them*

hearing what I'm doing" and if they heard her journaling, they *"would start badgering me and trying to dig into my life."*

P3 and P12 felt that journaling aloud with the VA in the presence of a partner could seem awkward. P12 said, *"I'm making lunch or dinner and my wife's around, I wouldn't say it is embarrassing, but it's a little awkward voicing it when someone else is around."* However, other participants had different perspectives. Specifically, P1 and P5 are married and mentioned helping each other track (including using the same VA device): *"my wife can remind me to journal if I've forgotten, and I can do the same for her, so it ended up being a good thing"* (P5). P2 expressed interest in being able to track with and on behalf of her boyfriend using the VA: *"It would be nice if my boyfriend was also using the same food journal, of being able to tell Alexa: 'Share this meal with [boyfriend's name] So having the capability of sharing [entry], that would have been nice."* Finally, P11 mentioned that due to her accent, she would sometimes ask her partner or children to help journal with Alexa: *"Alexa does not recognize my voice well [. . .] talk slowly and clearly for VA to understand you, do take effort even for native speaker [sic]. My sons and husband, [who are native speakers], also tried."* These examples illustrate the potential collaborative advantages of journaling with multiple devices, especially with the VA as it can be commonly situated in communal spaces.

4.2.6 Emotion and Cognition. Emotional and cognitive states can impact journaling. Study participants described how their general state of mind, impacted by events in in their everyday lives, could lead them to journal in ways that did not align with their original goals. For example, P14 had a daily calorie budget, and mostly used database search as a result. However, she said, *"I keep tracking even when I don't feel like I'm on top of it and I feel crappy about the whole thing. It would be useful to have something that counts for doing effort, even if it's just a text box. I can move forward with that."* Even when she did not feel emotionally motivated to journal and reached the end of the day without making an entry, she described it still being valuable to use a text description as a fallback to make an entry overviewing what she ate that day.

Beyond this more general influence, goals and tracking can also be influenced by state of mind in situ surrounding a journal entry. For example, P2 described having the goal of tracking macronutrients for her strength training, but found that she sometimes felt like choosing modalities which would not readily support tracking macronutrients: *"choice sometimes was on a whim, If I felt like taking a picture, I was going to take a picture. If I just felt like typing it in, then I just typed it in."* Likewise, P6 felt that often her modality choices were *"maybe it's associated with my [menstrual] cycle, it's a lot of flux and it's random. So that also will determine [choice]. One time I just was not feeling it, I was not happy, so I just took a photo."* Although P6 had a quantitative goal, her feeling in the moment led her to select a different modality.

4.3 Combining Modalities and Devices

Although participants rarely used more than one modality and device per entry, their thoughts on the utility of combining modalities varied. Eleven participants combined modalities in a journal entry at least once (Figure 2a), consisting of 7.8% of all entries. Of these, 90% included text descriptions to complement other modalities. Participants typically expressed one of three perspectives on combining modalities: it offered little added value over a single modality, it could be used in complimentary ways, or one modality could serve as a placeholder for more detailed journaling later. Most participants did not combine modalities, reporting that typically one would be enough to capture their foods. However, some participants considered that in certain situations, multiple modalities could jointly leverage each modality's particular characteristics or serve to correct VA errors. Finally, some participants initially used a modality that required less effort, later going back to add more detail to an entry through other modalities in other devices.

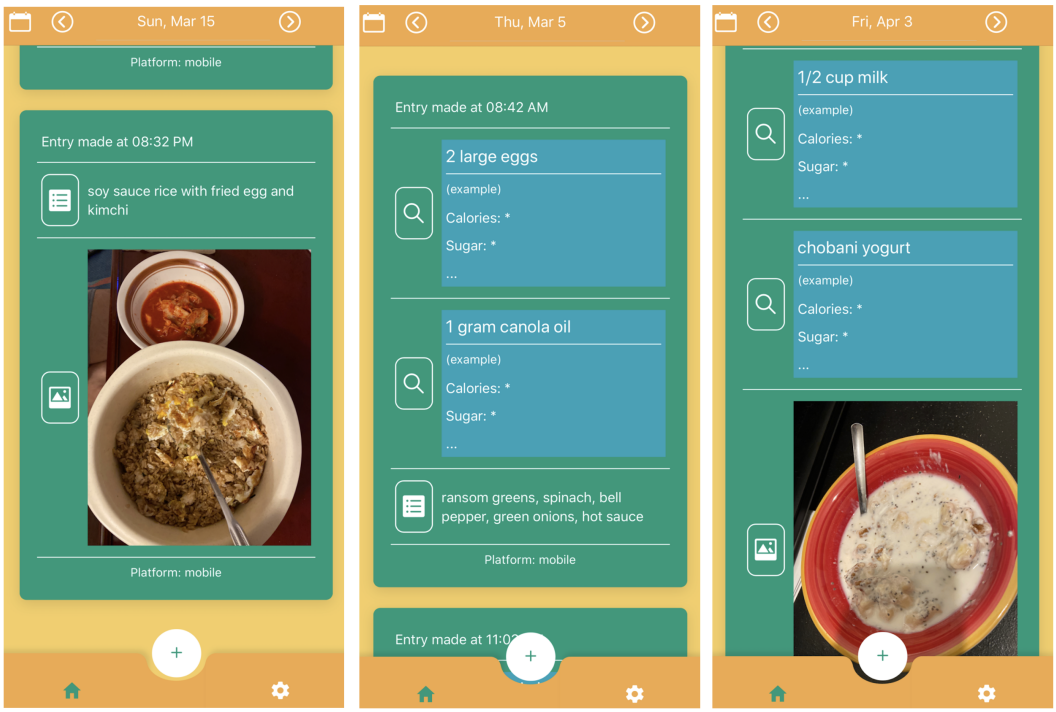
4.3.1 Little Added Value. The vast majority of entries participants created used a single modality. Participants felt that one modality was typically sufficient to satisfy their journaling intent and to *"reconstruct what I ate"* (P10) under most journaling situations, such as learning the nutrient information when using a database search or having the visual feedback of a picture. For example, P7 said *"So I think just choosing one option is good enough for me most of the time. I don't feel the need to have a picture, a description, and a barcode because I'd be able to identify what I ate based on the one method that I inputted it with."* Combining modalities also implied more effort per entry and could go against a desire for *"efficiency and to do as few steps as possible."* (P6), therefore more often participants aimed to use a single input modality because *"I was aiming to make it as simple as possible" (P4) and "so I can do it in only one step"* (P6).

4.3.2 Complementing. Combining modalities could also be a means of capturing more food details and when *"one modality was insufficient"* (P10). Four participants mentioned using pictures to convey the amount they ate (e.g., Figure 4a), while using text description or database search to *"annotate the picture with what specific items are in it"* (P9). P5 reserved database search for food items that would contribute to her calorie total for the day, sometimes combining database search with text description to add negligible calorie ingredients (e.g., Figure 4b): *"when you just do a handful of spinach or a handful of kale, that's never really much, it's like four calories, seven calories, so it doesn't really matter. That's just a text description."* P4 stated that the possibility of combining modalities was *"the biggest thing I like about the mobile, or the web, over the Alexa."* Participants occasionally leveraged other devices to correct VA's entry errors. P1 had once made a voice entry that was recorded as *"care o'clock bagel bacon and roasted tomatoes,"* she noticed this as an error, and edited the entry using her phone to the correct description *"carrot lox bagel, bacon and roasted tomatoes."* Similarly, P15 had made a voice entry recorded as *"for eggs"* and later corrected on phone to *"4 eggs"*.

4.3.3 Placeholder for Detailed Journaling. Participants with both awareness and quantitative goals occasionally used pictures for in-the-moment journaling as a placeholder for later creating a more detailed journal entry. Participants felt like doing so could help prevent skipping or forgetting to journal at all in situations where they were time-constrained, serving as *"a reminder to come back and log"* (P15) and preventing reliance on memory alone. For participants with awareness goals, this strategy could help keep a more accurate record of their food. P3, described,

> P03: *"Say like, I've got three days' worth of pictures of stuff that I ate, then I can just write down. For example, I got a picture of a bowl of pasta, then I can write down that I got the pasta with the cheese on it. It will be nice to be able to bring in more information later on so that you know that you properly logged what you ate, and you're not missing things. You're not forgetting things."*

Participants with quantitative goals also used this strategy, but for later searching for a food's nutritional information. P2 considered a variation of this strategy when eating out by taking a photo and later *"going online and pulling up their restaurant menu and having the macros put in that way,"* she also imagined that a future food journal could *"on a day that you just took a photo of getting an alert later in the evening of, 'Did you want to add detail to your meal?"'* P15 imagined a cross-platform approach could be useful, taking a picture with his phone and later editing on his computer to add detail (e.g., Figure 4c). He said, *"Like when I go onto the web, go back in and edit the items that I ate. I would use the image [from phone] one then the database one. So, I'll just take a picture, and then I'll come back and I'll add the items later."* These experiences indicate that combining modalities through the use of placeholders can increase the opportunity to provide more useful and accurate entries when there is a better or less constrained moment in their routine.



(a) (b) (c)

Fig. 4. Example of screens of modality combinations for a single entry. (a) P7 combining text description and image. (b) P5 combining text description and database searches. (c) P15 combining image and database searches. Images were used to capture portion sizes and distinguish between similar foods, while text was used alongside database searches for items which had negligible caloric value.

5 DISCUSSION

By extending the analysis of our deployment of ModEat [66], we identified reasons behind participant's default device and modality choices for food journaling and motivations for deviating from those defaults, including journaling goal, situational constraints, and presence of other people. Results also suggest that leveraging multiple modalities and devices, whether in the same entry or for different entries, has potential to better align with people's desires for food journaling and supporting a range of goals and journaling styles. In this section, we reflect on future implications, opportunities, and limitations of multimodality across multiple devices.

Several of the findings on default and deviation factors align with and expand prior work on people's device choices and perceptions on device affordances in multimodal ecosystems. Luger & Sellen and Porcheron et al. highlight that VA's are often touted for their usefulness for multitasking [61, 81], but current VA applications rarely surface that potential, instead expecting full attention. Participants' use of ModEat for multitasking highlight food journaling as a potentially practical multitasking application, taking advantage of handsfree interactions. Participant's use of ModEat also align with Jokela et al.'s takeaway that people factor device's interfaces, technical capabilities, and physical characteristics when choosing which to use for a particular task [43]. Participants also considered familiarity with devices and prior journaling experience when identifying default device(s) to use for journaling. However, maintaining a multi-device ecosystem can be technically

demanding to configure and maintain [92]. In addition, our findings also suggest that deciding among many journaling options can add some mental effort to consider choices.

5.1 Multimodality and Multi-device Support for Flexible Fallbacks

We observed that for participants who typically preferred to use higher-demand modalities like database searches, multimodality enabled the ability to use less demanding input forms (e.g., taking a picture, writing a brief description). This was typically in circumstances which required more casual or carefree journaling, like social situations or moments where their state of mind was such that they simply did not wish to create a detailed entry. A frequent concern with journaling systems is that long-term journaling is burdensome, and people can be demotivated to continue tracking their foods [5, 17, 25]. Participants still perceived such "light" journaling as useful, and those with quantitative goals imagined possibly improving the entry with further details of nutritional information later. Modalities that require less effort or time could serve as a flexible fallback and, although they might not completely satisfy a person's main food journaling goal, such modalities may help avoid skipping an entry altogether. Prior work has highlighted that missing entries might lead a person to lose the habit of journaling, with a day's missing record snowballing to longer-term lapses [23]. Therefore, **future journaling systems could make use of fallback modalities** to help people maintain a continuity of tracking, even if logs are not as detailed or aligned with goals. Likewise, **future systems could leverage multiple devices to also increase redundancy of options**, allowing journaling in situations that otherwise would be skipped due to a device's unavailability.

Participants also experienced information constraints in particular contexts that led them to fall back to a modality less desirable for their goal, such as not being able to describe a food well enough to search for it in a database. Past work has highlighted that information constraints are a frequent barrier to journaling, such as situations where food components are unknown (e.g., some restaurant meals, foods received from family or friends) [23]. Likewise, complex foods and homemade or ethnic foods pose additional levels of difficulty to journal, and can be more challenging than packaged foods or fast foods [23, 45]. Such constraints can prevent someone from using their default modality preference. Ultimately, **supporting multiple modalities can enable people to select among other available modalities as an alternative to skipping journaling** or creating a less satisfying entry with their preferred modality.

5.2 Multimodality and Multi-Device Support for Multiple and Shifting Goals

Participant's reports and journaling choices when using ModEat indicate that goals might change or preferences might be circumstantially influenced. We observed that modality and device choices varied even among participants with similar goals, as there was often more than one modality and device which could support that goal. For example, participants with awareness goals preferred one of a few modalities which supported open-ended description (e.g., text description, voice, images), but did not consistently leverage one of these modalities over the others. While participants with quantitative goals often preferred to use database searches, they varied in which device(s) they used for entry. Participants also frequently selected devices or modalities which deviated from their goals if their journaling circumstances made those approaches more convenient or less burdensome. Even if in rare occasions, multimodality also allowed for leveraging multiple data types in a single entry, which could support one's goals with increased details about their foods. Therefore, we envision that journals which support multiple modalities and devices have the **potential to simultaneously support different kinds of goals and might help with transitions between goals**.

The flexibility of increased modality options could better support people when their goals change or evolve, and enable people to investigate new goals. Prior personal informatics research has

suggested that systems often fail to support evolving goals, which often limits the longer-term effectiveness of such systems [33, 74]. Systems such as OmniTrack and Trackly [4, 49] highlighted the importance of designing tracking tools to provide flexible input formats to support people's varied goals. We observed that multimodality supports entry flexibility and changing goals. In particular, in trying modalities which deviated from the ones they typically used to support their goals, participants were able to briefly reflect on the benefits and drawbacks of modalities which better supported other goals. For instance, someone with an awareness goal might try to use a database search because it is an available modality, and realize that they found the information it provided valuable. They might then decide to shift their tracking goal to more quantitative measurement. Likewise, circumstances might lead someone with a quantitative goal to fall back to a more flexible and less burdensome modality like photo-taking, and in doing so, they find out they no longer desire nutritional information.

Care must be taken in how to support journaling across multiple modalities and devices. Despite the benefits from having more options to journal with, having options can be overwhelming and add mental effort to the process. Furthermore, people might have clear aversions to some devices, such as towards smart speakers out of privacy concerns. In addition, devices themselves require maintenance (e.g., charging) and configuration (e.g., syncing, app installation), which may make them either temporarily unavailable or result in burden exceeding perceived added value. Food journaling systems therefore **should not require all options to be available or actively maintained**, instead allowing users to opt in or out of modalities and devices or prioritize some according to preferences.

One possible direction to reduce the degree to which multimodal systems are overwhelming is to support an initial setup phase with users deciding on a primary modality, and other modalities as desirable. Such selection needs to be based on the user's available devices and their afforded modalities, but additional devices and respective modalities could be made clear in case people want to acquire more options. It is also important to clarify the opportunities and limitations of modalities and devices in order to support user's deciding and selecting phases of self-tracking [33, 55]. In particular, people often configure more tracking techniques than they can realistically manage, requiring tools to indicate the potential burdens of new modalities or devices [89]. Future research is needed on what could be primary and secondary interaction preferences for voice assistants (if users desire to use them). For example, it is still unclear how users could configure a VA to be primarily quantitative and secondarily more open-ended, and vice-versa, or how VA interactions should be used as a secondary to primary modalities on other devices.

5.3 Future Design Opportunities and Challenges

While ModEat was primarily designed to create single-device journal entries, past work has highlighted opportunities to use multiple devices for a single activity either sequentially or in parallel [43]. Our findings demonstrate the value of sequential journaling, adding a food on one device and later adding context or clarifying what was journaled on a separate device. **Further research could explore the benefits and challenges of parallel device use for journaling**, integrating simultaneous device use for a single food entry. For example, VAs could be used for voice input while simultaneously taking a picture on a phone to illustrate the description. Modalities could also be used together in a single interaction, such as a person describing a journal entry to a VA triggering nutritional information to appear on an accompanying ambient display device for confirmation or for awareness.

Multimodality and shared devices can also facilitate family collaborative construction of journal entries. Three participants described receiving journaling help from their child(ren) and/or partner when using ModEat. Prior work has highlighted that journaling together can help family members

exchange social support [62], encourage parents and children to work together [79] to achieve goals [21], and can help distribute tracking burden across family members [80]. **Multimodal and multi-device systems could further support such collaborative efforts**. For example, several people using personal and/or shared devices can together co-construct entries of shared meals, perhaps using different modalities (e.g., one person takes a picture, another searches for a food item in a database, others record other food items). Context-aware versions of this approach can also enable semi-automated tracking, such as a system replicating one person's journal entry of a shared dinner to the journal of others that were present. Collaborative creation of entries, such as different people speaking meal components to a VA, can be a similar manual approach. Complexities emerge when people eat together but eat slightly different foods or quantities. For example, there is the need to investigate how co-construction of food logs might combine different modalities and devices between those present, and how such a log might record both a common family meal and the individual consumption.

Important questions remain on how data collected across multiple modalities can be leveraged for self-reflection and eventual action. ModEat sought to explore how multimodality can address common challenges to the collection stage [57] of food journaling, but many of the techniques currently used by food journals to represent or visualize self-tracking data may be less effective for multi-device and multimodal data. For instance, it is unclear how VAs could support interactions for reviewing previous input modalities, especially those particular to other devices. Should VAs try to describe pictures, or read detailed caloric information from a database search? How should screen-based devices show entries created through multiple conversational interactions with VAs? Baumer et al. highlight a need for systems to support reflective processes (e.g., beyond presenting data) [7], suggesting future consideration for the role of multimodal data in supporting deeper reflection on people's eating habits. It is important that these questions be addressed together with advances to collection and reflection on multimodal self-tracked data from multiple devices.

6 CONCLUSION

In extending the analysis of usage logs and participant interviews of the ModEat deployment, we observed that participants' modality and device choices primarily sought to satisfy their journaling goals. However, participants also faced circumstances which influenced or restricted modality and device choices and caused them to deviate from their preferred devices and modalities, including device availability and state of mind. Participants' use of ModEat suggests that multimodality and multi-device systems can potentially lower journaling burdens in some social contexts, or enable flexibility when timeliness is a priority. Combining modalities can help add detail to entries and potentially reduce skipping entries. Our work points to future opportunity to explore use of multiple devices for journaling in parallel, journal entry collaboration between family members using shared and personal devices, and support for reflection on multimodal data.

ACKNOWLEDGMENTS

We thank Kimberly Flores for helping to develop ModEat for voice assistants. We also thank Isil Oygür, and Zhaoyuan Su for feedback on deployment piloting, and our participants for their effort and willingness to contribute during the upheaval time of the COVID-19 pandemic. This research was supported in part by the National Science Foundation under award IIS-1850389.

REFERENCES

[1] Tawfiq Ammari, Jofish Kaye, Janice Y. Tsai, and Frank Bentley. 2019. Music, Search, and IoT: How People (Really) Use Voice Assistants. *ACM Trans. Comput.-Hum. Interact.* 26, 3, Article 17 (apr 2019), 28 pages. https://doi.org/10.1145/3311956

[2] Adrienne H. Andrew, Gaetano Borriello, and James Fogarty. 2013. Simplifying Mobile Phone Diaries: Design and Evaluation of a Food Index-Based Nutrition Diary. In *Proceedings of the International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth 2013)*. 260–263. https://doi.org/bbkk

[3] Ate. 2023. Ate - the Mindful Food Journal. Retrieved June 26, 2023 from https://youate.com/

[4] Amid Ayobi, Paul Marshall, and Anna L. Cox. 2020. Trackly: A Customisable and Pictorial Self-Tracking App to Support Agency in Multiple Sclerosis Self-Care. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2020)*. ACM, New York, NY, USA, 1–15. https://doi.org/10.1145/3313831.3376809

[5] Elizabeth Barrett-Connor. 1991. Nutrition epidemiology: How do we know what they ate?. In *American Journal of Clinical Nutrition*, Vol. 54. 182–189. https://doi.org/10.1093/ajcn/54.1.182s

[6] Eric P.S. Baumer, Sherri Jean Katz, Jill E. Freeman, Phil Adams, Amy L. Gonzales, John Pollak, Daniela Retelny, Jeff Niederdeppe, Christine M. Olson, and Geri K. Gay. 2012. Prescriptive persuasion and open-ended social awareness: Expanding the design space of mobile health. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW 2012)*. 475–484. https://doi.org/10.1145/2145204.2145279

[7] Eric P.S. Baumer, Vera Khovanskaya, Mark Matthews, Lindsay Reynolds, Victoria Schwanda Sosik, and Geri Gay. 2014. Reviewing reflection: On the use of reflection in interactive system design. In *Proceedings of the Conference on Designing Interactive Systems (DIS 2014)*. 93–102. https://doi.org/10.1145/2598510.2598598

[8] Abdelkareem Bedri, Diana Li, Rushil Khurana, Kunal Bhuwalka, and Mayank Goel. 2020. FitByte: Automatic Diet Monitoring in Unconstrained Situations Using Multimodal Sensing on Eyeglasses. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2020)*, Vol. 20. ACM, New York, NY, USA, 1–12. https://doi.org/10.1145/3313831.3376869

[9] Abdelkareem Bedri, Richard Li, Malcolm Haynes, Raj Prateek Kosaraju, Ishaan Grover, Temiloluwa Prioleau, Min Yan Beh, Mayank Goel, Thad Starner, and Gregory Abowd. 2017. EarBit: Using Wearable Sensors to Detect Eating Episodes in Unconstrained Environments. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3, Article 37 (sep 2017), 20 pages. https://doi.org/10.1145/3130902

[10] Joan-Isaac Biel, Nathalie Martin, David Labbe, and Daniel Gatica-Perez. 2018. Bites'n'Bits: Inferring Eating Behavior from Contextual Mobile Data. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT 2018)* 1, 4 (jan 2018), 1–33. https://doi.org/10.1145/3161161

[11] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[12] Virginia Braun and Victoria Clarke. 2019. Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health* 11, 4 (aug 2019), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

[13] Lora E. Burke, Molly B. Conroy, Susan M. Sereika, Okan U. Elci, Mindi A. Styn, Sushama D. Acharya, Mary A. Sevick, Linda J. Ewing, and Karen Glanz. 2011. The effect of electronic self-monitoring on weight loss and dietary intake: A randomized behavioral weight loss trial. *Obesity* 19, 2 (feb 2011), 338–344. https://doi.org/10.1038/oby.2010.208

[14] Michelle Clare Carter, Victoria Jane Burley, Camilla Nykjaer, and Janet Elizabeth Cade. 2013. Adherence to a smartphone application for weight loss compared to website and paper diary: Pilot randomized controlled trial. *Journal of Medical Internet Research* 15, 4 (apr 2013), e32. https://doi.org/10.2196/jmir.2283

[15] Pei-Yu (Peggy) Chi and Yang Li. 2015. Weave: Scripting Cross-Device Wearable Interaction. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. ACM, New York, NY, USA, 3923–3932. https://doi.org/10.1145/2702123.2702451

[16] Eun Kyoung Choe, Saeed Abdullah, Mashfiqui Rabbi, Edison Thomaz, Daniel A. Epstein, Felicia Cordeiro, Matthew Kay, Gregory D. Abowd, Tanzeem Choudhury, James Fogarty, Bongshin Lee, Mark Matthews, and Julie A. Kientz. 2017. Semi-Automated Tracking: A Balanced Approach for Self-Monitoring Applications. *IEEE Pervasive Computing* 16, 1 (jan 2017), 74–84. https://doi.org/10.1109/MPRV.2017.18

[17] Eun Kyoung Choe, Nicole B. Lee, Bongshin Lee, Wanda Pratt, and Julie A. Kientz. 2014. Understanding quantified-selfers' practices in collecting and exploring personal data. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, New York, NY, USA, 1143–1152. https://doi.org/10.1145/2556288.2557372

[18] Keum San Chun, Sarnab Bhattacharya, and Edison Thomaz. 2018. Detecting Eating Episodes by Tracking Jawbone Movements with a Non-Contact Wearable Sensor. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT 2018)* 2, 1 (2018), 1–21. https://doi.org/10.1145/3191736

[19] Chia-Fang Chung, Qiaosi Wang, Jessica Schroeder, Allison Cole, Jasmine Zia, James Fogarty, and Sean A. Munson. 2019. Identifying and Planning for Individualized Change. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT 2019)* 3, 1 (2019), 1–27. https://doi.org/10.1145/3314394

[20] James Clawson, Jessica A Pater, Andrew D Miller, Elizabeth D Mynatt, and Lena Mamykina. 2015. No longer wearing. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp 2015)*. ACM Press, New York, New York, USA, 647–658. https://doi.org/10.1145/2750858.2807554

[21] Nathalie Colineau and Cécile Paris. 2011. Motivating reflection about health within the family: The use of goal setting and tailored feedback. *User Modeling and User-Adapted Interaction* 21, 4-5 (2011), 341–376. https://doi.org/10.1007/s11257-010-9089-x

[22] Felicia Cordeiro, Elizabeth Bales, Erin Cherry, and James Fogarty. 2015. Rethinking the Mobile Food Journal. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2015)*, Vol. 2015-April. ACM, New York, NY, USA, 3207–3216. https://doi.org/10.1145/2702123.2702154

[23] Felicia Cordeiro, Daniel A. Epstein, Edison Thomaz, Elizabeth Bales, Arvind K. Jagannathan, Gregory D. Abowd, and James Fogarty. 2015. Barriers and Negative Nudges: Exploring Challenges in Food Journaling. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2015)*, Vol. 2015-April. ACM, New York, NY, USA, 1159–1162. https://doi.org/10.1145/2702123.2702155

[24] Mayara Costa Figueiredo, Clara Caldeira, Tera L. Reynolds, Sean Victory, Kai Zheng, and Yunan Chen. 2017. Self-Tracking for Fertility Care: Collaborative Support for a Highly Personalized Problem. *Proc. ACM Hum.-Comput. Interact.* 1, CSCW, Article 36 (dec 2017), 21 pages. https://doi.org/10.1145/3134671

[25] Mary Ruth Craig, Alan R. Kristal, Carrie L. Cheney, and Ann L. Shattuck. 2000. The prevalence and impact of 'atypical' days in 4-day food records. *Journal of the American Dietetic Association* 100, 4 (apr 2000), 421–427. https://doi.org/10.1016/S0002-8223(00)00130-9

[26] Alaina Darby, Matthew W Strum, Erin Holmes, and Justin Gatwood. 2016. A Review of Nutritional Tracking Mobile Applications for Diabetes Patient Use. *Diabetes Technology & Therapeutics* 18, 3 (mar 2016), 200–212. https://doi.org/10.1089/dia.2015.0299

[27] Pooja M Desai, Elliot G Mitchell, Maria L Hwang, Matthew E Levine, David J Albers, and Lena Mamykina. 2019. Personal Health Oracle: Explorations of Personalized Predictions in Diabetes Self-Management. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2019)*. ACM, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300600

[28] Linda Di Geronimo, Maria Husmann, and Moira C Norrie. 2016. Surveying personal device ecosystems with cross-device applications in mind. In *PerDis 2016 - Proceedings of the 5th ACM International Symposium on Pervasive Displays*. 220–227. https://doi.org/10.1145/2914920.2915028

[29] Tao Dong, Elizabeth F Churchill, and Jeffrey Nichols. 2016. Understanding the Challenges of Designing and Developing Multi-Device Experiences. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. ACM, New York, NY, USA, 62–72. https://doi.org/10.1145/2901790.2901851

[30] Daniel A Epstein, Monica Caraway, Chuck Johnston, An Ping, James Fogarty, and Sean A Munson. 2016. Beyond Abandonment to Next Steps. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2016)*. ACM, New York, NY, USA, 1109–1113. https://doi.org/10.1145/2858036.2858045

[31] Daniel A. Epstein, Felicia Cordeiro, James Fogarty, Gary Hsieh, and Sean A. Munson. 2016. Crumbs: Lightweight Daily Food Challenges to Promote Engagement and Mindfulness. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. New York, NY, USA, 5632–5644. https://doi.org/10.1145/2858036.2858044

[32] Daniel A. Epstein, Bradley H. Jacobson, Elizabeth Bales, David W. McDonald, and Sean A. Munson. 2015. From "nobody cares" to "way to go!". In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing - CSCW '15*. New York, New York, USA, 1622–1636. https://doi.org/10.1145/2675133.2675135

[33] Daniel A. Epstein, An Ping, James Fogarty, and Sean A. Munson. 2015. A Lived Informatics Model of Personal Informatics. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp 2015)*. Association for Computing Machinery, Inc, New York, New York, USA, 731–742. https://doi.org/10.1145/2750858.2804250

[34] Giannina Ferrara, Jenna Kim, Shuhao Lin, Jenna Hua, and Edmund Seto. 2019. A Focused Review of Smartphone Diet-Tracking Apps: Usability, Functionality, Coherence With Behavior Change Theory, and Comparative Validity of Nutrient Intake and Energy Estimates. *JMIR mHealth and uHealth* 7, 5 (may 2019), e9232. https://doi.org/10.2196/mhealth.9232

[35] Celia Framson, Alan R. Kristal, Jeannette M. Schenk, Alyson J. Littman, Steve Zeliadt, and Denise Benitez. 2009. Development and Validation of the Mindful Eating Questionnaire. *Journal of the American Dietetic Association* 109, 8 (aug 2009), 1439–1444. https://doi.org/10.1016/j.jada.2009.05.006

[36] Elliot G. Mitchell, Elizabeth M. Heitkemper, Marissa Burgermaster, Matthew E. Levine, Yishen Miao, Maria L. Hwang, Pooja M. Desai, Andrea Cassells, Jonathan N. Tobin, Esteban G. Tabak, David J. Albers, Arlene M. Smaldone, and Lena Mamykina. 2021. From Reflection to Action: Combining Machine Learning with Expert Knowledge for Nutrition Goal Recommendations. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. ACM, New York, NY, USA, Article 206, 17 pages. https://doi.org/10.1145/3411764.3445555

[37] Daniel Harrison, Paul Marshall, Nadia Bianchi-Berthouze, and Jon Bird. 2015. Activity tracking. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp 2015)*. ACM Press, New York, New York, USA, 617–621. https://doi.org/10.1145/2750858.2805832

[38] William D. Heizer, Susannah Southern, and Susan McGovern. 2009. The Role of Diet in Symptoms of Irritable Bowel Syndrome in Adults: A Narrative Review. *Journal of the American Dietetic Association* 109, 7 (jul 2009), 1204–1214. https://doi.org/10.1016/j.jada.2009.04.012

[39] Jack F. Hollis, Christina M. Gullion, Victor J. Stevens, Phillip J. Brantley, Lawrence J. Appel, Jamy D. Ard, Catherine M. Champagne, Arlene Dalcin, Thomas P. Erlinger, Kristine Funk, Daniel Laferriere, Pao Hwa Lin, Catherine M. Loria, Carmen Samuel-Hodge, William M. Vollmer, and Laura P. Svetkey. 2008. Weight Loss During the Intensive Intervention Phase of the Weight-Loss Maintenance Trial. *American Journal of Preventive Medicine* 35, 2 (aug 2008), 118–126. https://doi.org/10.1016/j.amepre.2008.04.013

[40] Home Food Safety. 2011. *Desktop Dining Survey: 2011 Results Americans' Food Safety Knowledge and Practice at Work*. Technical Report. www.homefoodsafety.org

[41] Jasmine K. Zia, Chia-Fang Chung, Jessica Schroeder, Sean A. Munson, Julie A. Kientz, James Fogarty, Elizabeth Bales, Jeanette M. Schenk and Margaret M. Heitkemper. 2017. The feasibility, usability, and clinical utility of traditional paper food and symptom journals for patients with irritable bowel syndrome J. *Neurogastroenterology & Motility* 29, 2 (feb 2017), e12935. https://doi.org/10.1111/nmo.12935

[42] Eunkyung Jo, Hyeonseok Bang, Myeonghan Ryu, Eun Jee Sung, Sungmook Leem, and Hwajung Hong. 2020. MAMAS: Supporting Parent–Child Mealtime Interactions Using Automated Tracking and Speech Recognition. *Proceedings of the ACM on Human-Computer Interaction* 4, CSCW1 (may 2020), 1–32. https://doi.org/10.1145/3392876

[43] Tero Jokela, Jarno Ojala, and Thomas Olsson. 2015. A Diary Study on Combining Multiple Information Devices in Everyday Activities and Tasks. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 2015)*, Vol. 2015-April. ACM, New York, NY, USA, 3903–3912. https://doi.org/10.1145/2702123.2702211

[44] David Jones. 2016. Interview: How the myfitnesspal app got 165 million users. https://www.linkedin.com/pulse/interview-how-myfitnesspal-app-got-165-million-users-david-jones

[45] Jisu Jung, Lyndal Wellard-Cole, Colin Cai, Irena Koprinska, Kalina Yacef, Margaret Allman-Farinelli, and Judy Kay. 2020. Foundations for Systematic Evaluation and Benchmarking of a Mobile Food Logger in a Large-scale Nutrition Study. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT 2020)* 4, 2 (jun 2020), 1–25. https://doi.org/10.1145/3397327

[46] Ravi Karkar, Jessica Schroeder, Daniel A. Epstein, Laura R. Pina, Jeffrey Scofield, James Fogarty, Julie A. Kientz, Sean A. Munson, Roger Vilardaga, and Jasmine Zia. 2017. TummyTrials: A Feasibility Study of Using Self-Experimentation to Detect Individualized Food Triggers. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. ACM, New York, NY, USA, 6850–6863. https://doi.org/10.1145/3025453.3025480

[47] Fahim Kawsar and J. Bernheim Brush. 2013. Home computing unplugged: Why, where and when people use different connected devices at home. In *UbiComp 2013 - Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. 627–636. https://doi.org/10.1145/2493432.2493494

[48] Da Jung Kim, Yeoreum Lee, Saeyeong Rho, and Youn Kyung Lim. 2016. Design opportunities in three stages of relationship development between users and self-tracking devices. In *Conference on Human Factors in Computing Systems - Proceedings*. ACM, 699–703. https://doi.org/10.1145/2858036.2858148

[49] Young-Ho Kim, Jae Ho Jeon, Bongshin Lee, Eun Kyoung Choe, and Jinwook Seo. 2017. OmniTrack: A Flexible Self-Tracking Approach Leveraging Semi-Automated Tracking. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT 2017)* 1, 3 (2017), 1–28. https://doi.org/10.1145/3130930

[50] Young-Ho Kim, Bongshin Lee, Arjun Srinivasan, Eun Kyoung Choe, Young-Ho Kim, Bongshin Lee, Arjun Srinivasan, and Eun Kyoung Choe. 2021. Data@Hand: Fostering Visual Exploration of Personal Data on Smartphones Leveraging Speech and Touch Interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2021) (CHI '21)* 21 (jan 2021). https://doi.org/10.1145/3411764.3445421 arXiv:2101.06283

[51] Ahmet Baki Kocaballi, Emre Sezgin, Leigh Clark, John M Carroll, Yungui Huang, Jina Huh-Yoo, Junhan Kim, Rafal Kocielnik, Yi-Chieh Lee, Lena Mamykina, Elliot G Mitchell, Robert J Moore, Prasanth Murali, Elizabeth D Mynatt, Sun Young Park, Alessandro Pasta, Deborah Richards, Lucas M Silva, Diva Smriti, Brendan Spillane, Zhan Zhang, and Tamara Zubatiy. 2022. Design and Evaluation Challenges of Conversational Agents in Health Care and Well-being: Selective Review Study. *J Med Internet Res* 24, 11 (15 Nov 2022), e38525. https://doi.org/10.2196/38525

[52] Alexander Kunst. 2019. E-health application categories used by U.S. adults 2017. https://www.statista.com/statistics/378850/top-mobile-health-application-categories-used-by-us-consumers/

[53] Liliana Laranjo, Adam G. Dunn, Huong Ly Tong, Ahmet Baki Kocaballi, Jessica Chen, Rabia Bashir, Didi Surian, Blanca Gallego, Farah Magrabi, Annie Y.S. Lau, and Enrico Coiera. 2018. Conversational agents in healthcare: A systematic review. *Journal of the American Medical Informatics Association* 25, 9 (2018), 1248–1258. https://doi.org/10.1093/jamia/ocy072

[54] Amanda Lazar, Christian Koehler, Joshua Tanenbaum, and David H Nguyen. 2015. Why we use and abandon smart devices. In *UbiComp 2015 - Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. 635–646. https://doi.org/10.1145/2750858.2804288

[55] Jong Ho Lee, Jessica Schroeder, and Daniel A. Epstein. 2021. Understanding and Supporting Self-Tracking App Selection. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT 2021)* 5, 4 (dec 2021), 1–25. https://doi.org/10.1145/3494980

[56] Uichin Lee, Kyungsik Han, Hyunsung Cho, Kyong-Mee Chung, Hwajung Hong, Sung-Ju Lee, Youngtae Noh, Sooyoung Park, and John M. Carroll. 2019. Intelligent positive computing with mobile, wearable, and IoT devices: Literature review and research directions. *Ad Hoc Networks* 83 (feb 2019), 8–24. https://doi.org/10.1016/j.adhoc.2018.08.021

[57] Ian Li, Anind Dey, and Jodi Forlizzi. 2010. A Stage-Based Model of Personal Informatics Systems. *Conference on Human Factors in Computing Systems - Proceedings* 1 (2010), 557–566. https://doi.org/10.1145/1753326.1753409

[58] Brian Y Lim, Xinni Chng, and Shengdong Zhao. 2017. Trade-off between Automation and Accuracy in Mobile Photo Recognition Food Logging. In *Proceedings of the Fifth International Symposium of Chinese CHI on - Chinese CHI 2017*, Vol. Part F1283. ACM Press, New York, New York, USA, 53–59. https://doi.org/10.1145/3080631.3080640

[59] Xi Lu, Yunan Chen, and Daniel A. Epstein. 2021. How Cultural Norms Influence Persuasive Design: A Study on Chinese Food Journaling Apps. *DIS 2021 - Proceedings of the 2021 ACM Designing Interactive Systems Conference: Nowhere and Everywhere* (jun 2021), 619–637. https://doi.org/10.1145/3461778.3462142

[60] Xi Lu, Edison Thomaz, and Daniel A. Epstein. 2022. Understanding People's Perceptions of Approaches to Semi-Automated Dietary Monitoring. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 6, 3, Article 129 (sep 2022), 27 pages. https://doi.org/10.1145/3550288

[61] Ewa Luger and Abigail Sellen. 2016. Like Having a Really Bad PA. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2016)*. ACM, New York, NY, USA, 5286–5297. https://doi.org/10.1145/2858036.2858288

[62] Kai Lukoff, Taoxi Li, Yuan Zhuang, and Brian Y. Lim. 2018. TableChat: Mobile Food Journaling to Facilitate Family Support for Healthy Eating. *Proceedings of the ACM on Human-Computer Interaction* 2, CSCW (nov 2018), 1–28. https://doi.org/10.1145/3274383

[63] Yuhan Luo. 2021. Designing Multimodal Self-Tracking Technologies to Promote Data Capture and Self-Reflection. In *Companion Publication of the 2021 ACM Designing Interactive Systems Conference* (Virtual Event, USA) *(DIS '21 Companion)*. New York, NY, USA, 11–15. https://doi.org/10.1145/3468002.3468232

[64] Yuhan Luo, Young Ho Kim, Bongshin Lee, Naeemul Hassan, and Eun Kyoung Choe. 2021. FoodScrap: Promoting Rich Data Capture and Reflective Food Journaling through Speech Input. In *DIS 2021 - Proceedings of the 2021 ACM Designing Interactive Systems Conference: Nowhere and Everywhere*, Vol. 13. ACM, New York, NY, USA, 606–618. https://doi.org/10.1145/3461778.3462074

[65] Yuhan Luo, Bongshin Lee, and Eun Kyoung Choe. 2020. TandemTrack: Shaping Consistent Exercise Experience by Complementing a Mobile App with a Smart Speaker. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2020)*. ACM, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376616

[66] Lucas M. Silva and Daniel A. Epstein. 2021. Investigating Preferred Food Description Practices in Digital Food Journaling. In *Proceedings of the ACM Designing Interactive Systems Conference: Nowhere and Everywhere (DIS 2021)*. ACM, New York, NY, USA, 589–605. https://doi.org/10.1145/3461778.3462145

[67] Lena Mamykina, Elizabeth Mynatt, Patricia Davidson, and Daniel Greenblatt. 2008. MAHI: Investigation of Social Scaffolding for Reflective Thinking in Diabetes Management. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2008)*. ACM Press, New York, New York, USA, 477. https://doi.org/10.1145/1357054.1357131

[68] Laura Maria, Christiane Attig, Thomas Franke, Britta Renner, Laura Maria König, Christiane Attig, Thomas Franke, and Britta Renner. 2021. Barriers to and Facilitators for Using Nutrition Apps: Systematic Review and Conceptual Framework. *JMIR Mhealth Uhealth 2021;9(6):e20037 https://mhealth.jmir.org/2021/6/e20037* 9, 6 (jun 2021), e20037. https://doi.org/10.2196/20037

[69] Weiqing Min, Shuqiang Jiang, Linhu Liu, Yong Rui, and Ramesh Jain. 2019. A Survey on Food Computing. *Comput. Surveys* 52, 5 (oct 2019), 1–36. https://doi.org/10.1145/3329168

[70] Manuel Müller, Morgan Harvey, David Elsweiler, and Stefanie Mika. 2012. Ingredient matching to determine the nutritional properties of internet-sourced recipes. In *2012 6th International Conference on Pervasive Computing Technologies for Healthcare and Workshops, PervasiveHealth 2012*. https://doi.org/10.4108/icst.pervasivehealth.2012.248681

[71] MyFitnessPal. 2023. MyFitnessPal: Calorie Counter, Diet & Exercise Journal. Retrieved June 26, 2023 from https://www.myfitnesspal.com/

[72] Michael Nebeling. 2017. XDBrowser 2.0: Semi-Automatic Generation of Cross-Device Interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2017)*, Vol. 2017-May. ACM, New York, NY, USA, 4574–4584. https://doi.org/10.1145/3025453.3025547

[73] Michael Nebeling and Anind K. Dey. 2016. XDBrowser: User-Defined Cross-Device Web Page Designs. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 5494–5505. https://doi.org/10.1145/2858036.2858048

[74] Jasmin Niess and Paweł W. Woźniak. 2018. Supporting Meaningful Personal Fitness: The Tracker Goal Evolution Model. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2018)*, Vol. 2018-April. ACM Press, New York, New York, USA, 1–12. https://doi.org/10.1145/3173574.3173745

[75] Jon Noronha, Eric Hysen, Haoqi Zhang, and Krzysztof Z Gajos. 2011. PlateMate: Crowdsourcing Nutrition Analysis from Food Photographs. In *Crowdsourcing Nutrition Analysis from Food Photographs. Proceedings of the ACM symposium on User interface software and technology (UIST 2011)*. ACM Press, New York, New York, USA, 1. https://doi.org/10.1145/2047196.2047198

[76] NSDR. 2023. Nutrition Data System for Research (NSDR). Retrieved June 26, 2023 from http://www.ncc.umn.edu/products/

[77] Katie O'Leary, Tao Dong, Julia Katherine Haines, Michael Gilbert, Elizabeth F Churchill, and Jeffrey Nichols. 2017. The Moving Context Kit: Designing for Context Shifts in Multi-device Experiences. In *DIS 2017 - Proceedings of the 2017 ACM Conference on Designing Interactive Systems*. ACM, New York, NY, USA, 309–320. https://doi.org/10.1145/3064663.3064768

[78] G. A. O'Reilly, L. Cook, D. Spruijt-Metz, and D. S. Black. 2014. Mindfulness-based interventions for obesity-related eating behaviours: A literature review. *Obesity Reviews* (2014). https://doi.org/10.1111/obr.12156

[79] Laura Pina, Sang-Wha Sien, Clarissa Song, Teresa M. Ward, James Fogarty, Sean A. Munson, and Julie A. Kientz. 2020. DreamCatcher: Exploring How Parents and School-Age Children can Track and Review Sleep Information Together. *Proceedings of the ACM on Human-Computer Interaction* 4, CSCW1 (may 2020), 1–25. https://doi.org/10.1145/3392882

[80] Laura R. Pina, Sang Wha Sien, Teresa Ward, Jason C. Yip, Sean A. Munson, James Fogarty, and Julie A. Kientz. 2017. From Personal Informatics to Family Informatics: Understanding Family Practices around Health Monitoring. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW 2017)*. ACM, New York, New York, USA, 2300–2315. https://doi.org/10.1145/2998181.2998362

[81] Martin Porcheron, Joel E. Fischer, Stuart Reeves, and Sarah Sharples. 2018. Voice Interfaces in Everyday Life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2018)*, Vol. 2018-April. ACM, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3174214

[82] Mashfiqui Rabbi, Min Hane Aung, Mi Zhang, and Tanzeem Choudhury. 2015. MyBehavior. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp '15*. ACM Press, New York, New York, USA, 707–718. https://doi.org/10.1145/2750858.2805840

[83] Mirana Randriambelonoro. 2022. Assessing Activity of Daily Living through Technology-Enabled Tools: Mobility and Nutrition Assessment: MiranaBot: A Nutrition Assessment Use Case. *Health Informatics* (2022), 27–47. https://doi.org/10.1007/978-3-030-94212-0_2

[84] Suzanne M. Rebro, Ruth E. Patterson, Alan R. Kristal, and Carrie L. Cheney. 1998. The Effect of Keeping Food Records on Eating Patterns. *Journal of the American Dietetic Association* 98, 10 (oct 1998), 1163–1165. https://doi.org/10.1016/S0002-8223(98)00269-7

[85] Recovery Record. 2023. Retrieved June 26, 2023 from https://www.recoveryrecord.de/

[86] John Rooksby, Mattias Rost, Alistair Morrison, and Matthew Chalmers. 2014. Personal tracking as lived informatics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2014)*. ACM, New York, NY, USA, 1163–1172. https://doi.org/10.1145/2556288.2557039

[87] Herman Saksono, Ashwini Ranade, Geeta Kamarthi, Carmen Castaneda-Sceppa, Jessica A Hoffman, Cathy Wirth, and Andrea G Parker. 2015. Spaceship Launch: Designing a Collaborative Exergame for Families. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*. ACM, New York, NY, USA, 1776–1787. https://doi.org/10.1145/2675133.2675159

[88] Jessica Schroeder, Jane Hoffswell, Chia Fang Chung, James Fogarty, Sean Munson, and Jasmine Zia. 2017. Supporting patient-provider collaboration to identify individual triggers using food and symptom journals. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW 2017)*. 1726–1739. https://doi.org/10.1145/2998181.2998276

[89] Jessica Schroeder, Ravi Karkar, Natalia Murinova, James Fogarty, and Sean A. Munson. 2019. Examining Opportunities for Goal-Directed Self-Tracking to Support Chronic Condition Management. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT 2019)* 3, 4 (dec 2019), 1–26. https://doi.org/10.1145/3369809

[90] Scott H. Sicherer and Hugh A. Sampson. 2014. Food allergy: Epidemiology, pathogenesis, diagnosis, and treatment. *Journal of Allergy and Clinical Immunology* 133, 2 (2014), 291–307.e5. https://doi.org/10.1016/j.jaci.2013.11.020

[91] Katie A. Siek, Kay H. Connelly, Yvonne Rogers, Paul Rohwer, Desiree Lambert, and Janet L. Welch. 2006. When Do We Eat? An Evaluation of Food Items Input into an Electronic Food Monitoring Application. In *2006 Pervasive Health Conference and Workshops*. IEEE, 1–10. https://doi.org/10.1109/PCTHEALTH.2006.361684

[92] Lucas M. Silva, Franceli L. Cibrian, Daniel A. Epstein, Arpita Bhattacharya, Elizabeth A. Ankrah, Elissa Monteiro, Jesus A. Beltran, Sabrina E. Schuck, Kimberley D. Lakes, and Gillian R. Hayes. 2022. Adapting Multidevice Deployments During a Pandemic: Lessons Learned From Two Studies. *IEEE Pervasive Computing* 21, 1 (jan 2022), 48–56. https:

//doi.org/10.1109/MPRV.2021.3104262

[93] Emma Simpson, Jennifer Bradley, Ivan Poliakov, Dan Jackson, Patrick Olivier, Ashley J Adamson, and Emma Foster. 2017. Iterative Development of an Online Dietary Recall Tool: INTAKE24. *Nutrients* 9, 2 (2017), 118. https://doi.org/10.3390/nu9020118

[94] Edison Thomaz, Irfan Essa, and Gregory D. Abowd. 2015. A Practical Approach for Recognizing Eating Moments with Wrist-Mounted Inertial Sensing. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Osaka, Japan) *(UbiComp '15)*. ACM, New York, NY, USA, 1029–1040. https://doi.org/10.1145/2750858.2807545

[95] Frances E. Thompson and Amy F. Subar. 2013. Dietary Assessment Methodology. In *Nutrition in the Prevention and Treatment of Disease*. Elsevier Inc., 5–46. https://doi.org/10.1016/B978-0-12-391884-0.00001-9

[96] Christoph Trattner, David Elsweiler, and Simon Howard. 2017. Estimating the Healthiness of Internet Recipes: A Cross-sectional Study. *Frontiers in Public Health* 5 (feb 2017). https://doi.org/10.3389/fpubh.2017.00016

[97] Christopher C Tsai, Gunny Lee, Fred Raab, Gregory J Norman, Timothy Sohn, William G Griswold, and Kevin Patrick. 2007. Usability and Feasibility of PmEB: A Mobile Phone Application for Monitoring Real Time Caloric Balance. *Mobile Networks and Applications* 12, 2-3 (jun 2007), 173–184. https://doi.org/10.1007/s11036-007-0014-4

[98] Bert Vandenberghe, Jasper Vanhoof, Roos Voorend, David Geerts, and Fabienne Dobbels. 2018. The 'Self' as Barrier for Self-Management Technologies in Healthcare?. In *Proceedings of the 12th EAI International Conference on Pervasive Computing Technologies for Healthcare*. ACM, New York, NY, USA, 336–346. https://doi.org/10.1145/3240925.3240974

[99] Shibo Zhang, Yuqi Zhao, Dzung Tri Nguyen, Runsheng Xu, Sougata Sen, Josiah Hester, and Nabil Alshurafa. 2020. NeckSense: A Multi-Sensor Necklace for Detecting Eating Activities in Free-Living Conditions. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 4, 2, Article 72 (jun 2020), 26 pages. https://doi.org/10.1145/3397313

[100] Jasmine Zia, Jessica Schroeder, Sean Munson, James Fogarty, Linda Nguyen, Pamela Barney, Margaret Heitkemper, and Uri Ladabaum. 2016. Feasibility and Usability Pilot Study of a Novel Irritable Bowel Syndrome Food and Gastrointestinal Symptom Journal Smartphone App. *Clinical and Translational Gastroenterology* 7, 3 (mar 2016), e147. https://doi.org/10.1038/ctg.2016.9

Received January 2023; revised May 2023; accepted June 2023