MAMAS : Supporting Parent–Child Mealtime Interactions using Automated Tracking and Speech Recognition

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Many parents of young children find it challenging to deal with their children's eating problems, and parent–child mealtime interaction is fundamental in forming children's healthy eating habits. In this paper, we present the results of a three-week study through which we deployed a mealtime assistant application, MAMAS, for monitoring parent–child mealtime conversation and food intake with 15 parent–child pairs. Our findings indicate that the use of MAMAS helped 1) increase children's autonomy during mealtime, 2) enhance parents' self-awareness of their words and behaviors, 3) promote the parent–child relationship, and 4) positively influence the mealtime experiences of the entire family. The study also revealed some challenges in eating behavior interventions due to the complex dynamics of childhood eating problems. Based on the findings, we discuss how a mealtime assistant application can be better designed for parents and children with challenging eating behaviors.

CCS Concepts: • **Human-centered computing → Interaction design**.

Additional Key Words and Phrases: children; eating behavior; family mealtime; magnetometer; parent–child interaction; semi-automated tracking; speech recognition;

ACM Reference Format:
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. *Proc. ACM Hum.-Comput. Interact.* 4, CSCW1, Article 66 (May 2020), 32 pages. https://doi.org/10.1145/3392876

1 INTRODUCTION

Developing healthy eating habits in childhood is closely related to the proper development of physical and mental health [28]. However, However, eating problems, such as refusing to eat certain foods, eating only small portions, and misbehaving (e.g., spitting out food, making noises, walking around the house) [21, 31, 93], are prevalent, as they are observed in 80% of children with developmental disorders and 20% to 50% of those without [73]. Therefore, parents often experience stressful confrontations with their children during mealtime [63], which can lead to aversive

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2573-0142/2020/5-ART66 $15.00
https://doi.org/10.1145/3392876

mealtime experience for the entire family [3, 87]. Research has repeatedly demonstrated that parent–child interaction during mealtime is one of the fundamental factors in forming children's healthy eating habits [17, 57, 68]. While parents' negative statements during mealtime are negatively correlated with a child's food intake [57], parental encouragement is positively correlated to a child's willingness to eat, time spent eating, and relative weight [55, 56]. As researchers recognize the importance of parent–child interaction, traditional eating behavior interventions focus on parents by teaching them how to interact with children during mealtimes [64].

The Human–Computer Interaction (HCI) and computer-supported cooperative work (CSCW) communities have focused on the role of caregivers when dealing with children's health or proper development. Researchers in this space demonstrated that using a record-keeping system allows caregivers to observe their children more carefully, understand their developmental status better, and appreciate the sentimental value of such records [46, 88, 92]. However, parents often find it difficult to keep records regularly due to various challenges such as multiple parenting responsibilities [47, 88] and lack of knowledge to identify and document health-related data [47]. One of the commonly used ways to alleviate parents' burden of keeping records is employing various types of sensors for the automation of assessment of certain behaviors, movements, and emotions [4, 18, 36, 75, 98]. Specifically, many studies in the HCI community have aimed to monitor parent–child conversation automatically for developmental interventions [39, 41, 89]. These studies showed that providing real-time feedback for parents through the automatic analysis of dialogue can enhance the quality of parent–child interactions.

Meanwhile, since eating is one of the most significant health-related activities, researchers have endeavored to automatically capture eating behaviors with various methods, such as acoustic sensing [6, 78] and motion-sensing [26, 77, 94]. Providing real-time feedback based on automatic eating behavior recognition is proven to help individuals reflect on and change their eating habits [49, 84]. Numerous technology-mediated interventions have been suggested to encourage children to adopt healthy eating habits by including instruments in the environment where children eat, such as smart utensils, plates, or trays [21, 42, 43]. Studies have shown that incorporating playful approaches into mealtime contexts motivates children to change their eating behaviors [44, 63, 79]. However, it has continuously been pointed out that the diverse sensory stimuli provided by such interactive systems might bring in unwanted distractions during mealtimes [21, 33, 63]. Therefore, technology-mediated interventions for children should be designed in a way that does not draw too much attention away from the meal itself [63]. Prior work also suggests that technological solutions can be effective methods for improving family mealtime experiences by leveraging the social aspect of the family mealtime [33, 63].

Building on prior research [60], we developed a system kit called MAMAS, a mealtime assistant to improve the eating behavior of children by monitoring children's food intake and parent–child interactions. Using a magnetometer and speech recognition, MAMAS noninvasively tracks children's mealtime behaviors as well as parent–child dialogue. The system supplements automatically-collected data with self-report questionnaires for parents. In addition, parents can engage in data-assisted self-reflection on the mealtime experiences with the meal reports, statistics, and visualizations provided by the system. In this paper, we set out to investigate the impact of MAMAS. Fifteen Korean parent–child pairs participated in the field deployment study, which involved interviews, questionnaires, and the use of MAMAS for three weeks. The findings of the study indicate that the use of MAMAS helped promote children's autonomous eating behaviors, enhance self-awareness of parents, improve parent–child relationships, and positively affect family eating practices. Our findings also revealed some difficulties in improving challenging eating behaviors due to the complex dynamics of childhood eating problems.

The specific contribution of this study is twofold. First, we discuss the opportunities and challenges in childhood eating behavior interventions based on the complexity of family mealtime experiences, which we discovered through the three-week field deployment study with 15 parent–child pairs. Second, we inform the design of a mealtime assistant system for improving children's challenging eating behaviors in three directions: 1) capitalizing on the benefits of manual tracking through a semi-automated tracking approach, 2) facilitating the self-reflection of parents with a specific focus on a subjective aspect of the mealtime experience, and 3) leveraging various means of providing sources for familial conversations to enhance the quality of family mealtime.

2 BACKGROUND AND RELATED WORK

2.1 Supporting Family Mealtime

Family mealtimes are critical for developing children's healthy eating habits, which are closely related to the proper development of their physical and mental health [15, 31]. Parental modeling of eating behaviors and the establishment of eating patterns greatly influence children's eating behaviors [15, 31]. However, parents often find mealtimes challenging, as they experience conflicts with their children due to refusing to eat certain foods, eating only small portions, and behaving inappropriately (e.g., spitting out food, making noises, walking around the house) [21, 31, 93].

Traditionally, researchers attributed the causes of problematic eating behaviors to children's aversion toward certain sensory qualities of food, such as textures and smells [3, 87], or food neophobia in early childhood [13, 32]. Such challenging eating behaviors during mealtimes often cause stressful confrontations between children and parents [63] and thus lead to aversive mealtime experiences for parents and the entire family [3, 87]. Moreover, parents are often concerned about their children's growth due to the limited dietary variety resulting from their challenging eating behaviors [69]. To deal with the aforementioned problematic eating behaviors of children, parents employ various techniques. Graduated exposure to the food (e.g., providing tiny pieces of vegetables with other ingredients and gradually increasing the size of the pieces) that children dislike is one of the most common methods [93]. Many parents give their children rewards for trying the food they resist [15, 17, 68]. Pretend-play techniques (e.g., pretending a spoon is a plane flying toward the child's mouth) are other common methods that many parents use to deal with their children's picky eating [33].

Research has repeatedly demonstrated that parent–child interaction during mealtime is one of the fundamental factors in forming children's eating habits [17, 57, 68]. Klesges et al. [55, 56] demonstrated that parental encouragement to eat is highly correlated to a child's willingness to eat, time spent eating, and relative weight. On the other hand, Koisvisto et al. [57] identified that parents' negative statements during mealtime were negatively correlated with a child's food intake. Similarly, Galloway et al. [32] and Carper et al. [16] showed that parents' highly controlling and pressuring feeding practices are associated with lower intake and foster negative affective responses to foods. These studies also pointed out that pressuring children to eat foods that they dislike might negatively affect a child's capacity to control food intake. Recognizing the importance of parent–child interaction, traditional eating behavior interventions focus on parents by teaching them how to interact with children during mealtimes [64]. Based on previous research, in this work, we set out to explore the impact of a novel system aimed at improving children's mealtime habits by promoting positive parent–child interactions.

2.2 Designing for Family-Centered Tracking

Research in HCI and CSCW has consistently placed emphasis on the family when it comes to dealing with a variety of health-related issues. Specifically, several studies emphasized the role of caregivers when dealing with children's health. Researchers investigated how to support parents of children with certain health conditions (e.g., newborn jaundice [24], preterm infants [62], ADHD [90], Type 1 Diabetes [96]). In addition, the parents' role has also been highlighted in assessing children's developmental status to detect developmental delays in the early stage. Kientz et al. [46], Suh et al. [92], and Song et al. [88] proposed systems for parents' tracking of children's developmental progress. These studies indicated that through using a record-keeping system of children's developmental progress, parents were able to observe their children more carefully, understand their children's developmental status better, and appreciate the sentimental value of such records.

Although parents are aware that continuous tracking of their children's health or development is recommended and beneficial, it is very challenging for them to regularly keep records of their children's developmental milestones because parents often have several responsibilities [47, 88]. In addition, parents often lack the knowledge to identify and document developmental milestones [47]. Therefore, various ways have been proposed to support parents in tracking children's health-related data despite the challenges. One of the suggested ways is involving health experts in collecting and interpreting data about children's developmental progress [10, 97]. Baby CROINC is a developmental tracker for parents that provides experts' curation of the input data. The motivation of the system is based on parents' challenges when collecting and interpreting children's developmental data without expert help [10]. Similarly, Kollenburg [97] explored the potential value of parent-tracked data related to a baby's health to help collaboration between parents and healthcare professionals for a baby's health. Another suggested way to assist a primary caregiver in tracking developmental progress is to facilitate collaborative assessment among multiple caregivers. BebeCODE has been suggested as a collaborative developmental tracking system to mitigate the limitations of a single caregiver's tracking, such as a poor recollection or limited observation [88].

In order to alleviate parents' burden of keeping records of children's health or developmental progress, many studies have employed various types of sensors as well for the automation of assessment of certain behaviors, movements, and emotions. Hayes et al. [36] suggested systems for parents to monitor their preterm infants' movement with wearable sensors at home. Sensor-embedded toys have been used to automatically assess children's motor actions [18, 98]. For children with developmental disorders, PlÃűtz et al. [75] and Albinali et al. [4] developed a sensing system for the automatic assessment of problem behaviors or stereotypical motor movements of children with developmental disorders. Researchers were also interested in capturing parental stress levels with electrodermal activity (EDA) sensors in order to provide *in situ* parenting support [74]. One of the underlying themes of the systems is that the solutions must be unobtrusive because caregivers are often under considerable emotional and physical strain and thus might not be able to make efforts to engage in intense monitoring.

Previous research in this area shows that a health-related tracking system for parents who are tracking on behalf of their children needs to consider ways to deal with the perceived burden of data collection and provide scaffolding for useful documentation and interpretation of their children's health or developmental progress. In this study, we seek to provide a helpful tool for parents to record their everyday mealtimes with children through various scaffolding or analysis reports such as mealtime surveys, conversation analysis, and capture of children's food intake.

2.3 Conversation Monitoring

The HCI and CSCW communities have explored how to better support group conversations in work or educational settings through conversation monitoring technologies. Researchers have aimed to develop a conversation monitoring system that analyzes and provides visualizations of conversational patterns and examine how this would influence group participation or dynamics.

Most research concerns automatically analyzing turn-taking patterns to measure the degree of participation in group meetings based on speaking length or time [9, 25, 40, 59], speech volume [11], and various other indicators of each participant's contribution such as the number of ideas generated and the number of questions raised during the meeting [52]. The motivation of monitoring conversation in these studies is to promote more balanced group conversation and thus enhance group collaboration in collaborative work or learning settings. However, Hirai et al. [37] argued that previous systems that were proposed to support group meetings tend to provide conversation visualizations in a way that can distract the group conversations; therefore, they suggested the need for an ambient conversation support system for group meetings. Building on this previous research, in this work, we suggest an unobtrusive conversation monitoring system for use during mealtimes that aims to help improve parent–child mealtime interactions.

Meanwhile, many studies have aimed to monitor parent–child conversation for improving the quality of the interactions. WAKEY [19] is a system consisting of a mobile application and a toy to help children complete morning tasks more efficiently, and parents improve their communication skills while interacting with their children during their morning routines. Much work primarily focuses on providing interventions for children with developmental challenges or language delays. SpecialTime [39] is a system developed for parents to practice their parent–child Interaction Therapy (PCIT) skills at home by providing real-time feedback to parents through the automatic classification of parent–child dialogue. While SpecialTime [39] focused on capturing the linguistic meaning of parent–child conversation, TalkBetter [41] and TalkLIME [89] focused on detecting meta-linguistic aspects of the conversations. In line with the previously mentioned research on conversation monitoring for work settings, TalkBetter [41] and TalkLIME [89] also aimed at detecting turn-taking patterns of parent–child dialogue in real-time for providing *in situ* feedback on parent–child interactions for children with language delays.

The common ground of these studies is that they deal with parents instead of directly addressing children when providing interventions for parent–child interactions. In this study, we seek to provide a system kit for parents to track their mealtime conversations with children to enhance parent–child interactions and thus improve children's mealtime habits.

2.4 Capturing Eating Behaviors with Sensors

Since eating is one of the most significant health-related activities, researchers have endeavored to automatically capture eating behaviors with various methods, including acoustic sensing and motion sensing. However, it has been proven that capturing eating behaviors accurately and unobtrusively is very challenging [77].

2.4.1 Acoustic sensing. Many studies have utilized audio sensors such as microphones placed on the ear [5, 6] or around the throat [12, 78, 100] to detect eating behaviors. In the lab setting, this approach is a highly accurate method for recognizing eating-related activities [67], such as chewing [6, 7, 82], swallowing [7, 83], and biting [85]. However, it has been pointed out that wearing these types of sensors is too obtrusive or uncomfortable [7, 85] and not appropriate for soft food that does not require much chewing [101]. Furthermore, there has been a criticism that most experiments were conducted in controlled lab settings with a small set of food and little background noise, and thus there is a significant gap with real-life eating situations [66].

Recognizing such limitations, more recent research has explored how the acoustic sensing of eating behaviors works in real life [66, 95]. Thomaz et al. [95] used a wrist-mounted device as an unobtrusive eating behavior recognition method from ambient sounds in everyday settings. Nonetheless, there are various challenges in detecting eating behaviors through audio sensing in real life due to the large differences between the eating environments [66] and background noise [67, 77], which has been reported to be worse when using wristband-type acoustic sensors because they are farther away from the ear [67]. In addition, using acoustic sensors in daily life often raises privacy concerns [67, 77]. Therefore, instead of using acoustic sensors, we employed motion sensors embedded in a smartphone to capture children's food intake.

2.4.2 Motion sensing. While motion sensing has generally proven less accurate than audio sensing, it has an advantage over audio sensing in that it raises fewer privacy concerns [67]. Thus, many researchers have attempted to detect eating behaviors using motion sensors placed on the wrist [5, 7, 26, 27, 67, 86, 94] or head/jaw [66, 77, 82]. Wrist-mounted devices have been used to detect intake gestures [5, 7, 27, 94] and count bites [26, 85, 86]. While some studies have used specialized sensor systems comprised of different types of sensors such as accelerometers [26, 75], inertial sensors [5], and piezoelectric sensors [82], recent studies have capitalized on motion sensors embedded in commercial smartwatches [26, 94].

Motion sensors are also placed around the neck or ear to capture the head or jaw movement. Sazonov et al. [82] attached strain sensors around the ear to detect chewing motion based on lower jaw movement. Similarly, Cheng et al. [22] placed capacitive sensors around the neck to detect swallowing motion. Meanwhile, Rahman et al. [77] exploited another off-the-shelf technology, Google Glass, to identify eating based on head movement. However, these methods are too obtrusive and uncomfortable to be employed in everyday mealtimes, especially for children.

Therefore, instead of placing sensors on the wrist or around the neck, we decided to attach magnets to children's silverware as an unobtrusive way of capturing the food intake of children during mealtimes in their everyday lives. In addition, we capitalized on the smartphone as one of the most commonly used off-the-shelf technologies that can be readily used to collect data to understand mealtime contexts.

2.4.3 Multi-Modality. Based on previous research, researchers have recognized the need for multiple sensing modalities when it comes to recognizing eating behaviors in real life [7, 67]. The multi-modality approach can not only offset each type of sensor's limitations but also significantly improve the accuracy of detecting eating behaviors [67]. Liu et al. [61] jointly used a microphone to monitor chewing activities and a wearable camera to take snapshots when a chewing activity was detected. Thomaz et al. [95] utilized wrist-based motion sensors combined with a wearable camera that took photographs each minute. Similarly, Mirtchouck et al. [66, 67] proposed multimodal sensing using audio sensing, head motion sensing, and wrist motion sensing. These studies demonstrated that a combination of sensing modalities can significantly enhance the accuracy of eating behavior recognition in everyday settings. In addition, as the aforementioned studies using off-the-shelf technologies indicate, Mirtchouck et al. [66] pointed out that the multiple sensing modalities need to be integrated into a single device to avoid the burden that users may feel due to wearing multiple sensors. The results of these studies suggest that mealtime behaviors need to be captured through multiple, various means, ideally through a single device. Based on this insight, we implemented multiple features to collect data to understand mealtime behaviors, such as capturing food intake with motion sensors and self-report surveys, through a smartphone.

2.4.4 Feedback & intervention. While the previously mentioned studies solely focused on accurately detect eating behaviors in various environments, researchers have also further explored real-time feedback on eating behavior that provides interventions for slowing eating speed or reducing energy intake [48–51, 84]. Kim et al. [50, 51] and Scisco et al. [84] presented systems to measure a user's eating speed and provide visual and tactile feedback in real-time. Kim et al. [48, 49] explored different types of feedback, such as graphics, text, clock, vibration [49], and avatar feedback [48].

These studies demonstrated that providing data-based feedback can help people become more reflective about their eating habits and engage in behavior changes, such as slowing eating speed.

In summary, the previous research on eating behavior recognition includes various types of sensing modalities, with each method having pros and cons. To detect eating behaviors in real life with high accuracy, multi-modal sensing is necessary, although multiple sensors need to be incorporated into a single, simple device. Since smartphones are already pervasively adopted and have various types of sensing modalities, such as a camera, accelerometer, and gyroscope, they can be exploited as a great tool for eating behavior recognition in daily life [94]. Furthermore, providing data-based feedback based on sensor data can affect users' eating behaviors. Thus, in this work, we leveraged motion sensors embedded in a smartphone to detect food intake based on intake gestures with the aim of providing interventions for improving the eating habits of children.

2.5 Designing for the Family Mealtime Context

Recognizing the opportunities in improving children's eating habits with technology, researchers have attempted to provide technology-mediated interventions to encourage children to adopt healthy eating habits (e.g., trying various foods or eating larger portions) [20]. Many studies have included instruments in an environment where children eat, such as smart utensils, plates, or trays. Kadomura et al. [43–45] and Joi et al. [42], and Chen et al. [21] developed sensor-embedded forks and spoons to detect eating-related activities or food intake using different types of sensors, such as color sensors [44], accelerometers [44], and inertial sensors [43]. Other researchers have leveraged smart plates and trays as technological solutions for children's challenging eating behaviors, primarily using pressure sensors [101], weight sensors [42, 63], and magnetic sensors [34]. These studies suggest that data-collection tools to understand family mealtime contexts can be seamlessly integrated when including instruments in existing tableware.

Prior work indicates that technological solutions can be effective methods for improving family mealtime experiences [33, 63]. Specifically, Ganesh et al. [33] and Joi et al. [42] put emphasis on considering the social aspects of family mealtimes. For example, FoodWorks [33] highlighted the role of interactive technology enabling picky eaters to seek praise by attaining rewards and other family members to encourage them to eat their disliked food. Joi et al. [42] also demonstrated that playful, smart tableware could reduce pressuring parental prompts and enhance positive encouragement and thus improve family mealtime interactions. Other studies have attempted to enhance mealtime conversation through monitoring and visualizing the utterance rate among people sharing a meal [71, 72] or sharing media, such as music, photos, and tweets, at the dining table [30, 70]. These studies show that such methods have the potential to enhance mealtime communication.

Most of the studies aimed at improving children's eating habits have focused on providing positive feedback to encourage children to concentrate on eating and try disliked food during mealtimes. Ways of providing encouraging feedback include using lights [20, 21, 34], entertaining images or shapes [20, 21, 42, 44], or sounds [20, 21, 34, 44, 45]. Ganesh et al. [33] utilized emerging technology, augmented reality, to provide digital augmentation of food and virtual rewards for children when they completed a meal. These approaches were proven effective in encouraging children to use utensils, maintaining children's attention, and increasing children's willingness to try novel food.

As one of the common ways of motivating children to adopt healthy eating behaviors, several studies have suggested more interactive approaches such as games and virtual/robotic companions. Specifically, we review the research approach that is aimed at incorporating eating behavior interventions into mealtime contexts. One approach is to incorporate a mobile game with smart tableware. For example, Lo et al. [63] developed a mobile racing game used with a weight-sensitive tray that can provide children's eating activities as game inputs during mealtimes. Similarly, Hungry Panda is a mobile game used with the Sensing Fork, which is designed to encourage children to eat a variety of food types [44]. Several studies have employed a pet-like virtual or robotic companion in their interactive games for promoting healthy eating behaviors during mealtimes. Pollak et al. [76] developed a mobile game that prompts users to take pictures of their meals and provide feedback through a virtual pet. Likewise, Randall et al. [79] proposed a system consisting of a sensor-embedded plate and a robotic companion to motivate children during mealtimes. The proposed systems were designed to detect eating activities, whether children completed their meals, the variety of food types, and the healthiness of the food in the pictures based on weight sensors [79], color sensors [44], and manual annotation [76]. The results of these studies showed that this playful approach motivates children to change their eating behaviors.

However, it has continuously been pointed out that the diverse sensory stimuli provided by such interactive systems might bring in unwanted distractions during mealtimes [21, 33, 63]. Thus, technology-mediated interventions should be designed in a way that does not draw too much attention away from the meal itself [63].

In summary, previous research provides insights into technological interventions for challenging eating behavior: 1) technological interventions for challenging eating behavior need to be seamlessly integrated into family mealtime contexts by leveraging the existing tableware; 2) providing positive and encouraging feedback, either from a system or parents, can motivate children (and parents) to adjust their eating behaviors; and 3) providing different types of feedback often helps, although the potential distraction from the meal itself needs to be considered.

Inspired by prior work, we developed a system kit that aims to improve children's challenging eating behaviors by monitoring children's food intake and parent–child interactions. This kit can be seamlessly incorporated into normal familial mealtime because it is comprised of magnets that can be readily attached to silverware that children are using, a specialized tray that is designed to be placed on a smartphone, and a mobile application for data collection. We focused on providing encouraging feedback to parents, instead of children, by analyzing parent–child conversation during mealtimes with the aim of enhancing mealtime communication. In this way, we attempted to design this system in an unobtrusive and noninvasive way to avoid distracting children from the meal itself.

3 STUDY DESIGN AND PROCEDURE

3.1 Preliminary Study

To understand the challenges and current practices of parents during mealtime, we conducted a survey on 78 parents. We recruited participants through a local pediatric clinic's bulletin board. The respondents were raising 'picky eaters' whose ages ranged from 1 to 6. Survey questions for parents covered general information, challenges, behavioral patterns, experiences, and emotions related to mealtimes with their children.

To gain insight into the various options that are in practice to improve children's picky eating, we also conducted semi-structured interviews with three child behavioral experts in South Korea. The expert interview participants were a pediatrician, a clinical psychologist, and a psychiatrist who had regularly consulted with children displaying problematic eating behaviors and their families for more than 20 years. Interview questions for our three experts covered major factors that affect mealtime habit formation and methods to improve children's eating habits.

In sum, the survey and expert interviews revealed that parent–child mealtime interaction plays a critical role in forming children's eating habits. Thus, we decided to focus the design on providing support and encouragement to parents. The parents were stressed because they felt the methods they were using were not effective. They also believed the methods harmed mealtime conversation and the overall parent–child relationship. In addition, we learned that promoting parents' positive feedback to children is vital. Even though our expert participants called for more positive feedback for children, over 60 of the survey respondents said they had expressed negative feelings (e.g., anger) to their children during mealtime. Moreover, we found out that sensory stimuli need to be minimized during mealtime. Our experts unanimously suggested that children should not be exposed to external media, such as handheld screens. Drawing on the design guidelines developed through the preliminary study, we have proposed a prototype system of a mobile application called MAMAS [60]—a Mealtime Assistant using a Magnetometer and Speech recognition.

3.2 System Design

Building on prior research [60] in which we presented an early working prototype with partial functionality based on findings from formative user research, in this work, we implemented a fully working system kit called MAMAS to conduct a deployment study with families with young children in real-world settings.

3.2.1 System Overview. Through MAMAS, parents can track a variety of children's eating behaviors as well as the parents' responses using a smartphone along with a customized bowl and silverware with magnets attached (see Figure 1 (left)). During the meals, MAMAS records parent–child dialogue and tracks the number of times the child picks up a challenge menu item. After the meal ends and all the data are sent to the server, parents are prompted to answer short self-report surveys about each meal, including their level of satisfaction and the behaviors of the child and parent during mealtime (see Figure 2). MAMAS then creates and sends an analysis report on mealtime interaction using the magnetometers, speech recognition, and self-report survey data (see Figure 3 (a,b)). Parents can review past reports or observe weekly or monthly trends as well (see Figure 3 (d)). The detailed design of the app is as described below and a concrete use scenario is illustrated in the demo video. [1]

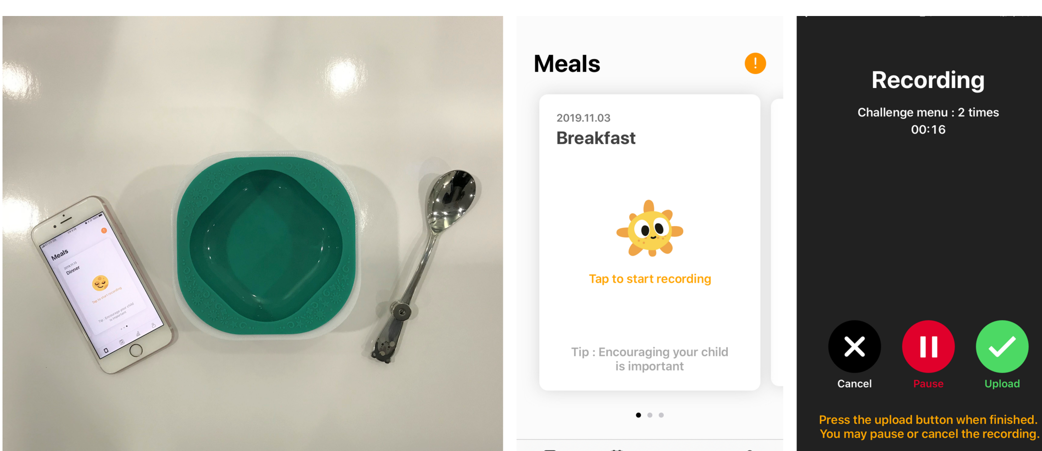

Fig. 1. MAMAS system: a mobile application, a specialized bowl, and a spoon with magnets attached (left), Meals tab (center), Recording page (right)

[1] https://youtu.be/4cXrq2MTURw

3.2.2 Noninvasive Tracking of Mealtime Behaviors. Parents (users) can start tracking a meal at the main 'Meals' tab. The tab consists of three cards representing breakfast, lunch, and dinner of the day, and the user can easily navigate to the recording screen by tapping the card of their choice. After parents press the 'Start' button, MAMAS tracks two main behavioral patterns during mealtimes. First, MAMAS counts how many times the child ate the challenge menu item by utilizing magnetometers embedded in smartphones, which we described above. The 'challenge menu item' refers to a healthy menu item that a child may resist. Before every mealtime, the parent user attaches small magnets to the handle of the child's silverware and places a smartphone under the child's dish using the bowl specially designed for the experiment (see Figure 1 (left)). Second, it records the parent's and child's speech during mealtime using the smartphone's microphone. This recording is later analyzed using speech recognition and sentiment classification models. To give flexibility in dealing with unexpected occurrences in everyday settings, we added a 'Pause' button that allows the user to pause or cancel the recording at any time. After the meal, users can stop the voice recording and tracking of the magnetometer to upload the tracked data. Upon the upload, the back-end system calculates the duration of the meal and prompts the parent to answer the self-report survey.

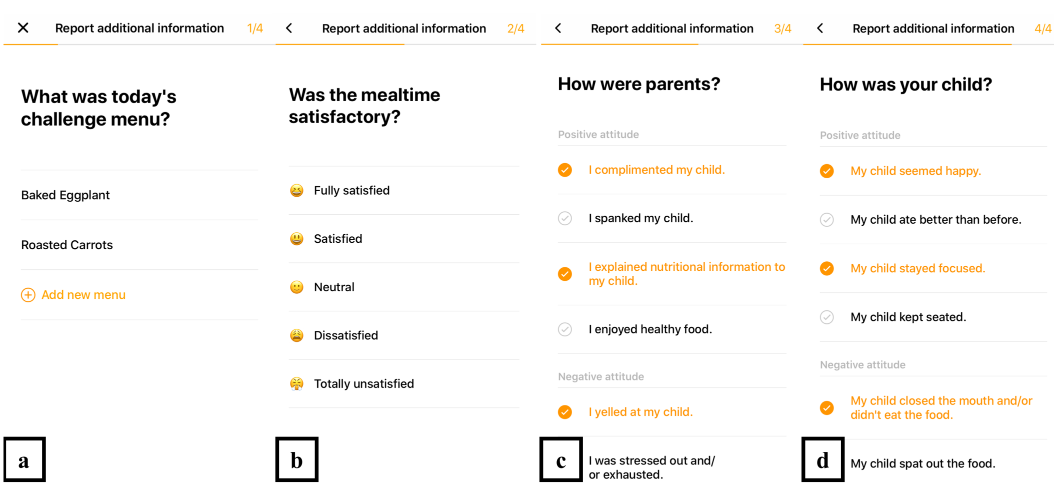

Fig. 2. MAMAS Self-report survey (a,b,c,d)

3.2.3 Data Augmentation with Self-Reporting and Quantification. Parents can answer the self-report survey (see Figure 2) through the in-app prompt given after submitting recordings. In addition to that, reflecting the feedback from a preliminary study that parents are often busiest before and after mealtimes, MAMAS also allows parents to answer questions later in the day by tapping the survey button on the app. To encourage the completion of the self-report survey, it also sends a push notification on a daily basis for incomplete assessments. When the mealtime recording and self-report survey data arrive at the server, it analyzes the data to create meal reports (Figure 3 (a,b)). The analysis consists of three steps.

First, the server converts voice recordings to text sentences using Google Speech-to-Text (STT) API. Then, it selects three positive sentences using the sentiment classification model, which is described in detail in 3.2.6. The text file produced by the STT API goes through a pre-processing and embedding process to enter the main classification network, where the probability of being a positive sentence is calculated for each sentence. The MAMAS database saves positive sentences for presentation. Lastly, it evaluates the total score of the meal according to our formula using the indices collected from the mealtime: duration, intake, and the ratio of positive and negative sentences of a meal. The duration of a meal is weighted 20% in the total score since it was emphasized in the preliminary expert interview that ensuring adequate mealtime (15–30 minutes) and helping children to stay focused on eating within that time are fundamental. The intake of the challenge menu item is weighted by 40% to reflect the direct improvement in children's actual behavior. As the MAMAS app focuses on the interaction of parents and children during mealtime and underlines parents' positive language habits for its improvement, the ratio of positive sentences is weighted 40%. On average, the analysis takes approximately ten minutes. After the analysis, MAMAS notifies the user that the report is ready.

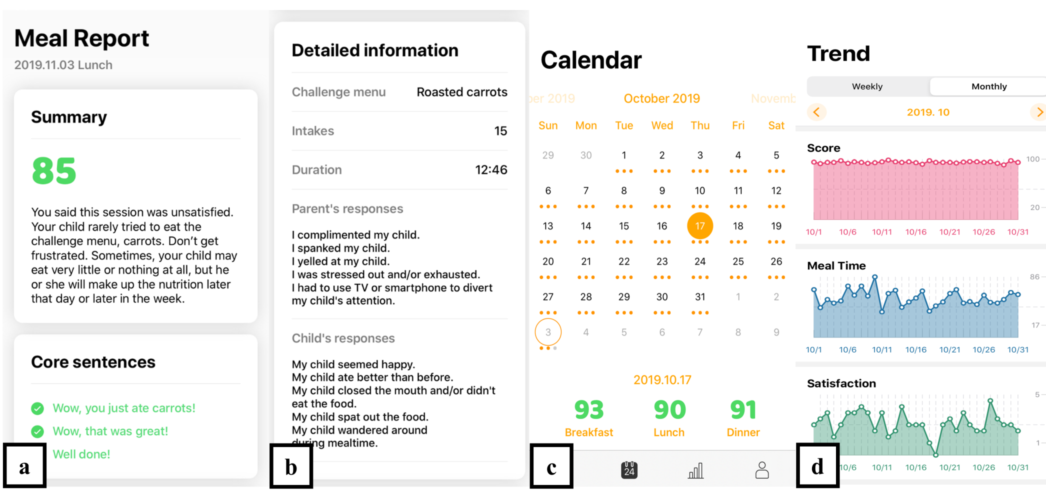

Fig. 3. MAMAS Meal report (a,b), Calendar tab (c), and Trend tab (d)

3.2.4 *Data-Assisted Self-Reflection on Mealtime Interaction.*

The user can read meal reports by tapping the push notification or selecting a certain date in the 'Calendar' tab. As we intended to design an app that helps parents to reflect on their own language habits during mealtime with children, the system gives three main positive sentences at the top of each meal report, followed by a detailed description of the meal (see Figure 3 (a,b)). Parents can see the challenge menu item of each meal, how many times children took the food, and the overall duration of the meal. The report also shows self-reported data regarding mealtime behaviors of parents and children. Finally, users are provided with expert advice on parental language habits and current clinical practice to improve children's eating habits. This function was added, as many participants asked for experts' advice and guidance on improving a child's behavior during the early prototyping and pilot test stage. Thus, snippets of advice are randomly chosen from our database, which were collected from expert interviews and a parenting guidebook published by the government of Korea [58].

The 'Calendar' tab allows users to view and compare previous meal reports (Figure 3 (c)). Meal reports are represented as orange dots under the corresponding date in the calendar tab. By selecting a date, the user can view the total score of the meal and navigate to detailed meal reports.

Users can also check weekly and monthly trends of the quantified data (Figure 3 (d)). For the total score, duration, level of satisfaction, and intake of the challenge menu item, line graphs were adopted to help the users analyze upward or downward trends in each index. To visualize the number of times the child took each challenge menu item, we used horizontal bar graphs to help the users make an easier quantitative comparison between menus. For each of the graphs, the user can open each meal report by tapping on the x-axis (date) of the graph.

3.2.5 System Design Iterations. The initial setup provided to the participants in the field deployment study was comprised of a silicone bowl, a 3D-printed bowl holder, and small neodymium magnets (see Figure 1 (a)). The silicone bowl was used to hold the challenge menu item. The holder held the bowl and was placed on a smartphone for recording. Moreover, the magnets were attached to a fork or spoon to capture food intake through the application. The magnets were wrapped with waterproof tape to prevent them from rusting on the silverware.

However, as we deployed the system kit in real life, we faced several unexpected challenges. To deal with such challenges, throughout the study, we tried to be as responsive to participants' needs as we could by regularly checking in and encouraging them to contact us whenever they had questions. Then, we went through some iterations to accommodate participants' needs that emerged during the course of the study. Therefore, even though our participants might have expected some temporary confusion and inconvenience, we believe their general experiences with the system were not negatively impacted. We outline the iterations that we went through in the following paragraphs.

First, our participants raised the concern that the silverware could still rust when they washed the dishes even though the magnets were wrapped with waterproof tape. In addition, they mentioned that it was annoying to wash the magnet-attached silverware because it attracted other silverware. Therefore, in order to deal with the issues, we changed our magnets to vinyl-covered magnets that could be easily attached and detached from silverware (see Figure 4 (a)).

Second, several participants mentioned that their children used chopsticks instead of a fork, so they wanted to use chopsticks for this experiment. However, we could not attach the magnets we had to chopsticks because they were too large. Therefore, we tried ring-shaped magnets that fit chopsticks with several participants (see Figure 4 (b)). However, participants complained that the ring-shaped magnets made using chopsticks more difficult for children because they caused the chopsticks to stick to each other. Therefore, we decided to allow only a fork or spoon instead of being open to chopsticks.

Third, our participants were worried that their children might swallow the magnets by accident. Therefore, they wanted the magnets to be kept as far as possible from children's mouths. However, it was challenging to accurately capture eating gestures when the magnets were far from the mouth. To solve this problem, we decided to use much stronger magnets that secured the accuracy of the eating gesture recognition even though they were placed farther from the mouth.

Fourth, participants who were using a kid's plate for their children pointed out that using a separate bowl was inconvenient. They mentioned that having a separate bowl seemed to distract their children from eating. Therefore, we attempted to address the problem by using a kid's plate (see Figure 4 (b)) instead of a bowl and a holder. However, through an experiment, we found out that using a kid's plate decreased the quality of audio recordings because the smartphone needed to go underneath the plate where the external sound was shielded. On top of that, most participants reported that their children seemed to adjust to the new mealtime tableware, so the new setup did not distract them anymore. Therefore, we decided to keep the initial bowl and not include a plate.

Lastly, as we proceeded with the field deployment study, we found out that the conversion from voice recordings to text sentences was not accurate enough due to the unsatisfactory quality of audio recordings with a microphone embedded in a smartphone placed under the silicone bowl. Therefore, we decided to use a small wire microphone to improve the quality of audio recordings.

3.2.6 Implementation. MAMAS was implemented on iOS, and the front-end app was developed using Swift. Participants were sent an invitation via Apple TestFlight service, with which they could download and update the app remotely. To convert voice recordings to text sentences, Google Speech-To-Text API was used. The back-end server was backed by Google Firebase to save tracking data and self-assessment answers and run the convolution neural network (CNN) [53] sentence sentiment classifier built using Tensorflow.

The sentence sentiment classifier was built to classify sentiments into positive or negative to suggest the top three positive sentences to users. We used a transfer learning approach with a model trained using an existing sentiment dataset containing 200K short movie reviews shorter than 140 characters with a rating between 1 to 10. [2] It consisted of 100K negative reviews (ratings from 1 to 4) and 100K positive ones (ratings from 9 to 10). We excluded neutral reviews (ratings from 5 to 8) for training purposes. Even though the training data was not directly from the mealtime conversations, it contained Korean colloquial sentences that we believed could be applied to classify family mealtime conversations. We decided to use this dataset because we were able to acquire much larger amounts of data for training than we would have by collecting the mealtime conversation data from scratch. Because CNN performed the best among long short-term memory (LSTM) [38], recurrent neural network (RNN) [65], and a combination of CNN and LSTM [102] in our tests, we decided to use CNN for our system. After training with 50 epochs (batch size = 32), the model showed 82.5% accuracy (82.3% precision, 78.1% recall). Considering the result of a study [99] showing the 82% agreement of two human annotators' judgments on subjective expressions, we found the performance of our classifier reasonable to use for our experiments.

For the module aimed at capturing food intake in MAMAS, we utilized magnetometers embedded in smartphones. Magnetometers detect changes in the strength of magnetic fields, which primarily depend on the distance from magnetic objects and magnetic strengths. Therefore, magnetometers embedded in smartphones can detect changes in values as magnetic objects come closer to or farther away from them. We devised an unobtrusive way to detect children's food intake by attaching neodymium magnets to children's silverware so that a smartphone, placed underneath the customized bowl, could detect when the magnet-attached silverware approached the bowl. Through lab-based empirical experiments that involved a series of iterations with magnets of varying sizes, we determined that the proper size of the magnets and threshold to count the number of intakes. When tested in the lab environments, the module detected 74 in 100 trials of intakes on average.

3.3 Field Deployment Study

3.3.1 Study Procedure. After developing the fully working prototype system, we conducted a pilot study, which involved a three-day use of the application and an exit interview, with three participants. The purpose of the pilot study was to examine the feasibility of the study protocol and the system. After the pilot study, we proceeded to a three-week deployment study to examine how the application affects the mealtime of both a child and a parent. We present the qualitative findings from the pilot study, along with the three-week deployment study in the sections below.

Before they started using MAMAS at home, we met participants in person and introduced them to the system kit comprised of a bowl specialized for the experiment, magnets, and the mobile application. Then, participants were asked to use the system for three weeks at home to record their mealtime experiences. After three weeks, we met each participant again for a one-on-one interview. The individual interviews were conducted to gain qualitative descriptions of participants' experiences using the system during mealtimes.

[2] https://github.com/e9t/nsmc

3.3.2 Questionnaire Measures and Survey. To examine how the three-week use of MAMAS affects family mealtime experiences, two validated measuring tools, the Eating Behavior Test for infants and young children (EBT) [35] and the Parenting Stress Index (PSI), [1] were used for pre- and post-surveys. The EBT consists of three sections—child's eating behavior, parent's eating behavior, and parent's mealtime education. A higher T-score on the child's eating behavior and parent's eating behavior sections indicates that one's eating behavior is more challenging. For parent's mealtime education, a T-score above 60, between 40 and 59, and below 39 means the parent is overly involved in the child's mealtime, appropriately involved, and under-involved, respectively. We used the Korean Parenting Stress Index-Short Form (K-PSI-SF), which consists of 36 questions rated on a 5-point scale ranging from strongly disagree to strongly agree, to identify how the use of MAMAS affects parenting stress. The total score of the K-PSI-SF ranges from 0 to 100, with a higher total score meaning greater parenting stress. In addition, participants completed the Mealtime Behavior (MTB) survey, which was created by the research team to understand participants' mealtime practices, children's challenging eating behaviors, and ways parents deal with such challenges. The survey consists of 11 questions asking parent participants about their observation and subjective evaluation of the meals and their monthly effort at mealtime before and after using MAMAS. We used the results of this survey to support our qualitative findings.

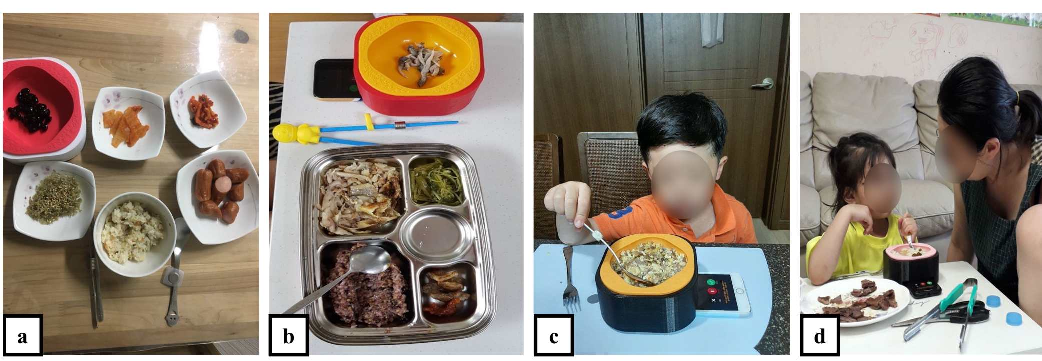

Fig. 4. Participants' mealtime settings using MAMAS (a,b), Participants using MAMAS (c,d)

3.3.3 Participants. Fourteen parents of children between the ages of 2 years and 8 years were recruited from the National Center for Mental Health in Korea (NCMH)(three), a local pediatrician's office (six), an online parenting community (one), and word-of-mouth (four) (Table 1). Since we intended to focus on the interaction between a primary caregiver and a child, we enrolled primary caregivers who were in charge of the mealtime education of a child who exhibited challenging eating behaviors (self-reported by parents). Most of the participants were mothers; only one was a father. One of the participants (MS2) participated in this study twice, the first time with his older child and the second time with his younger child. As the application was implemented on iOS, most of the participants who were iPhone users used their own smartphones, while three participants were loaned iPhones from the research team because they were Android users.

Ten participants had typically developing children, and four of the participants had children who had developmental disorders or were experiencing developmental delays 1. Three of the participants (MN1-MN3), who had regularly visited NCMH for developmental disorder consultations, were allowed to complete the Social Communication Questionnaire (SCQ) [81], Vineland-II [91], and Child Behavior Checklist (CBCL) [2] as a reward for participating in this study. These three surveys are clinically validated instruments for the assessment of developmental disorders or delays in

Table 1. Participant Demographics

Participant	Gender	Age	Child's gender	Child's age	Child's diagnosis
MP1	F	30s	F	2 years	N/A
MP2	F	30s	M	2 years	N/A
MP3	F	30s	F	4 years	N/A
MN1	F	30s	M	3 years	Autism Spectrum Disorder
MN2	F	30s	M	3 years	Language Delays
MN3	F	30s	M	5 years	Autism Spectrum Disorder
MS1	F	30s	F	4 years	N/A
MS2-1*	M	40s	M	8 years	N/A
MS2-2*	M	40s	F	6 years	N/A
MS3	F	30s	M	5 years	N/A
MS4	F	30s	M	8 years	N/A
MS5	F	40s	M	8 years	Autism Spectrum Disorder
MS6	F	30s	M	4 years	N/A
MS7	F	40s	M	3 years	N/A
MS8	F	40s	M	6 years	N/A

* MS2 participated in the experiments twice, once with his son (MS2-1) and again with his daughter (MS2-2).

psychiatric practices. The NCMH clinicians, who were our active collaborators, confirmed that completing those surveys and having complimentary debriefing sessions could be an incentive, because the typical cost for the assessment is approximately \$90. We do not report the results of these measures in this paper. The other 11 participants were compensated approximately \$40. The different types of incentives might have had different impacts on participants' motivations and behaviors, which we could examine in this paper. The study protocol was approved by the Institutional Review Board (IRB) of Seoul National University and the National Center for Mental Health in Korea (NCMH) prior to the study.

3.3.4 Data Analysis. We conducted a quantitative analysis of data logs from MAMAS, including system usage patterns, mealtime length, mealtime report scores, and parents' mealtime satisfaction level. The survey results for the pre- and post-study—the EBT and PSI—were compared with two-tailed paired t-tests reported in the section below.

For qualitative analysis, we audio-recorded and transcribed all the interviews for analysis. A thematic analysis [14] was used to analyze the data. Three researchers each independently conducted an initial coding of the dataset to identify recurring patterns and then discussed ways to organize, generate, and iteratively revise these patterns into themes.

4 FINDINGS

4.1 Quantitative findings

In this section, we report the quantitative results of analyzing the usage log and pre- and post-questionnaires from the field deployment study. Since three weeks is a relatively short time to examine the impacts of using a novel system, we do not intend to argue that the app usage has a direct correlation with the changes that we report in this section. Rather, we aim to emphasize the different aspects of positive changes that our participants experienced through using our system.

4.1.1 Usage Patterns. Upon analyzing the usage log of the field deployment study, we found that the meal for which our participants recorded the tracking data most frequently was dinner, followed

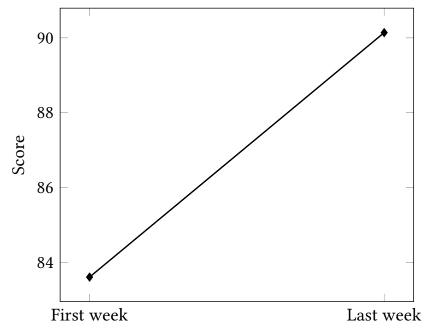

Fig. 5. Weekly average score of mealtime of first and last week

by breakfast and lunch (see Table 3). Among 216 tracking data entries, 130 records were of dinner, 59 were of breakfast, and only 27 were of lunch. This data reflects our participants' everyday life patterns. Because most participants' children spent daytime at school, kindergarten, or daycare centers on weekdays, the parent participants did not eat lunch with their children in most cases. Moreover, since most parent participants were busy in the morning taking their children to school, kindergarten, or daycare, and some even went to work after that, many of them skipped recording at breakfast or breakfast itself sometimes. On the other hand, most parent participants were able to have dinner with their children at home without time pressure.

The average mealtime length in the three-week deployment study decreased from 20.53 minutes to 19.73 minutes after using MAMAS. Among the 13 participants who used MAMAS over three weeks, nine showed a decrease in the length of mealtime with their child. The decrease in the mealtime length is not necessarily desirable, but according to [80], limiting children's mealtime to, for example, less than 30 minutes is ideal. In addition, considering that many participants were concerned that it took too long for their children to complete their meals, the decrease in children's average mealtime length implies desirable results. Our participants' interview data support this finding, as several parents stated that their children were able to better focus during mealtimes after using MAMAS. In addition, the average rate of positive expressions increased from 72.7% to 77.9% over the three weeks (see Table 2), which is also supported by our interview data on our participants' constant efforts to use positive expressions during mealtime after using MAMAS.

Reflecting the decrease in the average mealtime length and the increase in the rate of positive expressions at mealtime, the average weekly mealtime total score (calculated based on the meal duration (20%), number of times the challenge menu item was consumed (40%), and rate of positive sentences recorded (40%), also increased from 83.61 to 90.14 (See Figure 5). This increase implies that the use of MAMAS had an impact on participants' mealtime quality. Because most participants earned the full score for the number of challenge menu items consumed every meal, which was given for a count over five, the increase in the number of such items consumed did not have an impact on the total score. The limitation of the number of challenge menu items consumed is discussed in detail later.

4.1.2 Impacts on Parenting Stress and Eating Behaviors of Child. Overall, we see a positive tendency of the change of PSI. PSI slightly decreased from M=88.75, SD=12.32 to M=86.83, SD=17.43 by the mitigation of parental distress from M=31.67, SD = 5.8 to M=31.17, SD=7.2, of parent–children dysfunctional relationships from M=25.25, SD=6.38 to M=23.92, SD=5.73, and of difficult child factor from M=54, SD=28.6 to M=53.42, SD = 27.7. Although these results are not statistically significant, the overall decrease in PSI is in line with our qualitative findings covered in the following sections.

Table 2. The Rate of Positive Expressions(%)

	First week	Last week	Increase rate
MN1	87.3	86.5	-0.9
MN2	77.6	80.9	4.2
MN3	71.2	78.5	10.3
MS1	67.6	73.7	9.0
MS2-1*	77.0	77.9	1.2
MS2-2*	80.2	76.3	-4.9
MS3	73.8	81.1	9.9
MS4	63.9	92.5	44.8
MS5	63.3	63.6	0.5
MS6	51.1	57.8	13.1
MS7	85.5	83.0	-2.9
MS8	73.3	83.3	13.6
Avg	72.7	77.9	7.2
SD	9.73	9.08	

* MS2 participated in the experiments twice, once with his son (MS2-1) and again with his daughter (MS2-2).

Table 3. Number of Records

	Number of records	Meals recorded		
		Breakfast	Lunch	Dinner
MN1	35	15	6	14
MN2	12	2	2	8
MN3	7	1	5	1
MS1	22	3	2	17
MS2-1*	17	4	3	10
MS2-2*	15	0	3	12
MS3	12	6	0	6
MS4	19	9	2	8
MS5	14	0	1	13
MS6	18	16	0	2
MS7	13	0	0	13
MS8	9	1	2	6
Sum	193	57	26	110
Avg	16.08	4.75	2.17	9.17
Med	14.5	2.5	2	9
Std	6.99	5.46	1.82	4.69

* MS2 participated in the experiments twice, once with his son (MS2-1) and again with his daughter (MS2-2).

Each category in the EBT also shows a positive tendency, (i.e., the decrease of child's eating behavior score (from M=61.83, SD=8.78 to M=54.33, SD=8.34) and parent's eating behavior score (from M=50.66, SD=13.86 to M=48.33, SD=14.53) and the increase of parent's mealtime education score (from M=48.33, SD=15.12 to M=50, SD=13.25)). While the decrease in child's eating behavior score and parent's eating behavior score implies improvement in their eating behavior, the increase in the parent's mealtime education score does not necessarily indicate improvement because the desirable mealtime education score ranges from 40 to 59. Although the results above are also not statistically significant, they are parallel to our qualitative findings of the positive impact of MAMAS on the mealtime of the parent participants and their children.

4.2 Qualitative Findings

4.2.1 Child Autonomy and Eating Behaviors. Our findings indicate that children's autonomous eating behaviors increased by using MAMAS. For instance, MN1's child was able to prepare his meal by himself after he saw his mother set up the bowl, spoon with magnets attached, and smartphone. MN1 felt this new task motivated her child to eat by himself. Similarly, MS3 reported the following: *"Before using MAMAS, I had to feed my son from the beginning to the end during mealtime. When we started using MAMAS, I explained to my son that we were using this new tool to train him to eat better. Then, he started to try eating by himself with the spoon with magnets attached, at least in the early phase of the mealtime, even though I still had to help him finish the food in the later phase."* In other words, our parent participants were able to be less engaged in feeding their children after using MAMAS.

The use of MAMAS motivated children to not only eat by themselves but also try out ingredients they used to avoid, which were provided to them as challenge menu items. MS1 said, *"After using MAMAS, my daughter definitely became more motivated to try out ingredients that she used to avoid. When I set up the table, she tried finishing all the food in the bowl, no matter what—even carrots!"* Similarly, MS8 noted the following: *"My son never ate green onions before using MAMAS, but he came to eat dishes containing them without taking them out. Maybe there had not been enough motivation for him to try new ingredients, and MAMAS gave him the right motivation to try new things."* This implies that MAMAS had an impact on children's motivation to try foods that were new to them.

On top of that, our participants reported that their children were able to better focus during mealtime. Before using MAMAS, MS2 was frustrated that his son and daughter lost focus soon after they started eating and mostly spent their mealtime messing around. However, after using MAMAS, he was delighted that his children were able to focus on eating longer. Likewise, MS1 was satisfied that her child became more focused during mealtime and thus the average mealtime length decreased: *"As she came to concentrate better during mealtime, I was able to see that the mealtimes got a lot shorter; they used to be around 30 minutes but they became shorter, like about 15 minutes"*. Therefore, she came to find having meals with her children much less taxing than before.

On the other hand, not every child became more autonomous and motivated during mealtime after using MAMAS because of parents' psychological pressure associated with their study participation. As MN1's son had rarely eaten by himself, MN1 was concerned that her child's intake was too low when she left it up to her son. Therefore, she ended up feeding her son even more frequently than before using MAMAS, which is consistent with the increase in parental engagement in her EBT results.

4.2.2 Enhancing Self-Awareness of Parents. Even though our participants were aware of the fact that a machine-learning algorithm, not a human, was analyzing their mealtime interactions, they became more conscious of their behaviors and interactions with their children during mealtime as if humans were monitoring them. Most participants reported that they came to keep their temper during mealtime. MP1 said, *"Typically, I would have yelled at my daughter when she didn't seem to concentrate on eating. However, because I knew that all the interactions were audio-recorded, I tried to stay calm and speak softly to her"* Similarly, MS3 and MS4 realized negative wordings they often said to their children by using MAMAS, resolved that they would not repeat them next time, and speculated on how they could improve their children's focus on eating without speaking negatively.

In addition, some of the objective data, such as mealtime length, provided parents with some insights. MS2 was surprised to see that his children's average mealtime length was around 30 minutes because he had estimated it at almost an hour, as it felt so taxing to him. This finding had him reflect on his overall parenting style: *"I realized that I had rushed my children too much during mealtime even though they spent a proper length of time. They were just little kids. I should have given more time and let them mess around a bit. I talked with my wife about this and said we need to be more patient to our kids (MS2)."* Likewise, using MAMAS, MS3 discovered that there was no difference in her children's average mealtime length whether she fed them or let them eat by themselves: *"I had thought I should feed my children because it took so long for them to eat by themselves because they are not interested in eating in general. However, after I realized it takes almost the same length of time whether I feed them or not, I decided to let them eat on their own and stop feeding them and nagging (MS3)."* For some of our participants, the objective data pointed to a new question regarding their child's health. MS8 found out that her child's average mealtime length was too long, at about 80 minutes. She thought there was a need to think about the reason for it (e.g., new teeth coming in, constipation).

Moreover, the self-report questionnaire taught our participants about desirable/undesirable parental behaviors when it comes to eating education. For example, MN2 and MS3 came to know through one of the options in the questionnaire that parents need to show their children that they are enjoying meals. Thus, they tried to make sure that their children watched them enjoying meals. Similarly, MN2 and MP3 realized that negotiating over rewards for eating food that children resist could reinforce the pickiness because it was one of the negative parenting behaviors in the questionnaire: *"I tried to avoid saying things like 'Let's finish eating quickly and eat some ice cream,' as I learned that negotiating during mealtime is not desirable (MN2)."*

Such increased awareness resulted in some changes in our participants' overall attitudes toward the children's eating problems. Our participants made certain assumptions related to their children's eating problems before using MAMAS. Because many of the participants were exhausted by their children's eating problems, they had assumed that their children were so picky that there was no use in striving to fix the problems. However, our participants found out that their children were actually willing to try out new ingredients when they suggested it: *"I learned that he has grown up and is ready to try out new food, but I had just assumed he wouldn't eat unfamiliar ingredients. I felt sorry that I had not tried cooking different foods (MS4)."* Moreover, MS2 and MS6 had thought that their children's eating problems were related to their erratic preferences, which they could not help, but they came to realize that the eating problems were closely related to the quality of interactions and atmosphere at the table. MS6 noted: *"The fact that my children don't eat much made me think of myself as an incompetent parent. I was so stressed out and daunted by that feeling. However, using MAMAS, I was able to see that creating a positive atmosphere and having fun conversations do impact children's eating behaviors, which made me feel a lot better about myself as a parent. (MS6)"* The insight led our participants to resolve to make more efforts to improve their children's eating habits.

4.2.3 Impacts on Parent–Child Relationships. The three-week use of MAMAS affected the relationships between our participants and their children in different ways. Mostly, our participants experienced positive changes in their children's eating problems by using MAMAS. As mentioned in the previous section, many of our participants' children became more motivated to eat by themselves, willing to try out new ingredients, and focused during mealtimes. Accordingly, MS3 stated that she came to compliment her children more often for such positive changes, which made her and her children happier. In addition, from the parents' side, MS1 emphasized how her children's eating behaviors were related to her emotional wellbeing and the parent–child relationship: *"As my child came to eat well, I became much less stressed. And it had a great impact on the children. When mommy is calm and peaceful, so are the kids. Therefore, we get to spend a happy evening after dinner."* Using MAMAS affected not only the emotional aspect but also the physical aspect of children's health. MS1 noted: *"As she came to eat vegetables and have a balanced diet using MAMAS, her constipation got better, and I think that made her a lot less cranky at night as well. Nothing is more important than eating well and sleeping well for children."* Thus, they were able to have a much more enjoyable time in the evening.

On the other hand, some participants emphasized that improving the parent–child relationship comes first when it comes to dealing with children's eating problems. MS6 had been struggling with her children's eating problems for a long time. Through using MAMAS, she tried bringing interesting food-related stories to the table and had some fun conversations with her children. Then, her relationship with her children improved, and the atmosphere at the table became much more pleasant. As a result, her children became more willing to try out new ingredients and eat enough food.

No matter what comes first, our findings showed that the use of MAMAS contributed to creating a virtuous cycle of improving both parent–child relationships and children's eating problems.

4.2.4 Impacts on Family Eating Practices. The impacts of the use of MAMAS were not limited to the parent–child dyad; the eating practices of whole families were influenced by using MAMAS. Notably, some participants' families that used to eat separately came to eat together, while other participants' families that used to eat as a family came to eat separately after using MAMAS.

In many of the participants' families, the child/children and adults used to eat separately for different reasons. For example, MN1 said she needed to prioritize preparing her child's meal because she had a hectic schedule. MS2, MS7, and MS8 decided to eat separately from their children because it was too taxing for them to eat with them, as they messed around too much or took an inordinate length of time.

Notably, the family of one of our participants, MS3, changed their eating practices during the study. Before participating in this study, her family (children, parents, and grandparents) used to eat together. However, during the study, MS3 came to think that if they ate separately, she might be able to nag her children less, and her children might try eating by themselves more. Therefore, her family tried eating in different places: the children in the dining room and the adults in the living room. After trying the new way for a week, MS3 and her family members were satisfied with the changes. MS3 mentioned the following: *"When we ate with our kids, we could not eat well because they didn't focus on eating, and we had to spoon-feed them all the time. It was really stressful for us. After we started to eat separately, the kids tried eating by themselves more, and I came to nag less and compliment them more. The kids are happy, as they are complimented, and the adults are happy, as we can eat peacefully."* Through the experiment, she came to have new insights related to their family eating practices: *"I had thought that it would take too long if I waited for them to eat by themselves, but through the self-experiment, I found out that letting them eat by themselves and spoon-feeding them took the same length of time (MS3)."* Moreover, she noted that she would continue the new way for a while.

On the other hand, a couple of our participants changed their family eating practices in the opposite way because they felt they needed to eat with their children to use MAMAS properly.

Eating as a family had some positive impacts on their mealtime experiences. First, MP3 found that by staying at the table, her children came to wander around less: *"I used to do other chores while letting my children eat by themselves. Using MAMAS, I tried to stay at the table with my kids until they finished eating without doing other stuff. Then, I think they came to wander around a lot less, stay at the table, and focus more on eating."*

In addition, as they came to eat as a family after using MAMAS, most of the participants made conscious efforts to promote quality interactions with their children in creative ways. Some participants introduced nutritional information of the ingredients and origins of food to intrigue children, whether it was information that they had known before or they had found on the internet to share with their children. Other participants, including other non-primary caregivers, focused on encouraging children during mealtime, which created a better atmosphere at the table and made the children more motivated to eat. Meanwhile, some focused on the nostalgic aspect of food. MS2 shared some personal stories related to the dishes of the day, which resulted in children sharing their personal stories related to food as well: *"I constantly tried to share stories related to food, like some related to my childhood, memories of my wife and me when we were dating, and memories of my dad. [...] By sharing those stories, I felt there was much more talking and laughing, which was the best part for me."* Others utilized food-related puns for kids during mealtime. MS6 used some puns from a TV show that her kids loved and said it was extremely helpful for creating a positive atmosphere during mealtime: *"Our family's mealtime had been a disaster. My kids got so cranky because they were not interested in eating, they were tired, and one of them is suffering from atopy. [...] While participating in this study, I used some puns from a TV show that my kids love, something related to carrots. They absolutely loved it, laughed a lot, and ate carrots well!"* She reflected that using puns and songs helped reduce resistance toward food and make mealtimes fun for children.

Whatever strategies parents used, such positive interactions between parents and children helped replace sensory stimuli. Because most participants were struggling to make their children stay at the table, they often gave their children access to some kind of media, such as TV, smartphone, or comic books, while eating. MS4 and MS6 said they needed to let their children read comic books or watch TV in order to make them stay at the table. However, after they came to have some quality interactions using MAMAS, the children were able to stay at the table and focus on eating without the media.

4.2.5 Remaining Challenges: The Complex Dynamics of Childhood Eating Problems. Despite the potential benefits of using MAMAS to mealtime experiences mentioned above, there are remaining challenges to improving childhood eating problems due to their complex dynamics. Even though we examined several vital factors through survey results from parents of young children through a preliminary study, more factors turned out to affect childhood eating problems. Many factors were mostly related to children's natural temperament or preferences. First, most participants said their children exhibited challenging eating behaviors to varying degrees. For example, some avoided certain kinds of fruits and vegetables or fruits and vegetables in general. Other children had a fear of unfamiliar foods, so they only ate what they were used to eating. Second, some children had no interest in eating in general. Thus, they did not eat enough food, ate too slowly, or did not eat unless their parents spoon-fed them. Third, some children were easily distracted during mealtime and thus could not focus on eating. Therefore, many of them got up frequently during mealtime or could not stay at the table unless they were provided with toys, comic books, or a smartphone.

As many children have more than one of the issues mentioned above, improving such eating-related problems is difficult. Hence, the multiple challenges often result in negative impacts on children's overall health, parents' mental wellbeing, and parent–child relationships. MS2, MS3, and MS6 were concerned that their children were smaller than their peers, and they thought the reason was that the children were too picky or did not eat enough. Such concerns made the parents more sensitive to their children's eating problems. Moreover, because of the daily struggles during mealtime, both parents and children were stressed and exhausted, which had some negative impacts on parent–child relationships. MS1 and MS6 said the struggles with their children affected not only the mealtime but also the rest of the day, as their children often became cranky, and the parents became less patient throughout the day.

Even though most parents were willing to improve their children's eating-related problems and were aware of the ideal approaches, several obstacles made it challenging for parents to conduct consistent eating training at home. The hectic schedule of parents and/or children was one of the obstacles. For example, many parents said they had no choice but to spoon-feed their children in the morning to avoid being late for childcare or work, even though they knew that they needed to train their children to eat by themselves. Specifically, MN1 and MN3 had children with an autism spectrum disorder, and they had hectic schedules because of multiple therapy sessions. MN3 said she often had to pick up some simple food or have food delivered instead of cooking for her children because it ended up being too late when they got back home after all the therapy sessions. Because she thought home-cooked food is ideal for children, she was frustrated and dissatisfied with her family's current eating practices.

Family members are one other barrier to eating training at home. When parents have more than one child, it is challenging for them to focus on one and have quality interactions. MP3 noted the following: *"If I had only one child, I could talk to him as much as he wanted. However, since I have to take care of two kids at the same time, it is pretty challenging for me to remain encouraging and receptive during mealtime."* Living with grandparents also brought about some conflicts regarding children's eating training. MS3 mentioned the struggles between her and her parents because of their different perspectives on children's eating training: *"I wanted to set a time limit and take away the dishes when the time was over so that I could train them to eat by themselves. However, my parents think that kids need to eat enough no matter what, even if it means spoon-feeding them."* Therefore, MS3 was having a hard time conducting the eating education that she thought was appropriate for her children.

Due to such multiple issues of children's eating problems and obstacles to eating training, many of our participants were exhausted and said that they almost gave up on trying to overcome the challenges. In the next section, considering both the potential positive impacts of MAMAS on mealtime experiences and the remaining challenges mentioned above, we provide some practical implications to improve and further study childhood eating problems through technologies.

5 DISCUSSION

In this section, based on the potential positive impacts of MAMAS and the remaining challenges, we discuss some implications for designing technological interventions for childhood eating problems.

5.1 Semi-Automated Tracking Approach to Mealtime Behaviors and Interactions

Previous research has emphasized avoiding or minimizing putting extra burdens on parents who are often under considerable constraints when designing a record-keeping system for children's health or development [36, 74, 75]. Based on the argument, the motivation of this study stems from reducing the burden of parents struggling with their children during mealtimes. Therefore, our main focus was to make the process of recording mealtimes as simple as possible by automatizing the recording and analysis process. However, aligned with previous research [77], there are several obstacles to the accurate automatic detection of food intake, which we discuss in the limitations section in detail. Accordingly, the automatic detection of eating behavior was limited in capturing the real experiences of the family mealtime.

We argue that semi-automated tracking [23] can be an effective method to complement automatic tracking in terms of accuracy, as it combines the benefits of both automated and manual tracking while minimizing their limitations. Supporting awareness and providing full control over collected data are the strengths of manual tracking [23]. In addition, it has been found that manual tracking practices provokes mindful reflective thinking [8]. Based on the findings of this study, we see the potential of leveraging the manual tracking process for both parents and children instead of solely automated tracking for recording family mealtime. As for children, most participants agreed that recording mealtime with MAMAS itself helped motivate children to eat by themselves and try new foods. The children wanted to be actively engaged in using the system by checking their food intake shown on the screen while recording and pressing the 'start recording' and 'upload' buttons by themselves. Considering such children's reactions, one participant has suggested having children press a button every time they eat a bite and receive rewards instead of automatically detecting the food intake. Inspired by the findings, we would like to highlight the need for viewing children as proactive agents that can tackle their problematic eating behaviors along with their parents instead of passive objects of observation when it comes to designing feeding interventions. In this sense, we call for building technological rituals not only for parents but also for children to promote data collection and reflection for improving their own eating habits, although researchers need to consider ways to avoid causing distraction from the meal itself.

On top of that, as Ayobi et al. [8] argued, manual tracking may not necessarily be a burden that needs to be overcome with automation, even for parents who are under many constraints. Instead, the efforts required for manual tracking can be worthwhile for parents because it is an effective method for promoting self-exploration, self-reflection, and communication with children and other caregivers [8]. One of our participants also suggested that a more detailed self-report questionnaire, covering how much the child ate, how much was left over, and how much and why the child was wandering around, could supplement the automatically collected data. Therefore, future studies should investigate how to provide better support and scaffolding for a creative and reflective manual tracking process for parents.

In summary, we highlight the opportunity for a semi-automated tracking approach for recording family mealtime that capitalizes on the benefits of manual tracking by emphasizing the active role of children in the mealtime tracking process and supplementing automatic tracking data with self-reported data.

5.2 Increasing Self-Awareness of Parents Through Self-Tracking Practices

Research has demonstrated that parent–child interaction is one of the fundamental factors in forming children's eating habits [17, 57, 68]. Our findings indicate that monitoring family mealtime helped parents become more aware of their words and behaviors, which enhanced their self-regulation and self-control during mealtime. Some objective data (e.g., mealtime length) provided useful insights for parents regarding their children's eating habits. These findings are consistent with previous work that shows that conversation monitoring technologies lead individuals to engage in conversation in a more desirable way [25, 40]. Similarly, a self-report questionnaire provided a normative structure for parents to learn about desirable/undesirable attitudes during mealtime while answering it.

However, there were a few instances where participants noted some of the obstacles to gaining useful self-insights from MAMAS. First, our participants pointed out that the meal report did not seem to reflect the overall experiences of mealtimes. This is because the score is calculated based on automatically collected data such as the number of challenge menu items consumed, the mealtime length, and the ratio of parents' positive sentences without considering subjective data from the self-report questionnaire. For example, MN1 complained that sometimes the scores did not seem to reflect what the mealtime was really like because she achieved a high score even when she was stressed out, her son was wandering around, and she had to feed him throughout the mealtime. On the other hand, she sometimes received a low score even when she and her son had a pleasant mealtime. She assumed that she received a low score due to the small number of challenge menu items consumed even though her child ate three big chunks of meat, which was enough for him. Second, some parents were displeased that their mealtimes were evaluated based on a numerical scoring system. MS6 noted she felt the idea of her meals being judged based on scores was awkward because even schools these days do not evaluate students' performance based on numerical scores. Third, our participants said they wished they could record how satisfied their children were during and after mealtime. Because the system allows users only to record how satisfied parents were, but not how satisfied children were, they felt the system neglected an important aspect of mealtime experiences. Lastly, there was a concern that using MAMAS could put an extra burden on primary caregivers who were already stressed about their children's mealtime education. If stressed-out parents engage in excessive monitoring of their children's mealtime, they are likely to experience even more stress.

To deal with the issues that were discovered through this study and provide more useful self-insights, a feedback system needs to be designed to help parents better reflect on the subjective aspect of mealtime experiences as well as to provide the objective aspect. If there was a gap between the automatically evaluated numerical scores and subjective experiences, the gap could also provide an opportunity for parents to gain useful insights regarding their mealtime experiences. On top of that, when designing technologies for family mealtime, there is a need to support familial communication to more evenly distribute the parenting responsibility among multiple caregivers [88], instead of leaving children's mealtime education solely to a primary caregiver.

5.3 Providing Technological Support for Quality Family Conversations during Mealtime

Our findings demonstrated that parents could adopt creative ways to promote quality interactions with children during mealtimes by introducing relevant nutritional information, scientific trivia, stories related to the origins of foods, fun puns, and even personal stories related to food. These methods helped reduce psychological barriers to new foods, intrigue children who were disinterested in foods, and keep children at the table. Furthermore, they contributed to the improved family mealtime interactions.

Accordingly, as previous studies on conversation monitoring suggest [29, 70], we see the potential of leveraging various ways of providing 'food for conversation' for families through technological support when designing feeding interventions. One way to achieve this could be to provide an open database where parents can search for various food-related kids' videos, fairy tales, scientific trivia, and other nutritional information that can be used as references for parents. Another way could be to integrate ways to archive and retrieve family photos, memos, and videos that provoke familial memories. These resources will help parents engage children's attention to food during mealtime and enhance the quality of family mealtime interactions.

5.4 Facilitating Flexible Use of Tracking Systems

The purpose of this study was to examine the ways in which parents use this system in everyday settings. Therefore, we did not ask parents to use MAMAS in a specific way; instead, we left it up to the parents. Notably, we found a tendency that parents with relatively high PSI scores used the system in rigid ways, whereas parents with relatively low PSI scores used the system in flexible ways. For example, participants with relatively high PSI scores thought they had to talk only about encouraging their children to eat, which they felt unnatural and somewhat burdensome. While using MAMAS, MN3 felt pressured to talk only in proper ways to encourage her child to eat, so she came to talk less than before. In contrast, participants with relatively low PSI scores mentioned that they came to talk about their children's daily lives during mealtime after using MAMAS.

Likewise, participants with high PSI scores assumed they always had to select a challenge menu item that their children resisted when using MAMAS, so they often skipped recording when they were not able to cook something their children avoided. On the other hand, participants with low PSI scores were much more flexible when it came to selecting challenge menu items. For instance, MS3 was more concerned about her child not being interested in eating in general than avoiding certain foods. Therefore, she chose the main dish of every meal as a challenge menu item, instead of foods that her child avoided, and aimed at increasing her child's intake of nutritious food. Similarly, MS6 felt pressured at first to come up with novel recipes that her children might like to prepare a challenge menu item for every meal. However, she came to feel comfortable choosing a challenge menu item because she realized that just putting some diced vegetables in the food that they usually ate allowed her to create a challenge menu item without struggling to come up with a new dish that only consisted of 'challenging' ingredients.

The flexible use of MAMAS not only provided us with many useful insights in designing technological interventions for childhood eating problems but also alleviated our participants' burden of mealtime education and monitoring children's eating habits. Therefore, it is vital to help stressed-out parents, who tend to engage in rigid thinking, to engage in flexible practices when designing a new tracking system for parents. Supporting flexible technological practices could be achieved by 1) designing a tracking system that allows a wide variety of customization over what and how to track [54], 2) introducing various ways of using a new system instead of providing a detailed and rigid guideline, and 3) encouraging parents to freely use a system to accommodate their own needs, preferences, and commitments over time.

5.5 Limitations

5.5.1 Distraction. Even though we attempted to minimize sensory stimuli in the design of MAMAS that could distract children during mealtime, there were several instances in which the introduction of MAMAS to family mealtime practices provoked some distraction. First, several parents were already using their smartphone (e.g., watching videos for kids, video calling with grandparents) during mealtimes as their own strategy to make their children stay at the dining table. However, because the parent's smartphone was placed under the bowl and occupied with recording throughout mealtimes, the families were not able to use them and, thus, parents had a hard time making their children stay at the table. Second, in contrast to the issue mentioned above, some parents found having a smartphone at the table itself distracting. Some parents complained that having a smartphone at the dining table, even though it was underneath the bowl, made their children want to watch videos or play a game with it, and thus, they had a hard time focusing on eating. There were a few instances where not only the smartphone but also the other elements of the system were considered disturbing during mealtime. Most participants' children regarded the new bowl, tray, microphone, and magnets as toys and wanted to play around with them during mealtime. Therefore, parents mentioned that the new setup caused distraction during mealtime in some cases. However, most parents told us that their children became used to it quickly, so they did not attempt to play with them after just a couple of days. Therefore, we assume that our system was not particularly more distracting to children than any other novel objects.

5.5.2 Capturing Food Intake. Our approach to capturing food intake was to use embedded sensors in a smartphone and small magnets attached to a spoon to detect eating gestures. However, there were several limitations to this approach. First, this approach could not reflect differences among various types of food. For example, if a challenge menu item is an apple, just one bite of a piece of an apple is enough for a child, whereas a spoon of soup may not be enough. Second, there were a few instances where children only ate the ingredients that they liked without eating the ingredients that they disliked in the same dish. However, all eating gestures from the challenge menu item bowl were counted as challenge menu item intake. Third, several participants mentioned that the food intake was mismeasured when their children messed around with the spoon or food, held the spoon for a while around a bowl without eating, or reached out to other dishes nearby the challenge menu item bowl. Therefore, despite the system's tendency to underestimate the number of intakes, most participants reported that they found a number of false-positive cases while using the system. Fourth, some participants had been spoon-feeding their children because of their challenging eating behaviors. In this case, detected eating gestures might not be meaningful because children sometimes spat out the food or even did not allow their parents to put the spoon in their mouth. Lastly, some young children primarily used their hands when eating without using a fork or a spoon, so it was challenging for them to measure food intake.

5.5.3 Speech Recognition and Conversation Analysis. Due to the complexity of family mealtime environments, such as conversation among other family members and noises caused by children's discursive behaviors, there were many challenges in speech recognition. Therefore, we often found inaccurate sentences in the meal reports. On top of that, because of the technical limitations of the sentiment classification model that we used, we often observed that trivial or meaningless sentences were selected among the three positive sentences in meal reports. Therefore, there were several instances where our participants reported that the core sentences were not as accurate as they had expected. Interestingly, because of the inaccurate results, they said that they came to look back on the conversations carefully to figure out the origins of those sentences. As a result, it seemed that the technological flaw rather promoted reflection on the conversations that the individuals engaged in, even though it was not an intended outcome. Our next step is to figure out the most influential environmental variables that impact the quality of conversation analysis in the context of family mealtime through field experiments so that we can provide a detailed guideline for future MAMAS users.

6 CONCLUSION

In this study, we investigated the impact of a mealtime assistant system for improving children's challenging eating behaviors by monitoring children's food intake and parent–child interaction through a three-week deployment study. Our findings showed that the use of MAMAS helped increase children's autonomy during mealtime, enhance parents' self-awareness of their words and behaviors, promote parent–child relationships, and positively influence the mealtime experiences of the entire family. Furthermore, the findings of the study revealed some challenges in eating behavior interventions due to the complex dynamics of childhood eating problems. Based on the findings, we discussed the potential benefits of the semi-automated tracking approach, the importance of encouraging self-reflection on the subjective aspect of mealtime experiences, ways to provide technological support for quality family conversations during mealtime, and the need for facilitating the flexible use of tracking systems. We hope more research in this area will investigate ways to better assist parents in dealing with their children's challenging eating behaviors, considering the complex dynamics of family mealtimes.

7 AUTHOR'S CONTRIBUTION

Eunkyung Jo was responsible for defining the intellectual framework of this work. This included defining the problem space of this work based on the existing literature, working with co-authors to design and conduct the deployment study and stabilize MAMAS, determining implications for design after the studies, and writing the manuscript. Hyeonsuk Bang significantly contributed to building both the front-end and back-end sides of the MAMAS mobile system and creating MAMAS video usage scenarios. Myeonghan Ryu was responsible for the data collection process in this work. This included deploying MAMAS in each participant's home, conducting introductory and closing interviews, and performing quantitative and qualitative analyses of interview transcripts, surveys, and log data. Eun Jee Sung substantially contributed to understanding users' common needs and challenges and implementing the first version prototype drawing on the preliminary findings. Sungmook Leem greatly contributed to building the CNN model for sentiment analysis of parent-child conversations. Hwajung Hong significantly contributed to building the intellectual framework of this work with every author and served as the corresponding author of this work.

ACKNOWLEDGMENTS

We thank all the anonymous reviewers for their insightful reviews, which improved this paper. We wish to express our appreciation to the parents and children for their sincere participation. We also extend our gratitude to Dr. So Young Park at our local pediatrics office for her support in recruiting participants. We thank Dr. Yeni Kim at Dongguk University International Hospital and Dr. Jungwon Choi and the clinical psychologists at the National Center for Mental Health (NCMH) in Korea for providing participants with complimentary consultations. This work was generously supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI) funded by the Ministry of Health & Welfare, Republic of Korea (HI18C1180) and a grant of the Next-Generation Information Computing Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (NRF-2017M3C4A7083529) and a grant of the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2018S1A5B8070398).

REFERENCES

[1] R Abidin, J R Flens, and W G Austin. 2013. The parenting stress index. In *Forensic Uses of Clinical Assessment Instruments*. Taylor and Francis, 297–328.

[2] Thomas Achenbach and Leslie Rescorla. 2000. Manual for the ASEBA Preschool forms & profiles. *Burlington: University of Vermont, Research Center for Children, Youth & Families* (01 2000).

[3] William H. Ahearn, Todd Castine, Karen Nault, and Gina Green. 2001. An Assessment of Food Acceptance in Children with Autism or Pervasive Developmental Disorder-Not Otherwise Specified. *Journal of Autism and Developmental Disorders* 31, 5 (2001), 505–511. https://doi.org/10.1023/A:1012221026124

[4] Fahd Albinali, Matthew S. Goodwin, and Stephen S. Intille. 2009. Recognizing stereotypical motor movements in the laboratory and classroom. (2009), 71. https://doi.org/10.1145/1620545.1620555

[5] Oliver Amft, Holger Junker, and Gerhard Tröster. 2005. Detection of eating and drinking arm gestures using inertial body-worn sensors. *Proceedings - International Symposium on Wearable Computers, ISWC* 2005 (2005), 160–163. https://doi.org/10.1109/ISWC.2005.17

[6] Oliver Amft, Martin Kusserow, and Gerhard Tröster. 2009. Bite weight prediction from acoustic recognition of chewing. *IEEE Transactions on Biomedical Engineering* 56, 6 (2009), 1663–1672. https://doi.org/10.1109/TBME.2009.2015873

[7] Oliver Amft and Gerhard Tröster. 2009. On-body sensing solutions for automatic dietary monitoring. *IEEE Pervasive Computing* 8, 2 (2009), 62–70. https://doi.org/10.1109/MPRV.2009.32

[8] Amid Ayobi, Tobias Sonne, Paul Marshall, Anna L Cox, and U C L Interaction Centre. 2018. Flexible and Mindful Self-Tracking : Design Implications from Paper Bullet Journals. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (2018), To appear. https://doi.org/10.1145/3173574.3173602

[9] Khaled Bachour, Frdric Kaplan, and Pierre Dillenbourg. 2010. An interactive table for supporting participation balance in face-to-face collaborative learning. *IEEE Transactions on Learning Technologies* 3, 3 (2010), 203–213. https://doi.org/10.1109/TLT.2010.18

[10] Ayelet Ben-Sasson, Eli Ben-Sasson, Kayla Jacobs, and Eden Saig. 2017. Baby CROINC: an online, crowd-based, expert-curated system for monitoring child development. In *Proceedings of the 11th EAI International Conference on pervasive computing technologies for healthcare (PervasiveHealth '17)*. ACM, 110–119.

[11] Tony Bergstrom and Karrie Karahalios. 2007. Conversation Clock: Visualizing audio patterns in co-located groups. *Proceedings of the Annual Hawaii International Conference on System Sciences* (2007), 1–9. https://doi.org/10.1109/HICSS.2007.151

[12] Yin Bi, Wenyao Xu, Nan Guan, Yangjie Wei, and Wang Yi. 2014. Pervasive eating habits monitoring and recognition through a wearable acoustic sensor? *Proceedings - PERVASIVEHEALTH 2014: 8th International Conference on Pervasive Computing Technologies for Healthcare* (2014), 174–177. https://doi.org/10.4108/icst.pervasivehealth.2014.255423

[13] Leann L. Birch, Lisa Gunder, Karen Grimm-Thomas, and David G. Laing. 1998. Infants' consumption of a new food enhances acceptance of similar foods. *Appetite* 30, 3 (1998), 283–295. https://doi.org/10.1006/appe.1997.0146

[14] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101.

[15] Karen J. Campbell, David A. Crawford, and Kylie D. Hesketh. 2007. Australian parents' views on their 5-6-year-old children's food choices. *Health Promotion International* 22, 1 (2007), 11–18. https://doi.org/10.1093/heapro/dal035

[16] J. L. Carper, J. Orlet Fisher, and L. L. Birch. 2000. Young girls' emerging dietary restraint and disinhibition are related to parental control in child feeding. *Appetite* 35, 2 (2000), 121–129. https://doi.org/10.1006/appe.2000.0343

[17] Rosemary Casey and Paul Rozin. 1989. Changing children's food preferences: Parent opinions. *Appetite* 12, 3 (1989), 171–182. https://doi.org/10.1016/0195-6663(89)90115-3

[18] F. Cecchi, S. M. Serio, M. Del Maestro, C. Laschi, and P. Dario. 2010. Design and development of sensorized toys for monitoring infants' grasping actions. *2010 3rd IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechatronics, BioRob 2010* (2010), 247–252. https://doi.org/10.1109/BIOROB.2010.5627725

[19] Meng Ying Chan, Yi Hsuan Lin, Long Fei Lin, Ting Wei Lin, Wei Che Hsu, Chia Yu Chang, Rui Liu, Ko Yu Chang, Min Hua Lin, and Jane Yung Jen Hsu. 2017. WAKEY: Assisting Parent-child communication for better morning routines. *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW* (2017), 2287–2299. https://doi.org/10.1145/2998181.2998233

[20] Ying Yu Chen, Kelda Baljon, Bonnie Tran, Daniela K. Rosner, and Alexis Hiniker. 2018. The stamp plate and the kicking chair: Playful productivity for mealtime in preschools. *IDC 2018 - Proceedings of the 2018 ACM Conference on Interaction Design and Children* (2018), 373–380. https://doi.org/10.1145/3202185.3202759

[21] Ying-Yu Chen, Ziyue Li, Daniela Rosner, and Alexis Hiniker. 2019. Understanding Parents' Perspectives on Mealtime Technology. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 3, 1 (2019), 1–19. https://doi.org/10.1145/3314392

[22] Jingyuan Cheng, Sebastian Wille, Bo Zhou, Norbert When, Kai Kunze, Jens Weppner, Carl Christian Rheinländer, and Paul Lukowicz. 2013. Activity recognition and nutrition monitoring in every day situations with a textile capacitive neckband. *UbiComp 2013 Adjunct - Adjunct Publication of the 2013 ACM Conference on Ubiquitous Computing* (2013), 155–158. https://doi.org/10.1145/2494091.2494143

[23] 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 (2017), 74–84. https://doi.org/10.1109/MPRV.2017.18

[24] Lilian De Greef, Mayank Goel, Min Joon Seo, Eric C. Larson, James W. Stout, James A. Taylor, and Shwetak N. Patel. 2014. BiliCam: Using mobile phones to monitor newborn jaundice. *UbiComp 2014 - Adjunct Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (2014), 39–41. https://doi.org/10.1145/2638728.2638803

[25] Joan Morris DiMicco, Anna Pandolfo, and Walter Bender. 2004. Influencing group participation with a shared display. *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW* (2004), 614–623. https://doi.org/10.1145/1031607.1031713

[26] Yujie Dong, Adam Hoover, Jenna Scisco, and Eric Muth. 2012. A new method for measuring meal intake in humans via automated wrist motion tracking. *Applied Psychophysiology Biofeedback* 37, 3 (2012), 205–215. https://doi.org/10.1007/s10484-012-9194-1

[27] Yujie Dong, Jenna Scisco, Mike Wilson, Eric Muth, and Adam Hoover. 2014. Detecting periods of eating during free-living by tracking wrist motion. *IEEE Journal of Biomedical and Health Informatics* 18, 4 (2014), 1253–1260. https://doi.org/10.1109/JBHI.2013.2282471

[28] Carl J. Dunst, Deborah Hamby, Carol M. Trivette, Melinda Raab, and Mary Beth Bruder. 2000. Everyday Family and Community Life and Children's Naturally Occurring Learning Opportunities. *Journal of Early Intervention* 23, 3 (2000), 151–164. https://doi.org/10.1177/10538151000230030501

[29] Hasan Shahid Ferdous, Bernd Ploderer, Hilary Davis, Frank Vetere, and Kenton O'Hara. 2016. Commensality and the social use of technology during family mealtime. *ACM Transactions on Computer-Human Interaction* 23, 6 (2016). https://doi.org/10.1145/2994146

[30] Hasan Shahid Ferdous, Bernd Ploderer, Hilary Davis, Frank Vetere, Kenton O'Hara, Geremy Farr-Wharton, and Rob Comber. 2016. TableTalk: Integrating personal devices and content for commensal experiences at the family dinner table. *UbiComp 2016 - Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (2016), 132–143. https://doi.org/10.1145/2971648.2971715

[31] Jayne A. Fulkerson, Mary Story, Dianne Neumark-Sztainer, and Sarah Rydell. 2008. Family Meals: Perceptions of Benefits and Challenges among Parents of 8- to 10-Year-Old Children. *Journal of the American Dietetic Association* 108, 4 (2008), 706–709. https://doi.org/10.1016/j.jada.2008.01.005

[32] Amy T. Galloway, Laura M. Fiorito, Lori A. Francis, and Leann L. Birch. 2006. 'Finish your soup': Counterproductive effects of pressuring children to eat on intake and affect. *Appetite* 46, 3 (2006), 318–323. https://doi.org/10.1016/j.appet.2006.01.019

[33] Sangita Ganesh, Paul Marshall, Yvonne Rogers, and Kenton O'Hara. 2014. FoodWorks: Tackling fussy eating by digitally augmenting children's meals. *Proceedings of the NordiCHI 2014: The 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational* (2014), 147–156. https://doi.org/10.1145/2639189.2639225

[34] Seo Yoon Han and Eun Ji Kang. 2017. ChilDish: The Smart Plate and Cup for Children. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction (HRI '17)*. ACM, New York, NY, USA, 391–392. https://doi.org/10.1145/3029798.3034946

[35] Youngshin Han, Su An Kim, Yoonna Lee, and Jeongmee Kim. 2015. The Development and Validation of Eating Behavior Test Form for Infants and Young Children. *Korean Journal of Community Nutrition* 20, 1 (2015), 1.

[36] Gillian Hayes, Donald Patterson, Mohan Singh, Dana Gravem, Julia Rich, and Dan Cooper. 2011. Supporting the transition from hospital to home for premature infants using integrated mobile computing and sensor support. *Personal and Ubiquitous Computing* 15, 8 (2011), 871–885.

[37] Yuki Hirai and Keiichi Kaneko. 2015. Ambient conversation support in small face-to-face group meetings. *ACM International Conference Proceeding Series* 03-04-Dece (2015), 239–246. https://doi.org/10.1145/2833258.2833274

[38] Sepp Hochreiter and Jürgen Schmidhuber. 1997. Long short-term memory. *Neural computation* 9, 8 (1997), 1735–1780.

[39] Bernd Huber, Richard F. Davis, Allison Cotter, Emily Junkin, Mindy Yard, Stuart Shieber, Elizabeth Brestan-Knight, and Krzysztof Z. Gajos. 2019. SpecialTime: Automatically detecting dialogue acts from speech to support parent-child interaction therapy. *ACM International Conference Proceeding Series* (2019), 139–148. https://doi.org/10.1145/3329189.3329203

[40] Hayley Hung, Yan Huang, Gerald Friedland, and Daniel Gatica-Perez. 2011. Estimating dominance in multi-party meetings using speaker diarization. *IEEE Transactions on Audio, Speech and Language Processing* 19, 4 (2011), 847–860. https://doi.org/10.1109/TASL.2010.2066267

[41] Inseok Hwang, Chungkuk Yoo, Chanyou Hwang, Dongsun Yim, Youngki Lee, Chulhong Min, John Kim, and Junehwa Song. 2014. TalkBetter: Family-driven mobile intervention care for children with language delay. *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW* (2014), 1283–1296. https://doi.org/10.1145/2531602.2531668

[42] Yeong Rae Joi, Beom Taek Jeong, Jin Hwang Kim, Joongsin Park, Juhee Cho, Eunju Seong, Byung Chull Bae, and Jun Dong Cho. 2016. Interactive and connected tableware for promoting children's vegetable-eating and family interaction. *Proceedings of IDC 2016 - The 15th International Conference on Interaction Design and Children* (2016), 414–420. https://doi.org/10.1145/2930674.2930711

[43] Azusa Kadomura, Cheng Yuan Li, Koji Tsukada, Hao Hua Chu, and Itiro Siio. 2014. Persuasive technology to improve eating behavior using a sensor-embedded fork. *UbiComp 2014 - Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (2014), 319–329. https://doi.org/10.1145/2632048.2632093

[44] Azusa Kadomura, Kelvin Cheng Yuan Li, Andy Yen Chang Chen, Hao Hua Chu, Koji Tsukada, and Itiro Siio. 2013. Sensing fork and persuasive game for improving eating behavior. *UbiComp 2013 Adjunct - Adjunct Publication of the 2013 ACM Conference on Ubiquitous Computing* (2013), 71–74. https://doi.org/10.1145/2494091.2494112

[45] Azusa Kadomura, Koji Tsukada, and Itiro Siio. 2013. EducaTableware. (2013), 3071. https://doi.org/10.1145/2468356.2479613

[46] Julie Kientz, Rosa Arriaga, and Gregory Abowd. 2009. Baby steps: evaluation of a system to support record-keeping for parents of young children. In *Proceedings of the SIGCHI Conference on human factors in computing systems (CHI '09)*. ACM, 1713–1722.

[47] Julie A Kientz, Rosa I Arriaga, Marshini Chetty, Gillian R Hayes, Jahmeilah Richardson, Shwetak N Patel, and Gregory D Abowd. 2007. Grow and Know: Understanding Record-Keeping Needs for Tracking the Development of Young Children INTRODUCTION AND MOTIVATION. *CHI 2007 Procedings. Kids & Family* (2007), 1351–1360.

[48] Joohee Kim and Byung Chull Bae. 2018. Demo: A Smartwatch-based feedback system for eating rate guidance. *UbiComp/ISWC 2018 - Adjunct Proceedings of the 2018 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2018 ACM International Symposium on Wearable Computers* (2018), 384–387. https://doi.org/10.1145/3267305.3267669

[49] Joohee Kim and Byung Chull Bae. 2018. Demo: An animated emoji feedback system for eating rate guidance. *UbiComp/ISWC 2018 - Adjunct Proceedings of the 2018 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2018 ACM International Symposium on Wearable Computers* (2018), 388–391. https://doi.org/10.1145/3267305.3267577

[50] Joohee Kim, Kwang Jae Lee, Mankyung Lee, Nahyeon Lee, Byung Chull Bae, Genehee Lee, Juhee Cho, Young Mog Shim, and Jun Dong Cho. 2016. Slowee: A smart eating-speed guide system with light and vibration feedback. *Conference on Human Factors in Computing Systems - Proceedings* 07-12-May- (2016), 2563–2569. https://doi.org/10.1145/2851581.2892323

[51] Joohee Kim, Mankyung Lee, Kwang Jae Lee, Tae Yang Lee, Byung Chull Bae, and Jun Dong Cho. 2016. An eating speed guide system using a wristband and tabletop unit. *UbiComp 2016 Adjunct - Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (2016), 121–124. https://doi.org/10.1145/2968219.2971460

[52] Taemie J. Kim, Agnes Chang, Lindsey Holland, and Alex Pentland. 2008. Meeting mediator: Enhancing group collaboration with sociometric feedback. *Conference on Human Factors in Computing Systems - Proceedings* (2008), 3183–3188. https://doi.org/10.1145/1358628.1358828

[53] Yoon Kim. 2014. Convolutional neural networks for sentence classification. *arXiv preprint arXiv:1408.5882* (2014).

[54] 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. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3 (2017), 67:1—-67:28. https://doi.org/10.1145/3130930

[55] R C Klesges, T J Coates, G Brown, J Sturgeon-Tillisch, L M Moldenhauer-Klesges, B Holzer, J Woolfrey, and J Vollmer. 1983. Parental influences on children's eating behavior and relative weight. *Journal of Applied Behavior Analysis* 16, 4 (1983), 371–378. https://doi.org/10.1901/jaba.1983.16-371

[56] Robert C. Klesges, James M. Malott, Pamela F. Boschee, and Jill M. Weber. 1986. The effects of parental influences on children's food intake, physical activity, and relative weight. *International Journal of Eating Disorders* 5, 2 (1986), 335–345. https://doi.org/10.1002/1098-108X(198602)5:2<335::AID-EAT2260050212>3.0.CO;2-T

[57] Ulla Kaisa Koivisto, Jan Fellenius, and Per Olow Sjödén. 1994. Relations between parental mealtime practices and children's food intake. , 245–258 pages. https://doi.org/10.1006/appe.1994.1023

[58] Korea Health Promotion Institute. 2014. *Happy Mealtime: Healthy Eating Tips for Children.* Technical Report. Ministry of Health and Welfare, Seoul, Korea.

[59] Youngki Lee, Chulhong Min, Chanyou Hwang, Jaeung Lee, Inseok Hwang, Younghyun Ju, Chungkuk Yoo, Miri Moon, Uichin Lee, and Junehwa Song. 2013. SocioPhone: Everyday face-to-face interaction monitoring platform using multi-phone sensor fusion. *MobiSys 2013 - Proceedings of the 11th Annual International Conference on Mobile Systems, Applications, and Services* (2013), 375–388. https://doi.org/10.1145/2462456.2465426

[60] Sungmook Leem, Eun Jee Sung, Sungjin Lee, and Ilyoung Jin. 2018. MAMAS: Mealtime assistant to improve eating behavior of children using magnetometer and speech recognition. *ASSETS 2018 - Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility* (2018), 483–485. https://doi.org/10.1145/3234695.3240988

[61] Jindong Liu, Edward Johns, Louis Atallah, Claire Pettitt, Benny Lo, Gary Frost, and Guang Zhong Yang. 2012. An intelligent food-intake monitoring system using wearable sensors. *Proceedings - BSN 2012: 9th International Workshop on Wearable and Implantable Body Sensor Networks* (2012), 154–160. https://doi.org/10.1109/BSN.2012.11

[62] Leslie S. Liu, Sen H. Hirano, Monica Tentori, Karen G. Cheng, Sheba George, Sun Young Park, and Gillian R. Hayes. 2011. Improving communication and social support for caregivers of high-risk infants through mobile technologies. *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW* (2011), 475–484. https://doi.org/10.1145/1958824.1958897

[63] Jin Ling Lo, Tung Yun Lin, Hao Hua Chu, Hsi Chin Chou, Jen Hao Chen, Jane Yung Jen Hsu, and Polly Huang. 2007. Playful tray: Adopting ubicomp and persuasive techniques into play-based occupational therapy for reducing poor eating behavior in young children. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 4717 LNCS (2007), 38–55. https://doi.org/10.1007/978-3-540-74853-3_3

[64] Robert J (Robert Joseph) McMahon. 2003. *Helping the noncompliant child : family-based treatment for oppositional behavior / Robert J. McMahon, Rex L. Forehand ; foreword by Sharon L. Foster.* (2nd ed.. ed.).

[65] Tomáš Mikolov, Martin Karafiát, Lukáš Burget, Jan Černockỳ, and Sanjeev Khudanpur. 2010. Recurrent neural network based language model. In *Eleventh annual conference of the international speech communication association.*

[66] Mark Mirtchouk, Drew Lustig, Alexandra Smith, Ivan Ching, Min Zheng, and Samantha Kleinberg. 2017. Recognizing Eating from Body-Worn Sensors. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 3 (2017), 1–20. https://doi.org/10.1145/3131894

[67] Mark Mirtchouk, Christopher Merck, and Samantha Kleinberg. 2016. Automated estimation of food type and amount consumed from body-worn audio and motion sensors. *UbiComp 2016 - Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (2016), 451–462. https://doi.org/10.1145/2971648.2971677

[68] Sue N. Moore, Katy Tapper, and Simon Murphy. 2007. Feeding strategies used by mothers of 3-5-year-old children. *Appetite* 49, 3 (2007), 704–707. https://doi.org/10.1016/j.appet.2007.07.009

[69] Sari Mustonen and Hely Tuorila. 2010. Sensory education decreases food neophobia score and encourages trying unfamiliar foods in 8-12-year-old children. *Food Quality and Preference* 21, 4 (2010), 353–360. https://doi.org/10.1016/j.foodqual.2009.09.001

[70] Kazushi Nishimoto, Kenta Amano, and Masao Usuki. 2006. PHotOluck: A home-use table-ware to vitalize mealtime communications by projecting photos onto dishes. *Proceedings of the First IEEE International Workshop on Horizontal Interactive Human-Computer Systems, TABLETOP'06* 2006 (2006), 9–16. https://doi.org/10.1109/TABLETOP.2006.24

[71] Kyohei Ogawa, Yukari Hori, Toshiki Takeuchi, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. 2012. Table Talk Enhancer: A tabletop system for enhancing and balancing mealtime conversations using utterance rates. *CEA 2012 - Proceedings of the 2012 ACM Workshop on Multimedia for Cooking and Eating Activities, Co-located with ACM Multimedia 2012* (2012), 25–30. https://doi.org/10.1145/2390776.2390783

[72] Kyohei Ogawa, Toshiki Takeuchi, Kunihiro Nishimura, Tomohiro Tanikawa, and Michitaka Hirose. 2011. Utterance rate feedback for enhancing mealtime communication. *Proceedings - 2011 IEEE InternationalSymposium on Multimedia, ISM 2011* (2011), 369–374. https://doi.org/10.1109/ISM.2011.67

[73] Christina Ong, Kar Yin Phuah, Endrina Salazar, and Choon How How. 2014. Managing the 'picky eater' dilemma. *Singapore Medical Journal* 55, 4 (2014), 184–190. https://doi.org/10.11622/smedj.2014049

[74] Laura Pina, Kael Rowan, Asta Roseway, Paul Johns, Gillian R. Hayes, and Mary Czerwinski. 2014. In situ cues for ADHD parenting strategies using mobile technology. *Proceedings - PERVASIVEHEALTH 2014: 8th International Conference on Pervasive Computing Technologies for Healthcare* (2014), 17–24. https://doi.org/10.4108/icst.pervasivehealth.2014.254958

[75] Thomas Plötz, Nils Y. Hammerla, Agata Rozga, Andrea Reavis, Nathan Call, and Gregory D. Abowd. 2012. Automatic assessment of problem behavior in individuals with developmental disabilities. *UbiComp'12 - Proceedings of the 2012 ACM Conference on Ubiquitous Computing* (2012), 391–400. https://doi.org/10.1145/2370216.2370276

[76] John P. Pollak, Geri Gay, Sahara Byrne, Emily Wagner, Daniela Retelny, and Lee Humphreys. 2010. It's time to Eat! Using mobile games to promote healthy eating. *IEEE Pervasive Computing* 9, 3 (2010), 21–27. https://doi.org/10.1109/MPRV.2010.41

[77] Shah Atiqur Rahman, Christopher Merck, Yuxiao Huang, and Samantha Kleinberg. 2015. Unintrusive eating recognition using Google Glass. *Proceedings of the 2015 9th International Conference on Pervasive Computing Technologies for Healthcare, PervasiveHealth 2015* (2015), 108–111. https://doi.org/10.4108/icst.pervasivehealth.2015.259044

[78] Tauhidur Rahman, Alexander T. Adams, Mi Zhang, Erin Cherry, Bobby Zhou, Huaishu Peng, and Tanzeem Choudhury. 2014. BodyBeat: A mobile system for sensing non-speech body sounds. *MobiSys 2014 - Proceedings of the 12th Annual International Conference on Mobile Systems, Applications, and Services* (2014), 2–13. https://doi.org/10.1145/2594368.2594386

[79] Natasha Randall, Swapna Joshi, and Xiaohang Liu. 2018. Health-e-Eater: Dinnertime Companion Robot and Magic Plate for Improving Eating Habits in Children from Low-Income Families. *ACM/IEEE International Conference on Human-Robot Interaction* (2018), 361–362. https://doi.org/10.1145/3173386.3177828

[80] Nancy R. Reau, Yvonne D. Senturia, Susan A. Lebailly, and Katherine Kaufer Christoffel. 1996. Infant and toddler feeding patterns and problems: Normative data and a new direction. , 149–153 pages. https://doi.org/10.1097/00004703-199606000-00002

[81] Michael Rutter, Anthony Bailey, and Cathrine Lord. 2003. *The social communication questionnaire: Manual.* Western Psychological Services.

[82] Edward S. Sazonov and Juan M. Fontana. 2012. A sensor system for automatic detection of food intake through non-invasive monitoring of chewing. *IEEE Sensors Journal* 12, 5 (2012), 1340–1348. https://doi.org/10.1109/JSEN.2011.2172411

[83] Edward S. Sazonov, Oleksandr Makeyev, Stephanie Schuckers, Paulo Lopez-Meyer, Edward L. Melanson, and Michael R. Neuman. 2010. Automatic detection of swallowing events by acoustical means for applications of monitoring of ingestive behavior. *IEEE Transactions on Biomedical Engineering* 57, 3 (2010), 626–633. https://doi.org/10.1109/TBME.2009.2033037

[84] Jenna L. Scisco, Eric R. Muth, Yujie Dong, and Adam W. Hoover. 2011. Slowing Bite-Rate Reduces Energy Intake: An Application of the Bite Counter Device. *Journal of the American Dietetic Association* 111, 8 (2011), 1231–1235. https://doi.org/10.1016/j.jada.2011.05.005

[85] Jenna L. Scisco, Eric R. Muth, and Adam W. Hoover. 2014. Examining the utility of a bite-count-based measure of eating activity in free-living human beings. *Journal of the Academy of Nutrition and Dietetics* 114, 3 (2014), 464–469. https://doi.org/10.1016/j.jand.2013.09.017

[86] Yiru Shen, James Salley, Eric Muth, and Adam Hoover. 2017. Assessing the Accuracy of a Wrist Motion Tracking Method for Counting Bites Across Demographic and Food Variables. *IEEE Journal of Biomedical and Health Informatics*

21, 3 (2017), 599–606. https://doi.org/10.1109/JBHI.2016.2612580 arXiv:1806.05352

[87] Annatjie M. Smith, Saartjie Roux, N. T. Naidoo, and Daniel J.L. Venter. 2005. Food choices of tactile defensive children. *Nutrition* 21, 1 (2005), 14–19. https://doi.org/10.1016/j.nut.2004.09.004

[88] Seokwoo Song, Juho Kim, Bumsoo Kang, Wonjeong Park, and John Kim. 2018. BebeCODE: Collaborative Child Development Tracking System. In *Proceedings of the 2018 CHI Conference on human factors in computing systems (CHI '18)*, Vol. 2018-. ACM, 1–12.

[89] Seokwoo Song, Seungho Kim, John Kim, Wonjeong Park, and Dongsun Yim. 2016. TalkLIME: Mobile system intervention to improve parent-child interaction for children with language delay. *UbiComp 2016 - Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (2016), 304–315. https://doi.org/10.1145/2971648.2971650

[90] Tobias Sonne, Jörg Müller, Paul Marshall, Carsten Obel, and Kai Grønbæk. 2016. Changing family practices with assistive technology: MOBERO improves morning and bedtime routines for children with ADHD. *Conference on Human Factors in Computing Systems - Proceedings* (2016), 152–164. https://doi.org/10.1145/2858036.2858157

[91] Sara S Sparrow. 2011. *Vineland Adaptive Behavior Scales.* Springer New York, New York, NY, 2618–2621. https://doi.org/10.1007/978-0-387-79948-3_1602

[92] Hyewon Suh, John R. Porter, Alexis Hiniker, and Julie A. Kientz. 2014. @BabySteps: Design and evaluation of a system for using twitter for tracking children's developmental milestones. *Conference on Human Factors in Computing Systems - Proceedings* (2014), 2279–2288. https://doi.org/10.1145/2556288.2557386

[93] Amy Tanner and Bianca E. Andreone. 2015. Using Graduated Exposure and Differential Reinforcement to Increase Food Repertoire in a Child with Autism. *Behavior Analysis in Practice* 8, 2 (2015), 233–240. https://doi.org/10.1007/s40617-015-0077-9

[94] Edison Thomaz, Irfan Essa, and Gregory D. Abowd. 2015. A practical approach for recognizing eating moments with wrist-mounted inertial sensing. *UbiComp 2015 - Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (2015), 1029–1040. https://doi.org/10.1145/2750858.2807545

[95] Edison Thomaz, Cheng Zhang, Irfan Essa, and Gregory D. Abowd. 2015. Inferring meal eating activities in real world settings from ambient sounds: A feasibility study. *International Conference on Intelligent User Interfaces, Proceedings IUI* 2015-Janua (2015), 427–431. https://doi.org/10.1145/2678025.2701405

[96] Tammy Toscos, Kay Connelly, and Yvonne Rogers. 2012. Best intentions: Health monitoring technology and children. *Conference on Human Factors in Computing Systems - Proceedings* June 2014 (2012), 1431–1440. https://doi.org/10.1145/2207676.2208603

[97] Janne Van Kollenburg, Sander Bogers, Heleen Rutjes, Eva Deckers, Joep Frens, and Caroline Hummels. 2018. Exploring the value of parent-tracked baby data in interactions with healthcare professionals: A data-enabled design exploration. *Conference on Human Factors in Computing Systems - Proceedings* 2018-April (2018), 1–12. https://doi.org/10.1145/3173574.3173871

[98] Tracy L. Westeyn, Gregory D. Abowd, Thad E. Starner, Jeremy M. Johnson, Peter W. Presti, and Kimberly A. Weaver. 2012. Monitoring children's developmental progress using augmented toys and activity recognition. *Personal and Ubiquitous Computing* 16, 2 (2012), 169–191. https://doi.org/10.1007/s00779-011-0386-0

[99] Theresa Wilson, Janyce Wiebe, and Paul Hoffmann. 2005. Recognizing contextual polarity in phrase-level sentiment analysis. In *Proceedings of human language technology conference and conference on empirical methods in natural language processing*. 347–354.

[100] Koji Yatani and Khai N. Truong. 2012. BodyScope. (2012), 341. https://doi.org/10.1145/2370216.2370269

[101] Bo Zhou, Jingyuan Cheng, Paul Lukowicz, Attila Reiss, and Oliver Amft. 2015. Monitoring Dietary Behavior with a Smart Dining Tray. *IEEE Pervasive Computing* 14, 4 (2015), 46–56. https://doi.org/10.1109/MPRV.2015.79

[102] Chunting Zhou, Chonglin Sun, Zhiyuan Liu, and Francis Lau. 2015. A C-LSTM neural network for text classification. *arXiv preprint arXiv:1511.08630* (2015).

Received January 2020; accepted March 2020