FamilyScope: Visualizing Affective Aspects of Family Social Interactions using Passive Sensor Data

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This work presents FamilyScope, a sensor-based family informatics system that enables reflection upon family data collected from family activity scenarios (e.g., game playing and movie watching) that include affective aspects of a family's social interactions. We conducted a user study with ten families (n=30) in a smart home testbed to observe how our system supports data reflection of the affective and behavioral states among family members. Our findings showed that FamilyScope facilitated family data reflection on affective and behavioral aspects of family interactions. Overall, families reported that the system well reflected family members' general tendencies in terms of affective and behavioral responses and even helped them gain new insights about each other. Based on the findings, we provide practical design approaches for collective reflection in family informatics systems.

CCS Concepts: • **Human-centered computing → Empirical studies in collaborative and social computing**; **Visualization design and evaluation methods**.

Additional Key Words and Phrases: Family informatics, Sensor data, Visualization

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1 INTRODUCTION

A family can be considered a small social network where individuals interconnect with each other through shared activities, times, and routines [7]. Previous studies that view family as a social unit have emphasized that such shared moments play an important role in consolidating family relationships and emotional ties among family members [81, 83]. Thus, exploring how families feel

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and respond through familial activities has become an important indicator in defining “emotionally healthy" families.

In terms of what constitutes a socially and emotionally healthy family, existing theoretical models have presented several explanations. For example, McMaster’s family functioning model [23] emphasizes the social aspects of family members, focusing on how each family responsibly engages in family-based activities and shows affection to each other. In addition, Walsh’s family resilience model [79] highlights one’s capability to recover and adapt in terms of family conflicts and stress. From these theoretical perspectives, we find the importance of exploring the affective aspects of family members in construing family social interactions. To observe and assess such family interaction, prior studies have primarily used self-report questionnaires derived from well-known theories in family health [22], or direct video-based observations in family contexts [26].

Meanwhile, there has been a growing interest in leveraging data-driven approaches to collect and reflect upon family health as well. While a large body of HCI studies has focused on self-reflection based on personal data, (i.e., personal informatics) using sensor-rich tracking tools [42, 45], recent HCI studies have begun to realize the importance of understanding family practices around health monitoring and designing tools that support families to collaboratively review their data (i.e., family informatics) [60]. Pina et al.’s study [60] has argued that the current dominant paradigms of self-reflection and its relevant technology designs are insufficient to support maximizing health across the family, as many aspects of health or health-related behaviors affect and are affected by others. Current HCI studies on family informatics generally use mobile and wearable devices to acquire family data from real-world contexts with system designs that enable meaningful reflection on their family, which are largely confined to the physical health domain (e.g., sleep and physical activity) [59, 60, 66]. With this context in mind, we observe that social computing studies have yet to investigate family health with a focus on analyzing and sharing the affective and behavioral states of a family observed from social interactions.

Therefore, we conducted a user study with a prototype system called FamilyScope, which provides quantified and visualized representations of passive sensor data collected from real-life scenarios that involve family units (e.g., eating together and watching TV). To support reflection on affective and behavioral states from family interaction, we collected physiological and motion data using a wearable device to observe emotional and behavioral states. We then extracted related features from passive sensor data and integrated the videos that were recorded during family activities on the system to help with reflection. For the data representation, a visualization method was selected to help family members comprehend the data in a simple and intuitive manner (e.g., charts and graphs).

With FamilyScope, we set out the following research questions (RQs) to investigate how families perceive and make use of the system and whether the system helps families reflect upon their social interaction:

- (RQ1): How do families leverage FamilyScope’s features to support a data exploration process?
- (RQ2): How do families reflect on affective aspects of their social interaction via FamilyScope?

To answer these questions, we conducted user studies for a data collection and system evaluation along with exit interviews (n=30). Our results showed that FamilyScope’s system design is effective in reflecting affective aspects of a family’s social interaction. Most families evaluated that the FamilyScope well reflected their general tendencies in terms of psychological and behavioral responses and even commented that the system enabled novel discoveries about themselves and their family members, leading to deeper understandings of each other. In this study, we call this family data reflection process as “family co-reflection,” which refers to family members collaboratively discussing each other’s data and the data of the entire family to assess their affective interaction and shared patterns. According to a well-known theory of reflection, we consider FamilyScope to be a system that supports reflection *on-action*, which refers to a type of reflection that offers general insights based on the entirety of a certain task once it is completed [70].

Taken together, the key contributions of our study are as follows:

- We designed and implemented FamilyScope, a data-driven and theory-grounded visualization system for exploring affective family interaction.
- We conducted an in-depth qualitative analysis on the feasibility of family data analytics for supporting reflection and exploration of affective aspects in a family's social interaction.
- We provided empirical findings and design implications on how family data-based visualization systems can help facilitate understanding of a family's social interaction.

2 BACKGROUND AND RELATED WORK

We provide an overview of the theoretical background of family health in terms of social interaction and review how studies on family-based data are being conducted in the HCI field.

2.1 Family Health and Functioning Theory

Family health refers to "a resource at the level of the family unit that develops from the intersection of the health of each family member, their interactions and capacities, as well as the family's physical, social, emotional, economic, and medical resources [81]. Family health has been studied in many fields, especially social science, psychology, and family studies [23, 55, 57, 78, 79]. In family health-related discourse, family function is an important concept considered by many researchers. It is the social and structural properties of a family, which include interactions and relationships within the family (i.e., levels of conflict, quality of communication) [23]. According to prior studies, healthy family functioning occurs when family members clearly communicate and responsibly engage in family-based activities and affection expression [41]. Here, we review two representative family health models that emphasize family functions for maintaining and strengthening social aspects of family health.

The McMaster model [23], a representative model for family functioning, evaluates family functions in six aspects, focusing on the social characteristics of the family and the various interaction processes within family members. *Problem-solving* refers to the ability to address issues that threaten family integration and functionality. *Communication* refers to the exchange of information between family members. *Roles* refers to the extent to which the activity required for the roles allocated to each member of the family is carried out. *Affective Responsiveness* refers to the ability to respond to a given stimulus with appropriate quantity and quality. *Affective Involvement* refers to the degree to which family members show interest in personal interests, activity, values, etc. *Behavioral Control* refers to the methods used to control family conditions and adaptation.

The Family Resilience model [79] is another well-known model that is related to family crisis and adaptation. This model evaluates the family's ability to recover and adapt to conflict and stress faced by the family, taking into account three dimensions: Belief System, Organizational Patterns, and Communication Process. The belief system is related to interpretation, attitude, and attitude toward crises and countermeasures. The organizational patterns are associated with maintaining family internal structures, emotional bonding among family members, and the ability to organize resources. The communication process is related to problem-solving through clear message delivery through words and actions, sharing and immersion of emotions, and sharing opinions.

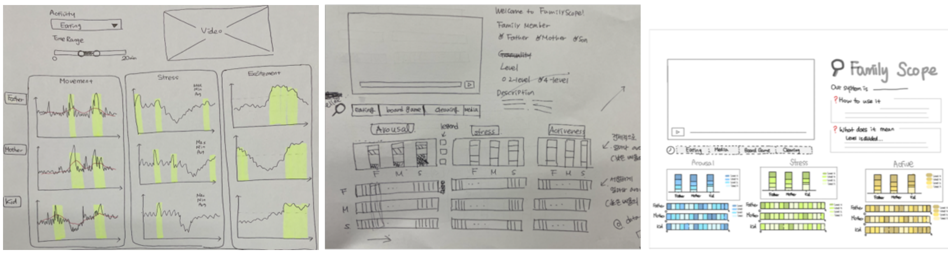
These models both illustrate psychosocial relationships within families and family functions can significantly influence one's behavior and emotional wellbeing [16, 62]. Based on these models, several validated questionnaires have been developed for assessing general states of family health [19, 22, 56]; for example, the family health scale [19] measures family social and emotional health processes using items such as "We care for one another," and "There is a feeling of togetherness." While useful in assessing overall family health, such questionnaires cannot be used to perform fine-grained analyses of affective states during familial activities. Participants can self-report their moment-by-moment affective states by reviewing recorded videos following a retrospective affect judgment protocol [58]. This kind of self-report annotation has been considered a valid way to log how family functions and their emotions and behaviors, but it can cause a high burden of manual responses depending on responders' motivation level (e.g., how much they are motivated to respond) [11]. The limitation calls for an in-depth evaluation of family health that entails automatic tracking of emotional and behavioral aspects using passive sensing. As a first step to complement the limitations of self-reports, this work explores the feasibility of sensor data to quantify affective (e.g., emotional arousal and stress) and behavioral states (e.g., activeness) of family social interaction within the broader scope of family health.

2.2 HCI Studies on Family Informatics and Family Data Reflection

2.2.1 Personal informatics to family informatics. In the field of HCI, there is a growing interest in leveraging family-generated data to investigate families (e.g., social support for chronic disease management [50]), which has been largely dealt with in the fields of social science, psychology, and family studies. Viewing family itself as a single unit, researchers have been exploring data collection and reflection in family contexts [16], which is called "family informatics" [60]. This extends the existing concept of personal informatics that has primarily focused on supporting data collection and reflection for *individual* users; e.g., self-tracking physical, emotional, and social data for learning actionable insights for wellbeing [13].

A large body of existing scholarship in the field of affective and ubiquitous computing has examined automatic tracking of a user's affective states (e.g., stress, emotion, and depression) and their relationships with everyday behaviors [49, 61, 80]. Furthermore, an increasing number of HCI researchers embrace reflection as one of their crucial design goals [5]. For example, several studies support self-reflection of individuals' affective states and behaviors by representing or visualizing collected data [12, 17, 29]. However, existing studies have primarily focused on individual contexts, and there is a lack of consideration of *interpersonal* contexts. This work treats a *family* as the most basic social unit [50] that generates and reflects interpersonal data.

2.2.2 Family informatics and family data reflection. Family informatics studies have primarily focused on physical health management and promotion (e.g., sleep and mental health management), and remote family communication with emotional support. Several studies explored managing and promoting physical health, such as Spaceship Launch [66], a family-participating functional exercise game to promote physical activity, and Snack Buddy [68], a family-level intervention system for supporting healthy snacks and meals. Existing studies for sleep and mental health care include DreamCatcher [59], a family-sharing dashboard for jointly tracking sleep patterns and sleep quality of family members, and MOBERO [74], a mobile application for supporting morning/sleeping routines in families with children with ADHD. Supporting remote family communication was examined in Phamilyhealth [6], a health-related photo-sharing system, Ticket to Talk [82], an inter-generational interaction supporting tool using selected media in consideration of the interests of relatives suffering from dementia, and Time-Turner [72], a coaster interface supporting past data reflection and family communication. Sharing remote family information could also encourage emotional support of family members, such as Whereabouts Clock [10], which represents the location of distributed family members to support emotional connectedness, and Digital Family Portraits [51], a digital portrait visualizing elderly's daily-lives to support peace-of-mind of extended



(a) Initial prototype (b) Second prototype (c) Third prototype

Fig. 1. Paper prototyping for designing FamiyScope

family members. These family-centric health technologies were effective in tracking and reflecting family data by allowing families to jointly generate and share data.

Overall, to the best of our knowledge, there has been a lack of studies that use data generated from intra-family interactions to quantify a family's social interactions that occurred during family activities. Our work aims to design a family informatics system supporting family reflection on affective aspects of social interaction data. Several concepts of reflection involving multiple stakeholders have been suggested in the literature. Collaborative reflection shows that groups of people record, reflect, corroborate data, and have discussions for problem-solving and decision-making [46, 65, 76]. Similarly, co-reflection in learning contexts denotes collaborative critical thinking processes between two or more individuals to facilitate intersubjective understanding or knowledge building [84]. Building upon existing concepts of reflection involving multiple stakeholders, our work investigates how family members explore and reflect interpersonal data *together* to acquire a mutual understanding of affective aspects of family activities. Based on the design of FamilyScope, we aim to study whether family-based data exploration and reflection can facilitate a deeper understanding of a family's social interactions.

3 DESIGN CONSIDERATIONS

As a first step in designing FamilyScope, we considered several design possibilities that could best represent the affective aspects of a family's social interaction. For intuitive and comprehensible data delivery, we selected the visualization method. A large body of HCI studies on both personal and family informatics have frequently used visualization to quantify users' data collected from their daily lives [30, 40]. For affective aspects, we referred to two components of the McMaster model [23]: *Affective Responsiveness* and *Affective Involvement*. Below, we elaborate on how we can observe each component in everyday family activities and how we represented each aspect on FamilyScope.

Affective Responsiveness refers to how each family member responds to a particular event or another family member's emotional response to the event. For example, we can observe the emotional changes of family members during mealtime as they prepare food, eat together, and have conversations along the way. From this example scenario, one plausible observation is that one family member can get upset as he/she gets to prepare all the dishes while others sit around and wait for the dinner to come out. In this case, the one who expresses anger can influence other family members' affective states. To represent such cases, we aimed to show changes in individual data during family interaction on FamilyScope.

Affective Involvement refers to family members' emotional and behavioral engagement in familial activities, which can also be interpreted as the level of participation and mutual empathy. For example, we can observe that the level of engagement among family members may differ when doing house chores when one family member is not actively participating in house cleaning, while the other is actively participating. In such situations, we may observe apparent differences in their behavioral activeness and plausibly emotional status as well (one being angry while the other being relatively stable). To discover and represent such engagement patterns through FamilyScope, we provided features that enable participants to compare family data within the same time slot and family data throughout the entire activity.

Considering the family members' data literacy, especially children, we decided to visualize semantically abstracted data at the ordinal level instead of offering raw continuous sensor values. In addition, we visually encoded such ordinal data with color saturation, which was effective in representing sequentially ordered data [44]. Furthermore, FamilyScope provides multiple facets that allow users to both identify changes in data collected from an individual member and a specific data type and to see the entire view of aggregated data from family members. In other words, we provided two magnifying views of the family's interaction process based on data: the individual and family levels. In addition, the video is placed on top to provide contextual information about the overall situation of family activities. Family members can navigate to specific time points in the video that corresponds to affective states to help review *micro-moments* of social interactions as in the video interaction guidance [71].

To improve the design of FamilyScope, we conducted three iterations of paper prototyping by conducting heuristic evaluation, as shown in Fig. 1. The first prototype mainly focused on reviewing trends in family members' affective and behavioral states with line charts and video (Fig. 1a). Based on the prototype, we invited two graduate students who have rich experiences in interface design and explained the concept of the prototype and usage scenarios in family contexts. They were asked 1) if they could review affective responsiveness and involvement between family members, and 2) if they could easily understand the visualization components of the system. After getting feedback for further improvement, we designed a second prototype (Fig. 1b). We invited two other graduate students majoring in HCI and asked similar questions in the initial iteration. In particular, they provided feedback to improve visualization components (e.g., colors and layouts). Finally, three of the authors summed up the feedback and designed a third paper prototype (Fig. 1c) by mainly considering the color encoding and overall layout of the system.

4 IMPLEMENTATION

Based on design considerations derived from the family functioning model, we implemented FamilyScope, which visually represents affective states inferred from physiological sensor readings along with corresponding videos, allowing collective reflection on the family interaction process.

4.1 Extracting Affective and Behavioral States

For retrieving physiological sensor readings, we employed Empatica's E4 wristband, which supports collecting various sensor data, including heart rate, inter-beat interval (IBI), electrodermal activity (EDA), skin temperature, and 3-axial acceleration. In our prototype, each E4 device was connected to a dedicated smartphone via Bluetooth, where sensor readings were first sent to the phone and subsequently uploaded to Empatica's cloud server via WiFi. In addition, we recorded the family's shared activities using Reolink's IP cameras to help family members recall how they interacted.

Following the data analysis pipeline in a prior study [69], every 60 seconds of sensor readings were then used to extract affective and behavioral states, including emotional arousal, stress, and behavioral activeness, as below:

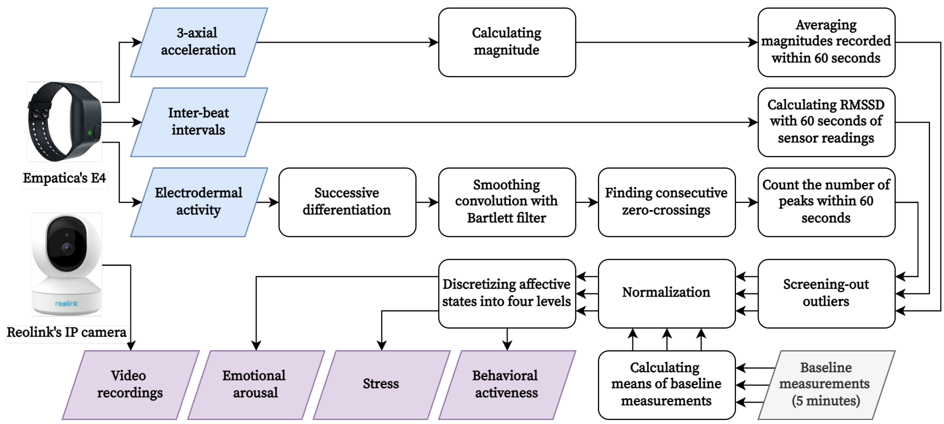


Fig. 2. A flow diagram of FamilyScope's data processing pipeline

- *Emotional arousal* was for quantifying how much family members feel excited during shared activities. For this, we used EDA data that reflects changes in the electrical properties of the skin because a high arousal state corresponds to more sweating, leading to an increase in skin conductance [8]. The EDA response consists of tonic and phasic components [15]. The tonic component slowly varies regardless of a specific stimulus; thus, it is relevant to baseline arousal. On the contrary, the phasic component corresponds to temporary arousal. One widely used method for measuring sympathetic arousal is to count the number of peaks of phasic components within a unit of time, where the higher number of peaks is relevant to a highly aroused state [2, 8]. Following the EDA data processing proposed by Kim et al. [33], we extracted emotional arousal by: (1) eliminating tonic components by successive differentiation; (2) smoothing signals by convolution with a Bartlett filter for noise reduction; (3) finding peaks based on zero-crossing detection; and (4) counting the number of peaks within every 60 seconds.
- *Stress* was intended to measure how much family members stressed out during shared activities. For this, we employed heartbeat data captured via IBI signals, where an inter-beat interval denotes the time between two consecutive heartbeats. The variation between IBIs known as heart rate variability (HRV) is a well-known stress reactivity indicator [32], which is widely used in HCI studies [47, 48, 67]. While various measures for stress using IBIs have been studied, we employed the root mean square of the successive difference between consecutive IBIs (i.e., RMSSD; $\sqrt{T^{-1}\sum^{T}|\mathrm{IBI}_{t-1}-\mathrm{IBI}_{t}|^{2}}$), since it is reliable for accessing HRVs using short-term sensor readings [53]. Here, a lower RMSSD denotes higher stress.
- *Behavioral activeness* was intended to measure the extent to which each family member is physically engaged in shared activities. For this, from every trial-axial acceleration signal, we first calculated their magnitude (i.e., $\sqrt{x^2+y^2+z^2}$). We then averaged magnitude values within 60 seconds, which was used as behavioral activeness. This measure is presented along with affective states and recorded videos to offer contextual information about current affective states.

After extracting each state, we removed outliers that exceeded a specific threshold. In detail, we first calculated the median absolute deviation (MAD), which is a robust measure of statistical dispersion. We then empirically set the threshold as $\mathrm{median}(x) \pm 3\mathrm{MAD}$. Any extracted state beyond this threshold was considered an outlier and screened out.

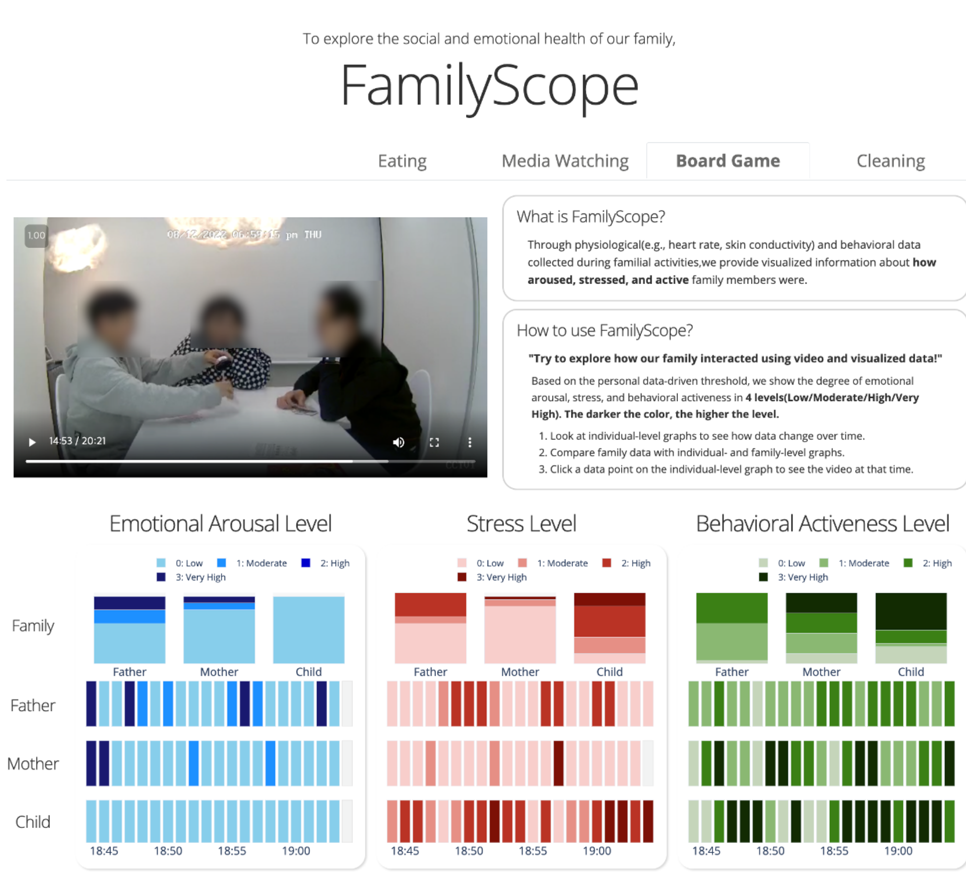
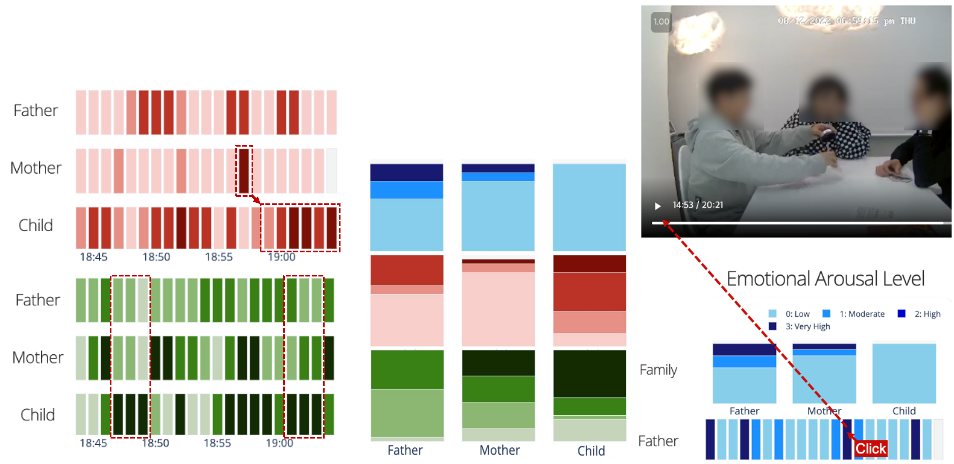


Fig. 3. Overview of FamilyScope's dashboard

The affective and behavioral states we extracted would be differently ranged depending on family members. For example, the level of emotional arousal extracted from a specific family member whose sweat glands are somewhat highly activated might always be greater than that of other members, even though they are not aroused. We normalized the extracted states between zero and one to address such individuals' variations. For this, we further extracted affective and behavioral states while family members were stationary and meditating for five minutes. Such states were assumed to indicate the minimum level of affective and behavioral states (i.e., a zero point in the normalized range). For example, behavioral activeness would be minimized when family members put their wrists down, compared with when they engaged in shared activities. In our prototype, the mean of three metrics during a 5-minute meditation period was used as the minimum boundary for normalization. On the contrary, the maximum value of affective states extracted during shared activities was considered to be the maximum value, one, in the normalized range. Normalized affect states were then ordinally discretized into four levels, namely, *low* (0.0–0.25), *moderate* (0.25–0.5), *high* (0.5–0.75), and *very high* (0.75–1.0). The overall processing pipeline is illustrated in Fig. 2.



(a) Individual-level view (b) Family-level view (c) Data-to-video navigation

Fig. 4. Components of FamiyScope's dashboard

4.2 Visualizing Affective and Behavioral States

We implemented a web-based dashboard that provides interactive visualization of family members' affective and behavioral states with video recordings during shared activities (see Fig. 3). Users can choose data for a specific activity (e.g., among eating, media watching, board game, and cleaning) for the upper-right tab. This dashboard was comprised of (1) an individual-level view presenting changes in affective and behavioral states in a time domain; (2) a family-level view summarizing each member's affective and behavioral states during a session of a given shared activity; and (3) data-to-video navigation for supporting micro-moment reviewing of what happened at a specific time. In the following, we describe design components in the final design and review the major changes that occurred in iterative prototyping.

Table 1. Design features and related affective components

	Visual representation	Supporting visualization tasks	Related affective components
Individual-level view	Time series bar graph for supporting the changes of individual's level (Color intensity encoding)	Changes within each person over time Similarity/difference between people	Affective responsiveness Affective involvement
Family-level view	Stacked bar graph for proportions of each level per family members in entire activity	Overall tendency of family members throughout the activity	Affective involvement
Data-to-video navigation	Playable recorded video of the family at each activity	Video according to clicked data point	Affective responsiveness

4.2.1 Individual-level view. As shown in Fig. 4a, we provided a view of each family member's changes in affective and behavioral states over time to allow each member to explore when their states were similar or different from other members. Specifically, this view presented time-series bar plots illustrating behavioral activeness, emotional arousal, and stress during shared activities at one-minute intervals (e.g., one vertical bar corresponds to one minute). The color saturation of each bar corresponded to the levels of states, where the darker the color, the higher the level. By comparing three graphs of family members, the system supports reviewing *affective responsiveness* between them. For example, as shown in the red graph (e.g., stress level) of Fig. 4a, family members can check how the child's stress level responds after the mother is highly stressed. In addition, the system enables the review *affective involvement* of each family member through color saturation. As shown in the green graph (e.g., activeness level) of Fig. 4a, vertically comparing three members' graphs highlights the highly-saturated area where the child is actively involved compared to parents. In initial prototyping, we used line charts to visualize the trend of affective and behavioral states of individual members (Fig. 1a). However, it was re-designed to have vertical time-series bars (Fig. 1b and Fig. 1c) to easily compare affective and behavioral states between family members in a vertical manner.

4.2.2 Family-level view. As shown in Fig. 4b, our dashboard also provided a summary view of affective and behavioral states for each family member to allow them to understand how much each member was generally active, aroused, and stressed out during shared activities. The stacked bar plots were used to indicate the proportions of each level of state per family member. By visualizing the proportion of each level of state, the system allows users to review the overall proportion of *affective involvement* level during an activity. This family-level view was added from the second prototype (Fig. 1b) to represent the overall level of involvement by considering feedback from the first prototyping.

4.2.3 Data-to-video navigation. To support family members in recalling situational information corresponding to measured affective and behavioral states, we provided a dedicated view for video clips recorded during a given shared activity (see Fig. 4c). When family members clicked a bar of the individual-level view at a specific time that they wanted to see, this view made the video play. For example, when a family member clicks on the fifth time slot (i.e., 5 minutes) of the father's emotional arousal plot, the video navigates to the point five minutes after the initial start.

5 USER STUDY METHOD

We conducted a scenario-based semi-naturalistic user study with ten families consisting of three members (i.e., father, mother, and child) to explore the feasibility and user experiences of FamilyScope. In our scenario, family members engaged in four shared activities, namely, mealtime, media watching, playing a board game, and cleaning. These four activities are typical activities of *mealtime*, *leisure time* (media watching, playing a board game), and *maintenance time* (cleaning) in the categories of family activities [54]. The activities were selected through discussion among the researchers as suitable for observing affective aspects. While they engaged in each shared activity, affective and behavioral states and videos were recorded. After finishing the shared activities, they were asked to explore their affective and behavioral states with FamilyScope and participate in a group interview with three family members. The overall study procedure is illustrated in Fig. 5.

5.1 Recruitment

This study aims at engineering sensor-based family health monitoring and learning how families communicate with one another with FamilyScope. We conducted a user study on a family unit consisting of one child and both parents to reduce the complexity of the system's operation. Ten

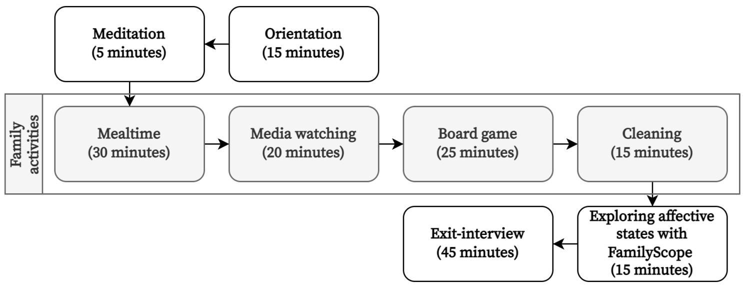


Fig. 5. Overall user study procedure

families were recruited (*n*= 30) via the online community of our university. Eligible criteria, except for the number of family members, were that their child's age ranged between 10 and 13 because a child younger than such an age might have difficulty comprehending our system. All families were offered approximately 80 USD as compensation for their participation in the user study. This study was approved by our university's Institutional Review Board (IRB).

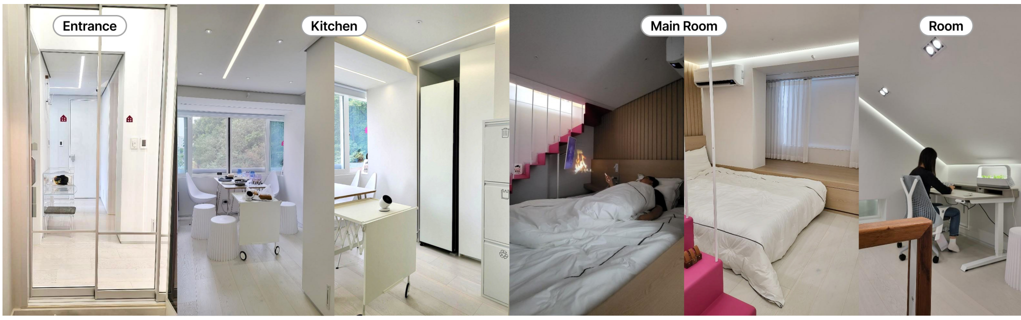
5.2 Study Procedure

For the user study, we used a smart home testbed in our university's family housing, which is described in Fig. 6 with two bedrooms and a dedicated kitchen. One family at a time was invited to this site to conduct a user study. Before the user study, we had a brief orientation that explained our research purpose, study procedure, and which data were collected during the user study. Then, participants who agreed to participate were asked to sign an informed consent form. After the orientation session, we asked each family member to secure Empatica's E4 wristband on their non-dominant hands and leave the Android smartphone in their nearby places. This phone was used for wireless data collection from an E4 wristband. After we confirmed that sensor data from wristbands were collected well, family members engaged in a meditation session for *five minutes* to acquire baseline measurements of affective and behavioral states. During this session, participants were instructed to remain stationary as much as possible. Subsequently, family members conducted four shared activities with the assumption that all family members were in the same place at one point in time. Two cameras recorded video from a fixed location, as illustrated in Fig 6b to cover the kitchen and the main room. The kitchen was used for mealtime and board game activities, while the bedroom was used for media watching and cleaning activities. To differentiate sensor readings for each activity, we asked a father to tag the activity's start and end by pressing a session recording button on his E4 wristband. In the case of video data, a researcher manually annotated the start and the end of each activity.

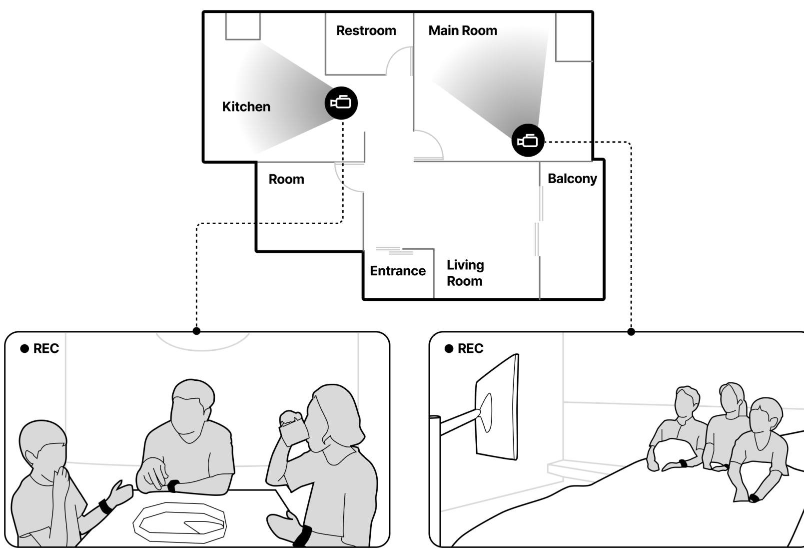
5.2.1 Engaging in shared activities. In the first shared activity, mealtime, we offered a pizza and asked participants to engage in casual conversation while eating together, just as they would in daily

Table 2. Participant's ages and their family members (G: Girl; B: Boy)

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Father	44	48	41	44	45	38	43	40	42	48
Mother	43	44	41	44	40	43	42	38	41	46
Child	12 (G)	13 (B)	11 (G)	10 (G)	11 (G)	10 (B)	13 (B)	10 (B)	11 (B)	11 (B)



(a) A view of the testbed built to resemble a real home



(b) Floor plan of the testbed with the experiment location marked

Fig. 6. A testbed setting for the experiment

life. This activity was conducted at the dining table in the kitchen. After mealtime, family members were asked to move to the main room to perform the second shared activity, media watching. We asked family members to sit on the bed and watch two videos: one was a university promotional video that was intended to elicit no specific emotion, and the other was about meeting a deceased mother through virtual reality. The reason for playing two videos was to observe how the emotional aspects of the videos impact family members' affective states. Next, family members engaged in the third shared activity, the board game, at the dining table in the kitchen again. We chose Halli Galli, a relatively easy game, considering the child's understanding of the game's rules. Before starting the game, we provided a sufficient explanation of the rules and guided them to proceed with about three rounds. During the board game, the researchers prepared the final shared activity, cleaning, in the main room (e.g., scattering books and pieces of paper on the floor). After the board game, family members moved to the main room and performed three cleaning tasks, including (1) finding and placing scattered books in order; (2) organizing writing supplies in each compartment of the

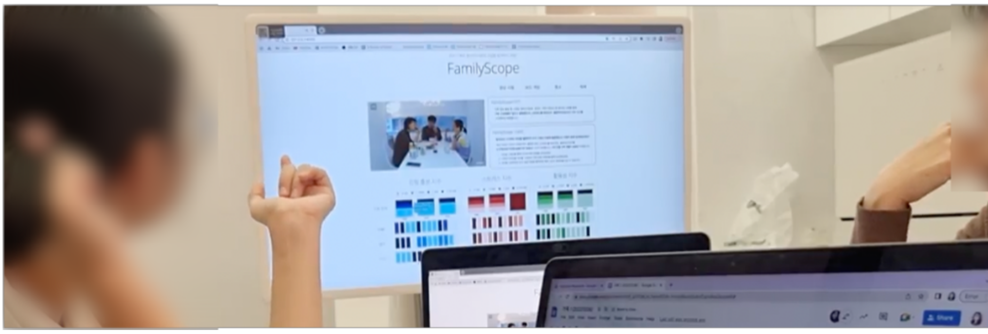


Fig. 7. A session of exploring affective and behavioral states using FamilyScope (Family 1)

Table 3. Questions for assisting family members in using FamilyScope. (R) corresponds to affective responsiveness and (I) corresponds to affective involvement

Shared activity	Questions
Mealtime	How did we change our feeling while eating meals? (R) Did we feel similar/different feelings while eating? (I)
Media watching	How did we feel about the emotional video content? (R) Did we feel similar/different feelings while watching videos? (I) Was there anyone who could not focus on the video? (I)
Board game	Did the family member get stressed or excited during the board game? (R) When did we participate in the board game most actively? (I) Who was the most excited/stressed family member during the board game? (I) Did we feel similar/different feelings while playing the board game? (I)
Cleaning	Did we get stressed due to someone not actively participating in cleaning? (R) Did we feel similar/different feelings while cleaning the room? (I)

drawer; and (3) sweeping the floor using a broom. Since we aimed to observe the social interactions between family members and their involvement in cleaning together, performance measures such as task performance and cleaning quality were not considered.

5.2.2 Exploring affective and behavioral states. After completing shared activities, affective and behavioral states and video streams were presented in FamilyScope. Then, we asked family members to explore their data collectively and reflect on the affective aspects of their interaction during shared activities (see Fig. 7). Especially, considering affective elements in the family functioning model, we presented several questions to assist family members in using FamilyScope and explore the feasibility of FamilyScope for supporting reflection on the affective aspects of family interactions, as shown in Table 3. The questions were presented in written form on the screen in Fig. 7. While participants explored the FamilyScope, researchers observed how they used the system and recorded the process in a text form. All of the conversations of families during the data exploration stage were audio-recorded.

5.2.3 Exit interview. To explore whether FamilyScope was feasible to support the collective reflection on affective and behavioral states during family activities, we conducted a semi-structured interview in the form of a focus group interview with three family members for approximately

Table 4. Category of participant responses from the interview

Theme	Sub-theme	Description
Perceived usability	Data types Data visualization Data-to-video navigation	Appropriateness of the data types and their representations Perceived usability in data visualization features Perceived usability in video recording feature
Reflection (What)	Confirming the old Discovering the new	Participants' existing perceptions of a family New insights discovered from family members
Reflection (How)	Self-reflection Co-reflection	Interpretation of personal data led by an individual Family members' collaborative discussion on family data
User perceptions on family data reflection	Positive Negative	Positive perceptions on family data reflection Negative perceptions on family data reflection

45 minutes. One primary purpose of this interview session was to investigate general opinions on FamilyScope's features for exploring family members' affective and behavioral data. Another purpose was to understand how well FamilyScope helped family members to reflect on the family's affective interactions and what new information be provided to family members. All interview sessions were recorded and transcribed.

We conducted thematic analysis [9] to analyze transcribed conversations during the interview. The process consists of six phases: familiarization with the data, generating codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. Following the process, two researchers conducted the process iteratively. After reading raw transcribed data, they collaboratively assigned thematic codes to each interview sentence. They used an inductive approach, which involves deriving thematic codes without predefined criteria. After assigning initial codes, they reviewed the codes, merged similar ones, and prioritized the themes mentioned by their frequency. Two researchers repeatedly reviewed and revised themes until they reached a consensus on the results. The finalized themes are summarized in Table 4. Here, we denote participants as Father (F), Mother (M), and Child (B: Boy, G: Girl) by family (F*k*-F/M/G: Family *k*).

6 RESULTS

In this section, we report the qualitative analysis of system evaluation sessions and exit interviews. Through this process, we explored how families leverage FamilyScope to explore and make sense of their data. Revisiting our RQs, we aim to answer the following questions:

- (RQ1): How do families leverage FamilyScope's features to support a data exploration process?
- (RQ2): How do families reflect on affective aspects of their social interactions via FamilyScope?

6.1 Perceived Usability of FamilyScope

Here, we report our findings on participants' overall data exploration experiences using FamilyScope and their perceived usability of representative features of the system – 1) Data types, 2) Data visualization, and 3) Data-to-Video navigation. For the system evaluation, we asked each family to explore FamilyScope and observed how each family leveraged and assessed the given design components. Overall, families perceived the system and its features as intuitive and less burdensome, as they did not have to go through the process of interpreting raw sensor data. The results of our user study concretely inform how data-driven design considerations in FamilyScope influence sensor-based data exploration and group-based data reflection.

6.1.1 Data types and its comprehensibility. FamilyScope presents quantified states of participants' affective and behavioral data (i.e., emotional arousal, stress, and behavioral activeness). For questions on data types, we asked participants about the appropriateness of the given data types and their representations, as well as potential challenges in understanding the data.

For the appropriateness of given data types and their representations, we asked whether the three data types presented in the system are sufficient for participants to make sense of the psychological and physical status of themselves and their family members. We also asked whether quantified data were helpful in better understanding family interactions. In general, participants commented that the given data types are easy-to-understand and appropriate for representing a family's emotional and social interactions. For example, F7-M said, *" Yes, the three data types are quite easy to understand and interpret. Arousal, Stress, and Activeness. The three terms are very intuitive!"* However, F6-F questioned the necessity of providing physical activeness, as a cue for understanding family interactions. He commented, *"For physical activeness, I'm not really sure whether this is highly related to assessing a family's emotional interaction. You could just move around by yourself, and if you're active, that means you interact more? For emotional arousal and stress, I get that they're really important and interconnected to each other."*

Participants generally perceived the quantified data to be quite an objective indicator of their psychological and physiological states and reported that such data representation helped them better understand their family interactions. For example, F5-F commented, *"Looking at myself and my family members through the data made me feel like I'm in the family TV reality show. You know, the counselors keep track of you and your family's footage and directly assess what the issue was. ... So the quantified data kind of makes you look at you and your family from a distance, which means you can get an objective point of view."*

As to challenges in understanding the data, some participants questioned the exact definition of emotional arousal and how the term differentiates from stress. F10-F questioned, *" I think the word 'arousal' is a bit vague. Are you excited because you feel good, or are you excited because you feel bad? This is unclear to me. If it means you're emotionally aroused because you feel bad, how is it different from stress?"* F6-M also asked for a clear definition of emotional arousal, saying, *"At a glance, you might not have difficulty understanding what each data type means. However, once you go deeper, it's kind of hard to understand the meaning of arousal. If it's high, is it bad, or if it's low, is it good?"*

6.1.2 Data visualization. Participants perceived that the color saturation encoding used in FamilyScope is an intuitive way to show the entire data at a glance. For example, F3-F said, *"It caught my eyes since the data is shown in color"*. Participants also reported that the color encoding method facilitates the easy understanding of sensor-based family data for all family members, including children. F4-M said, *"It was good to compare relative information as it showed the data as a difference in color saturation."* F2-F also said, *"When the color saturation is strong, it's easy for kids to understand their parents' state - 'Oh, my mom is calm and daddy's emotion swirls!"* F8-F further noted, *"Color coding looks good, but numerical values would be much better to infer what the data means!"*

In assessing whether quantified data presented in a bar graph well encapsulates the overall characteristics of a family, most of the participants agreed with the idea. For example, F1-M stated, *"The aggregated graph looks good to understand our family's overall status at a glance. And the individual graphs seem to be better at capturing the state of that time and showing more granular emotions of each member."* Some participants called for other types of graphs to better discover how their state changes over time. For example, F8-B suggested, *"With the current graph, I see that there are some changes happening, but it's not clear how they change over time. I'd like to see how myself and others' emotions change as we interact so that I can discover that we're actually influencing each other in a certain way? With line graphs, for example, we can explore changes and certain points* *where all family members peak together… I think providing line graphs would be better than just a simple bar graph."*

6.1.3 Data-to-video navigation. Overall, families actively leveraged video when they observed abrupt changes in their data or wished to recall specific events that occurred that corresponded to their data. Most of the participants reported that they used this "data-to-video" navigation to acquire contextual information that they could not recall by simply looking at the data. F1-G stated, *"It seems that I was excited because I did something, but I couldn't remember what I did. So I watched the video."* F4-M said, *"We usually checked the video when there was a rapid change in our emotional arousal and stress levels. I wanted to see what kind of conversation we had when we were eating pizza, and what was happening when playing the game."* F3-F added, *"I was wondering what was going on when all of my family members' emotions changed at the same time!"* Furthermore, we were able to confirm the significance of the data-to-video linked interaction. F2-M said, *"This, in my opinion, is absolutely necessary. Without the video, it may be difficult to trust the data because it is not possible to check what the situation was at the time."*

6.2 Family Data Reflection Using FamilyScope

Aside from asking participants how design components of the system helped them understand the overall system mechanism and their data, we further aimed to find out whether FamilyScope actually supported family data reflection in terms of affective states. In particular, we examined whether participants reflecting upon the aforementioned "affective responsiveness" and "affective involvement" are well reported through participants' responses. Revisiting the terms, *Affective Responsiveness* refers to how each family member responds to a particular event or other members. *Affective Involvement* refers to how behaviorally and psychologically family members are involved in family activities [23]. Not only observing what participants discover from the reflection, but we also aimed to observe how participants leverage the system to reflect on themselves and other family members. To understand data reflection behaviors for each scenario, we designed different questionnaires for each scenario (see Table 3). In the following, we elaborate on how participants reflected upon their family data.

6.2.1 Discovering the old and new. Participants generally reported that the captured data well reflected their existing perceptions of their own families. For example, F1-M noted, *"I think this data reflects our family's tendency in daily life. I think one's natural character affects a lot in this type of data collection."* F9-M said, *"Umm, I'm sorry, but is it okay if we cannot find something very different or new? Me and my boys are in a pretty good mood the whole time, especially when doing something together like playing games, so I think the data literally shows who we are."*

In terms of affective responsiveness, most families agreed that family members' expected emotional/behavioral responses to a certain event are also well represented through the system. For example, F10-M mentioned the following as she was reflecting upon the media watching. *"I feel as if these data are mirrors (laughs). Daddy is stress-free all the time. He's hardly ever influenced by anything! Good or bad, it's always okay for him. See? Even with such a sad scene, no big change. Mommy, as always, is sensitive (laughs). That's why my stress data is dark all the time, right? I think I was stressed from the very beginning while watching the media since I react very emotionally to sad stories… My kiddo, he can't stay still for just a minute at our house, and I can also see that while we're watching the very sad video."* F7-M also noted, *"My husband is very strict when it comes to cleaning and organizing. I think this is very apparent in the cleaning scenario. I've always thought that my son, like every teenage boy, has zero thought on everything, and I can definitely see that from the data as well. Calm and peaceful."*

In reflecting upon how family members were behaviorally and psychologically involved in family activities, participants perceived that their level of engagement in terms of emotional and behavioral aspects was similar to their usual patterns at home. For example, F7-F noted, *"Our family loves doing activities together like camping or skiing. At home, we also play board games quite often. Everyone participates and enjoys it. I could see that it's true in this experiment as well. See how everyone is excited and physically active during the game, just like we did at home."* F2-F further noted, *"Me and my kid are both very competitive and hot-tempered. This is especially true when we're playing games. On the other hand, my wife is very calm. You see the video and you can find that she barely cares about the game while me and my kid are going crazy."* F6-B said, *"When we're eating, like having dinner, dad always tries to eat more, and mom hates it. While we were eating pizza, he wanted to have another piece, but mom said no. You can see that mom's stress level increases when dad wanted more pizza."*

While we noted that existing perceptions of family members' usual interactions are generally well reflected in the data, some participants responded that they were able to gain new insights not only about themselves but also about other members. New understandings of themselves would include the following examples: *"I always thought I had a lot of emotional ups and downs, but the data showed that I'm actually quite calm. That was the most interesting part!"* (F3-M). F4-G said, *"When we were eating pizza, I looked like the most comfortable person on the outside. So, it was unexpected that emotional data fluctuated that much."* F6-F seemed surprised to see his data, saying, *"It seems like I'm a very dry person. My emotions are quite different from my wife's. I used to hear from people that I'm not quite empathetic, which I didn't buy into… But seeing this data, I am that kind of person. This is a bit sad… "*

Additionally, some participants reported that they could learn a new aspect of other family members' affective responsiveness that they had not acknowledged before. It is interesting to note that these new findings have primarily appeared in the cases of participants whose emotions are usually difficult to recognize based on their facial expressions. F3-M reported, *"It's usually hard to notice how angry or sad my husband is because he doesn't express himself well. So I was surprised that my husband's data showed the biggest variation."* Similarly, F4-M said, *"I didn't know my husband was so emotionally aroused. If I hadn't seen this data, I would have thought he wasn't that emotional (he's always expressionless). I think I can understand him better after seeing this."*. F9-M noted, *"Although I mentioned most of the data is pretty similar to our daily patterns. I'm quite surprised to find that my husband is such a good actor. His emotional arousal and stress are the highest among us when playing games, but he doesn't even blink his eyes! I can see that he is very focused and eager to win."*

6.2.2 Self-reflection and co-reflection. Another interesting point to note from the reflection session was *how* families leveraged the data for interpreting his/her own data (i.e., self-reflection) and other family members' data (i.e., co-reflection). Participants would generally be more interested in their own data and then move toward their family-level data and each member's data.

For self-reflection, participants would naturally first look at their own data but also refer to others' data to get more comprehensive information about his/her status during the activities and enrich his/her interpretations. In most cases, participants would easily recall and reflect on their own data. Participants would especially focus on high-stress levels and conjecture about the cause. They would also actively leverage data-to-video navigation to confirm their status, which showed similar footage of participants as they expected. F6-F noted, *"Oh, look at my data. All dark reds! Can I take a look at the video? I look uneasy all the time while others are happily eating (laughs). Well, I got a call from my work just before I got here, and I kept thinking about how to fix the issue at my work. Wow, the data is quite accurate. I'm quite impressed."*

Participants would also infer certain circumstances or his/her emotions by comparing the others' data represented in the same time mark when they had difficulty understanding their data. From this observation, we find that FamilyScope supports multidimensional data exploration, such as comparisons between different data types or comparisons between family members within the same data type. For example, F4-M would note, *"Oh, why was I upset around that time? I think I was pretty calm during the cleaning. My daughter's data seems very nervous and anxious at the same time. Oh, I remember. I felt like I had to sweep the floor, but my daughter insisted [on doing that], so I think I was a bit upset."* After watching the video, she added, *"Yes, and my kid was also very nervous since she had trouble putting stuff into the drawer, and we were running out of time. So, I naturally got stressed."* Similarly, F7-F questioned his drastic increase in stress, emotional arousal, and physical activeness during mealtime and explored his wife's data, saying, *"Now I get it. It's because you spilled the pickles. You were also very calm, but your stress level went up. And physical activeness for both of us is very high because we had to clean up that mess."*

Not only reflecting upon their own status and contextual information, but participants would actively discuss their family-level data and help each other make sense of their data. We call this type of reflection "co-reflection" as it involves collaborative thinking processes involving affective interactions to reach new intersubjective understandings [84].

For understanding overall family data, participants reflected on family activities in terms of empathic involvement. Participants stated that they could discover similarities or dissimilarities in emotional tendencies among family members in the overall activity through their data. For example, F1-G said, *"By the end of the game, my mom wasn't stressed, but I was rather very stressed. It appears that he [the father] was also under a lot of stress at the time. Perhaps it was because he was lost."* Participants also compared the changes in the whole family's emotional arousal data for each activity, such as eating or watching media. F3-F said, *"She [daughter] and I talked a lot over the meal, so I think we had similar emotional tendencies overall, while my wife was not as aroused as we were."* F1-M stated, *"It seems my husband was deeply immersed while we were watching the emotionally influential video. But, as my high stress and her [daughter] high activeness show up at a similar time, it seems that I couldn't concentrate well because my daughter kept interrupting me every time I got into it."* F4-M would report, *"Since this testbed is a new environment, I think we were all very aroused. I, especially, tend to get more nervous in a new setting. We were still getting used to the environment, and we were supposed to eat for the first activity (laughs). My wife and my kid also seems uncomfortable at first, but I think we all became relaxed after a while."*

Participants also tried to understand other members' feelings by interpreting their emotional responses reflected in the data. Participants attempted to explore whether family members' emotional status affected each other and speculated on reasons for changes in emotions if such tendencies were observed. F3-F said, *"I guess she (daughter) didn't know what the video was about at first. But since the mommy was crying next to her, it seemed like she was also getting 'in the zone' (laughs). I think that's why her arousal in the latter part came out high."* F4-M additionally reported, *"When I saw how stressed she [daughter] was when she lost the game, I found that she couldn't easily accept the fact that she lost."* F6-M and F6-B were surprised to find how F6-F was constantly stressed across all activities, saying, *"I've never thought how sensitive my dad is. He said it's because of the work and I feel kind of sorry that he is very stressed at work and it also affects his mood."*

Furthermore, when one participant shared an interpretation of their data, the other showed additional responses or explanations for their interpretation. For example, when F2-M stated, "*(Watching media) As you can see, there's no fluctuation in my emotional data. I think it's because I thought I wouldn't cry like that about my father.*" One father (F2-F) additionally commented, *"It's probably because you (mother) don't have good feelings for your father, so you didn't have that much empathy."* This collaborative data reflection process based on captured data allowed them to express sympathetic responses by interpreting scenes from other family members' perspectives, thereby helping them to better understand each other.

6.2.3 User perceptions on data sharing and family data reflection. As FamilyScope enables family members to view and reflect upon each other's emotional and behavioral data, we asked participants their opinions on sharing their personal data with their family members. Participants' responses varied across families and their positions within a family. For positive responses, F2-M responded, *"I think it's okay to share and view each other's data. By looking at the data, you can better understand your spouse and your kid. Besides, there's nothing much to hide! We are family."* F3-F noted, *"There's absolutely nothing wrong with sharing my data. I'm actually quite happy because it's difficult for me to express my feelings, but with such a system, my family members would notice my emotions through the data. Convenient! (laughs)"* F3-M further added, *"I agree. Sometimes it's hard to read my husband. At least with the data, I can guess if something's going on with him."* F4-G also noted, *"This is helpful in the sense that I can look back on myself and how I feel in a certain situation (e.g., expressing frustration during the game). By reviewing the data, I can better behave toward my parents when a similar situation comes up next time."*

One interesting thing to note from participants with positive attitudes toward data sharing was that they generally thought of collected data as a common asset, rather than personal data. For example, all members of Family 4 would claim that the ownership of the collected data equally belongs to each member, since the data is generated through family interactions. They also claimed that the data is a common asset since participants would not only reflect upon his/her own data but also leverage others' data for sensemaking. Generally, they seemed less concerned about potential privacy issues and focused more on the potential benefits the system could bring to their families.

For negative responses, however, most participants expressed a sense of repulsion toward sharing their personal feelings. F6-F said, *"Not all feelings should be expressed to my family. Some things are better left unsaid (laughs)."* F9-M noted, *"Personally, this is a very sensitive issue. As a mom, I'm always curious about what my teenage son is thinking, but I should keep the line. Well, this is just a one-time experiment, but I felt guilty when I looked at his data. I felt like I was peeking into my son's head."* Some participants also expressed concerns about potential family conflicts due to misleading data representations on the system. For example, F1-F argued, *"Well, you can't guarantee 100% that the system is always correct. What if your feelings were just fine but the system showed that you were stressed and upset? Then, it may lead to family conflicts while we're looking at the data. I don't like that… "* Similarly, F10-F noted, *"Feelings are feelings! If you turn them into numbers, is that the definite answer? I'm worried about highly relying on this type of system to assess myself and others' emotions."* Concerns about data disclosure were frequently cited among children as well. For example, F1-G commented, *"I was quite embarrassed when my parents would stare at my data and have active discussions on my status. This is a privacy invasion!"* F3-G added, *"I felt uncomfortable the whole time during reflection. Just because they're my parents doesn't mean they can have easy access to my data…I feel being monitored."*

Contrary to participants with a positive stance, participants who expressed a sense of discomfort in data reflection argued for a clear boundary between personal data and family data. F1-F would note, *"Although the data is collected from family-based activities, I still believe that each data is my data because it's from me! Well, the video data is an exception since we're all in it together."* F5-M further noted, *"We're family, and it's true that we share some commonalities. However, the data looks all different. It's not like we laughed or cried together at the exact same time. I think each data is just personal data generated through family activities."*

7 DISCUSSION

Throughout the user study, we observed how multimodal sensor data augmented with contextual data can help families reflect on and make sense of their affective status and social interactions. To facilitate family data reflection, we offered visualized sensor feedback as probes to enhance their sensemaking with the data. Based on our observations, we find that FamilyScope enables multi-faceted data reflection on both personal and group levels (self- and co-reflection, respectively). Informed by our findings, we provide our insights on family data reflection and opportunities for future design implications for family informatics systems.

7.1 Beyond Self-Reflection: Co-Reflection with FamilyScope

By allowing users to interact with their personal data as well as the data of their family, we uncovered mechanisms that interact with them. While a large number of studies still largely remain focused on self-reflection of personal data [36], our system design demonstrates that offering both personal and family-level data can enrich users' data sensemaking by supporting both *self-reflection* and *co-reflection*. For self-reflection, participants would initiate probing their own data and leverage other family members' data as social contexts to interpret their own data to make their understanding more comprehensive. Expanding from self-reflection, family members would then collaboratively discuss each other's data and the data of the entire family to assess their affective interaction and shared patterns, which we labeled as "co-reflection."

Such attempts to reflect multiple users' data are well-elaborated in prior studies as well. For example, Graham et al. [28] proposed an open-ended reflection through a "peer review" of self-tracking data, which led to *shared reflection* that motivates participants to keep up with their data collection while providing sources of advice and moral support. Another well-known concept is *collaborative reflection*, which refers to a type of reflection that involves members of a healthcare team pooling and reflecting on patient data to aid health-related decision-making [46, 65, 76]. Thus far, however, such reflections are premised upon utilizing a set of aggregated data, either anonymized or asymmetrically shared (e.g., sharing patient data with caregivers). Co-reflection with FamilyScope differs in the sense that it involves interpersonal data generated within *shared settings* through *shared activities* from intimate existing social ties like families. Furthermore, co-reflection with FamilyScope enables collaborative discussion among data generators to reach an intersubjective understanding and promote mutual awareness. While there are increasing perspectives on the family as a multiagent system that is responsible for sensing, monitoring, communicating, and sharing health-related challenges, our findings offer preliminary insights on designing systems that support users in their reflective activities that involve family units and data-driven reflection for families. Below, we elaborate on how people reflected upon their own and family members' data and what they discovered along the reflection process.

7.2 Discoveries: Old & New

7.2.1 Confirming existing perceptions. When participants began data reflection, they were drawn to shared patterns in the data that were similar to theirs, searching for the most similar visual pattern. By and large, participants attempted to form a "similar build" that shares characteristics of their data (e.g., similar color encodings and extremes). Overall, participants assessed that the data well-represented families' usual dispositions and confirmed their original perceptions of the family. Through the lens of sensor data, participants actively discussed the shared likeness of their family members, which allowed for *social discovery* (i.e., discovering patterns that are shared between an individual and a group) [25]. Participants commonly referred to general tendencies of data fluctuation to discover an acceptable range of emotions and incorporated their own data to construct the notion of an "emotionally healthy" family according to their own definition. Such behavioral patterns observed in participants echo prior studies on personal informatics that allowed open-ended access to others' data. From the studies, participants were able to define their own notion of what is "normal" to identify themselves with the group of other users [3, 25].

7.2.2 Discovering new insights. Another notable finding is that FamilyScope also enabled participants to discover new insights not only about themselves but about their family members as well. Upon seeing the data, several participants responded that they came to realize the actual feelings they had, which were not explicitly sensed during the user study. One participant even commented that she came to reconsider her disposition through the data reflection, saying that she used to think she was very emotional and moody, while her data showed a consistently stable pattern compared to her family members. Viewing participants' behavior through existing personal informatics studies, people either become more aware of certain aspects of their lives or acquire newfound insights into themselves through the use of self-tracking and reflection tools [31]. While these studies are limited to one's novel discovery about themselves in behavioral or physiological aspects (e.g., food intake, heart rate), our study highlights that sensor-based reflection tools can even help people find out their own latent psychological status.

In addition to the discovery of oneself, participants also mentioned that they were able to discover the hidden emotions of family members who would usually refrain from openly expressing his/her feelings. For example, one participant was surprised to find out that her husband's emotion data fluctuated and showed high levels of stress, contrary to her perception that her husband tends to be calm and less emotional. This data exploration further facilitates family members' active discussion about new insights and possibly deepens understanding of their affective involvements during family activities. However, we do not strongly assert that sensor data alone enables highly accurate and novel discoveries, as such claims may lead to confirmation bias. These findings on an expanded view of data reflection open up new avenues for future research not only on family informatics but also broadly for other social settings that involve multiple users (e.g., workplace).

7.3 Concerns on Family Data Reflection through Passive Sensing

Despite the reported benefits of family data reflection during the interview, participants also showed concerns about their emotional and behavioral data being shared with their family members for several reasons. Participants primarily reported concerns about privacy issues. Participants expressed discomfort with their emotional ups and downs being shared and monitored. For teenage kids, such repulsion was frequently reported as they imagined real-life scenarios in which their parents would look at their data and video footage to monitor everyday social activities. Since the video recording was part of the experiment and captured all family members during family activities, most of the participants were generally carefree when viewing the video. However, some participants reported that deploying a data-to-video navigation feature should be considered carefully if the system were to be implemented in real-life scenarios. Regarding the issue, participants commented that recorded areas should be strictly confined to public spaces like a living room or a kitchen.

Another reported concern was misleading data representation when participants were faced with counterintuitive insights from their data. Regarding the issue, a few participants questioned whether the passive sensor data collection is highly accurate and asked the research team if there are any chance that the data is not well aligned with the participants' perceived feelings. They expressed uncomfortable feelings toward potential cases in which they or their family members would misunderstand and judge others' emotions and behavioral intentions, which could lead to family conflicts. This finding is important to note, as we often observed some participants overriding their own interpretations of affective state. They tended to highly trust the system's outputs, even when these may have conflicted with their perceived affective states of themselves and others. While recall and revisitation of experiences are foundational to reflection [27], the results showed that the participants often neglected their own memories as opposed to the computerized memories, captured from sensor data. Prior studies on affective computing reported similar findings in that people overly trusted the system feedback provided by emotion-related intelligent algorithms [24, 75]. Such behavioral tendencies could also be attributed to "data-frame theory," which argues that data sensemaking is a natural cognitive process that involves fitting data (the "interpreted signal of events") into a frame or, conversely, fitting a frame around available data [34]. We posit that such cognitive processes that occur among participants (e.g., algorithm overtrust and incorrect mental models) may have lowered their sense of agency in terms of data interpretation.

7.4 Designing Tools to Support Family Data Reflection

Our findings on family data reflection uncovered mechanisms around how users reflect upon personal and others' data and discussed potential issues that may occur when designing for family informatics systems. We present design implications that support comprehensive reflection of both individuals and families and alleviate user concerns regarding data sharing.

7.4.1 Offering explanations to automatic detection of affective states. Aligning with existing pertinent research [14, 18], we have also observed that automated detection undermines the individual agency of users in terms of data reflection. Participants over-accepted and even questioned their emotional states even when the presented data did not correspond with their lived experiences. This illuminates the need for designing systems that are easier and more intuitive to comprehend from a user perspective. One design approach would be designing computational support that offers explanations about sensor-based detection mechanisms. We envision an explanation-driven system that explains sensory input and labeling, model training, and decision-making based on learned models [35, 43]. Another design consideration is leveraging manual user reports or enabling user feedback on system-generated information on collected data [11, 20, 63]. Past studies on emotional inference warned of the "reverse inference fallacy" [21] where misinterpretation of the data is likely to occur if there's a dependence on a single data type or measurement method. The multi-component nature of emotion (e.g., facial/behavioral expressions, physiological responses, self-reported feelings, and contextual appraisal) suggests that it is beneficial to corroborate multiple data sources. While computational support plays an important role in handling sensor data streams, a semi-automated approach with self-reporting to complement the pitfalls of automated tracking will not only increase user agency but also increase the accuracy of data collection.

7.4.2 Controlling automatic self-disclosure levels for privacy preservation. One caveat to further developing systems for family informatics, however, is privacy issues with "automated disclosure." Prior studies have pointed out that sensor-based tracking/reflection systems can passively and continuously track personal information, which leads to unwanted automated self-disclosure [39, 73]. In our user study, for example, not only parents, but especially children expressed discomfort toward their affective states and video footage being revealed to their parents, hoping for some form of privacy management method. Lederer et al. [38] discussed that personal privacy management in sensor-based systems requires user empowerment to adjust the level of detail or precision of disclosed information. For example, providing an optional "staging area" before disclosure actually takes place and enabling participants to review recent disclosures may increase a sense of self-censorship and lower user privacy concerns [1]. It will also be important to pay careful attention to the design of consent mechanisms to ensure the privacy of individuals can be preserved even within a tight-knit social tie like family.

7.4.3 From intra- to inter-family reflection. Most of the participants explicitly mentioned that the system guided them to recall and reaffirm their own predispositions and the characteristics of their family and helped to uncover newly discovered aspects of themselves and others. While self-discoveries through reflection tools have often been discussed in personal informatics, our findings on families as a sociotechnical unit open up new avenues for discussions on how future digital services can support the needs of reflection at a family level. While our study only enabled reflections within family members (i.e., intra-family reflection), we can also envision a fine-grained system that enables inter-family reflection to better facilitate understanding of their own and their families by comparing their data to that of other families that share similar characteristics. For example, one design approach would be a system that automatically suggests a cohort based on personal/familial information of families "like us" [25] with basic information such as similar family composition or sensor data similarities [37]. In terms of delivering such information, we can envisage a family dashboard that collates data about sensors and data similarities or dissimilarities within a cohort family. Raising such family-based social awareness can be leveraged in diverse domains that require family-based data, such as family therapy [52], or collective family health decisions [16]. Enabling clinician involvement in family-health (e.g., physical/mental health) intervention is another possible design consideration for further developing family informatics systems [63].

7.5 Limitations

One limitation of our study is that we considered few data types (i.e., physiological data, motion data, and video data) and limited activity scenarios (i.e., eating, media watching, playing a board game, and cleaning). To mitigate such concerns, further studies that consider additional data types (e.g., acoustic data, environmental data) and devices (e.g., smart speakers) are required to reflect more complex psychological states and contexts. Although participants responded that their affective responses didn't significantly differ from their usual interaction patterns at their real home, we posit that simulated home environments for the experiment (such as all family members doing a specific activity in a designated place) may have affected participants' behaviors in a certain way. To deal with the limitations of the current semi-naturalistic setting of direct video-based observations [26], alternatively conducting large-scale, in-the-wild experiments should be considered. Regarding the reflection analysis, we have solely relied on qualitative analysis, but it would be worth exploring how to leverage such a quantitative scale for reflection assessment in future studies (e.g., TSRI scale [4]). Furthermore, it is also worth considering various family dynamics [77], cross-cultural differences (e.g., collectivist vs. individualistic cultures), and socio-demographic status [64] to observe how participants externalize or communicate their affective status among family members.

8 CONCLUSION

We conducted a user study on FamilyScope, a family data reflection system that quantifies and visualizes affective aspects of a family's social interaction. The FamilyScope was designed and implemented based on a well-known family health model and its evaluation and user experience were conducted upon a scenario-based approach. Findings from our system evaluation session and post-interview suggest that the system's given features helped participants easily explore their own affective and behavioral states and overall family interactions. In terms of data reflection, participants responded that FamilyScope well reflects their general tendencies in terms of emotional and behavioral responses and that the system enabled novel discoveries about themselves and collective discussions with each other, which facilitated deeper understandings of each other. Our findings provided several design implications for designing and developing a family informatics system. Put together, we hope that our approach can be extended to a variety of family-based activities or other group-based users.

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