Sociotechnical Design Opportunities for Pervasive Family Sleep Technologies

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ABSTRACT

Getting the right amount of high quality sleep is crucial for overall health and wellbeing, and pervasive and ubiquitous computing technologies have shown promise for allowing individuals to track and manage their sleep quality. However, sleep technology research has traditionally focused on individual-level solutions. In this paper, we elucidate social requirements for family sleep technologies. We take a *family informatics* approach to sleep, through an in-home interview study with 10 families with young children. We describe families' current practices, values, and perceived role for technology, showing that sleep technology has many opportunities beyond individual-level tracking. We also provide design dimensions and implications for family-based sleep technologies, especially the potential for technologies that support family activities and rituals, encourage children's independence, and provide comfort.

CCS CONCEPTS

• **Human-centered computing** → *Empirical studies in interaction design.*

KEYWORDS

Health; Family informatics; Sleep; Children

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1 INTRODUCTION

Sleep is important for overall health and quality of life, and insufficient or poor-quality sleep can lead to a variety of serious health concerns [8]. People who sleep less than 7 hours a night are at increased risk for a variety of conditions, such as coronary heart disease, stroke, asthma, COPD (chronic obstructive pulmonary disease), and depression (National Center for Chronic Disease Prevention and Health Promotion 2017). Unfortunately, poor sleep is common: in the US, 1 in 3 adults reports getting fewer than 7 hours of sleep a night (CDC), and as many as 40% of preschool children experience sleep problems on a regular basis [24].

Furthermore, sleep researchers now recognize that family-level sleep concerns have a significant impact on the sleep quality of individual family members, and secondary effects on clinical, academic, and social factors in child development. This is especially true in families with young children [1]. A recent survey of sleep in American children reported more than 50% of parents lose an average of 30 minutes of sleep per night because of their children's night waking. However, there is good news: research suggests that parents *can* make a difference in their children's sleep habits and thus improve their own sleep quality [12].

While pervasive health researchers have begun to design and study individual sleep technologies for families, [9, 32] the current literature provides little holistic guidance for the potential roles and barriers for family-based sleep technologies. However, in other health application areas, researchers have begun to address the family itself as a health informatics context. In 2017, Piña et al. introduced the concept of *family informatics*, a family-level approach to health tracking technologies [27]. Piña and others have since refined this concept to align with Bronfenbrenner's Ecological Systems Theory [23, 26], treating the family as a microsystem and acknowledging influence across layers from the sociocultural to the individual. Researchers have also adopted a *lived informatics* model [14, 30], showing the human processes and influences on personal tracking technologies.

In this paper, we show how pervasive sleep tracking technologies for families can have benefits and uses beyond individual-level tracking. We ground our findings in an empirical home-based interview study with 10 families with young children. Through these in-depth interviews, we show that family-based sleep technologies may have the greatest impact by supporting parents and children alike in setting and maintaining healthy sleep habits, rather than concentrating primarily on sensing and tracking. We describe challenges faced by families across three phases: bedtime, nighttime, and waking. We show how family members' sleep quality affects each other, especially the impact of children's sleep on parents. We then discuss ways technologies could support sleep practices through facilitating parent-child coordination and rewarding and enforcing rules and rituals, and finally we draw from the family resilience literature to discuss opportunities for family informatics technologies through the lens of dynamic family processes.

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2 RELATED WORK

2.1 Pervasive sleep technologies

Over the past decade, HCI and Pervasive Health researchers have designed a number of sleep-related technologies, predominantly focusing on sensing, tracking, and sensemaking for individuals. In 2011, Choe et al. identified key design considerations, challenges, and opportunities for sleep technologies [10]. They showed the potential for sleep technologies to track sleep trends over time and to 'nudge' people into healthier sleep habits, and they noted potential challenges: different cultural approaches to sleep and tensions between technology and sleep. The team then continued this line of research, focusing first on the bedroom environment and its impact on people's sleep quality. Their system, *Lullaby*, used a combination of temperature, light, and motion sensors, audio and photos, and an off-the-shelf sleep sensor in order to enable users to interrogate the relationship between environmental factors and their quality of sleep [17]. Choe et al. extended this work in 2015 with the *SleepTight* system, a smartphone-based widget for sleep tracking and reflection [11]. In 2016 Liang et al. designed the *SleepExplorer* desktop sleep infovis system to provide users with even more fine-grained analysis and sensemaking abilities [20].

In the years since the first pervasive sleep-tracking research, commercial technologies that incorporate or support an understanding of sleep duration and quality have become widely available. These technologies take a variety of forms, such as mobile applications, wearable devices, and embedded sensors within other devices, such as phones [21]. Commercially-available systems contain many of the functions first proposed in early research systems, such as tracking the amount and quality of sleep or tracking environmental changes such as humidity an noise. However, studies of commercial sleep trackers have also identified barriers created by the technologies themselves. In a CHI 2017 paper, Ravichandran et al. noted that the inconsistent and opaque nature of sensors' sleep inference, as well as the interfaces' undue emphasis on sleep 'stages' (e.g. REM sleep) can mislead users and may lead to inferences at odds with sleep experts' recommendations [28].

2.2 Interpersonal and family informatics

Much pervasive sleep research falls within the area of *personal informatics*, the study of individaul reflection and tracking of information about the self. In 2010, Li, Dey, and Forlizzi defined personal informatics systems as "those that help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge" [19]. Since then, personal informatics has emerged as a major research agenda for HCI, and researchers have worked to characterize and address the social relations and life circumstances that surround and influence these systems. Rooksby et al.'s *lived informatics* approach shows how tracking is "enmeshed with everyday life and people's outlook on their future" [30]. Epstein et al. enriched this approach by focusing on tracking processes—such as deciding when and what to track, and selecting tools—and explicitly addressing lapses and resumption [14]. With respect to families, Pina et al.'s *family informatics* research shows the importance of identifying 'ripple effects' between family members, and the value of distributing the burdens of tracking across family members [27]. Piña et al. found that individual-focused personal informatics technologies failed to address complex family needs and to account for various intra-family roles, such as parents as carers, and failed to distribute the burdens across the family.

HCI researchers are actively working to deepen this sociotechnical view of personal health technologies. For example, Murnane et al., in a recent CSCW paper [23], describe this shift from personal informatics to 'social ecologies', and advocate for designs that support social relations in the case of mental health recovery and management. They also provide an ecological model for personal informatics for serious mental illness, based on Bronfenbrenner's *Ecological Systems Theory* from community psychology [2]. Piña and colleages have also adopted an ecological approach in their recent work on inter-generational family collaborative problem solving [26].

2.3 Pervasive technology in the home

There is also a rich tradition of studying technology for family home life. This research—often referred to as 'Domestic HCI'—treats the home as a sociotechnical system involving space, place, people, and artifacts. In a 2015 review of Domestic HCI research, Desjardins et. al surveyed the past several decades of HCI studies on the topic, identifying key genres of work, including social routines in the home, ongoing domestic practices, and the concept of 'smart homes.' One long-running example is the Georgia Tech Aware Home, which has served as a 'living lab' for novel domestic technologies since 1998 [18]. However, home-based technologies have not always lived up to their promise. In 2011, Brush et al. identified several challenges for smart home technologies, such as 'high cost of ownership, inflexibility, poor manageability, and difficulty achieving security' [4].

Health technologies for the home have also been widely studied in HCI, often with a focus on although interpersonal household factors. In a 2013 Ubicomp paper, Grönvall and Verdezoto examined home-based healthcare technology specifically, identifying seven themes of concern (beyond pure functionality): people, resources, places, routines, knowledge, control and motivation [13]. HCI researchers have also found indications of interpersonal aspects to sleep, although more research in this area is needed. In their 2015 review of sleep tracker use, Liu et al. noted that sleep is a "shared activity", finding that users encountered difficulty in tracking sleep continuously because their sleep partner has a negative attitude towards sleep tracking technologies.

2.4 Sleep and the family

While much research in sleep technology has focused on individuals, family-level sleep concerns also have a measurable impact on the sleep quality of individuals [12]. Sleep researchers have found that establishing proper bedtime routines (and addressing sleep resistance) is a key factor in improving family-level sleep in families with young children [1]. Night waking, though less common, still affects about 1 in 3 young children [22].

Over the last few years, HCI researchers have begun to study family-level sleep technologies. However, this is an emerging research area with few exemplars and no holistic studies to guide

future design and research. The studies that have been done primarily seek to address parent-child conflict during the day, and use bedtime and morning rituals as an intervention opportunity. One example is Sonne et al.'s *MOBERO*, a smartphone-based system that assists families establish healthy morning and bedtime routines with children with ADHD. Families who used *MOBERO* reported significant improvements in ADHD-related behaviors and child's sleep habits [32]. In 2017, Chan et al. 2017 developed the *WAKEY* system, which helps parents and children to establish proper morning routine using a stuffed animal with interactive tokens. In a pilot test, *WAKEY* reduced parent-child conflicts and helped families reinforce morning habits [9].

There are more sleep-centric technologies in the commercial market, although few have been studied from an HCI perspective. For example, the *Lully Sleep Guardian* combines a bed sensor in the child's bed with a mobile app for the parent, and proactively vibrates when night terrors are likeliest to occur[29]. *Remi* is a sleep trainer and baby monitor for families with children up to 10 years old [16]. One system that *has* been studied in HCI is *Owlet*, a smart sock for infants. In their recent study of the interpersonal impact of this system on mothers and babies, Wang et al. "found that participants occasionally elected to check the virtual baby represented through vitals present on their mobile phones instead of their actual baby" [34].

3 METHODS

We conducted a semi-structured home-based interview study to better understand current family-level sleep practices, values, and opportunities for design. We interviewed 10 families in central Indiana. All families had at least one young child age 2-6 for whom sleep was a concern but not a clinical issue. We selected the age range of 2-6 as it corresponds to a developmental stage where children are establishing and gaining greater control over their own sleep habits, but parental involvement in their sleep practices is still high and parents' sleep quality is highly correlated with children's [7]. The study was approved by the Indiana University IRB. We conducted interviews during December 2018.

We recruited families through posted flyers in public places around Indianapolis, and in local Facebook groups that contained words in their titles such as 'mom', 'dad', and 'parents'. We also snowball sampled, asking participants to recommend other families who might be interested. Each potential participating family then filled out a short questionnaire to assess their eligibility and availability for the study. Participants were predominantly middle class families living in standalone homes in the central Indiana area. Families in our study generally follow a traditional work, school, and sleep schedule. Eight families are Caucasian; One family has a Hispanic parent and one family has an African-American child. For an overview, see Table 1. We also discuss the limitations of our sample at the end of the paper.

Prior to the interview, we asked families to fill out sleep quality surveys to help guide our discussion. Families filled out the Pittsburgh Sleep Quality Index (PSQI) [5] for participants 12 and up, and the Children's Sleep Habits Questionnaire for children age 2-11 [25]. This process helped families to reflect on sleep and sleep concerns before we arrived, and allowed us to customize each interview towards issues of salience for that family. For example, the father in Family 6 mentioned challenges with insomnia, which allowed us to mention that during the interview. While no family reported clinically-significant sleep issues affecting their children, families did report sleep distractors, such as stress or poor sleep due to one or more family member waking during the night.

#	*Parents*	*Children*	*Home*	*Location*
1	F-31/M-33	F-3	Apt	Urban
2	F-32/M-34	M-5/M-3/F-1	House	Rural
3	F-39/M-39	M-5	House	Rural
4	F-39	F-5	Townhouse	Rural
5	F-36/M-30s	M-4	House	Urban
6	F-30s/M-46	M-4/M-4	House	Urban
7	F-39/M-41	F-7/M-5/F-5	House	Urban
8	F-41/M-43	M-4/F-2	House	Urban
9	F-34/M-36	M-7/M-4/M-2	House	Urban
10	F-41/M-40	F-6/F-18mo	House	Urban

Table 1: Participant demographics.

We visited each family's home, conducting a 60-90 minute semi-structured interview followed by a home tour. In our interviews, we asked families about their day-to-day schedules, sleep challenges (drawn from their responses to the sleep questionnaires and any problems reported in-person), and sleep distractors. We also asked about existing technologies or tools they use to track or aid with sleep, and their perceptions of the potential for technological solutions. Parents and children were all present throughout. Finally, we discussed sleep technologies directly, showing families examples of available sleep technologies. We presented images and brief descriptions of four currently-available sleep trackers: a wrist band, a sleep mask, a mat-based bed sensor, and a sleep-tracking ring. During this discussion, we also asked families to reflect on the perceived utility and acceptability of the technologies. We then discussed their wishes for future sleep-based technologies.

During the post-interview tour, we asked families about their best and the worst typical family sleep scenarios, and asked them to show us any technology or artifacts which they use to improve the sleep experience. We included the home tour because we believed that the context would encourage families to reflect on their sleep experiences.

Throughout the data collection period, the authors met to discuss emerging themes and adjust areas of focus for the interviews. The first author, who conducted the interviews, memo'd about the interviews. The authors then discussed the interviews and began to identify themes. We stopped the interview study after 10 families because we achieved saturation. We then met to thematically analyze the interview data and, over the course of our meetings, we identified major opportunities and barriers.

4 FINDINGS: CHALLENGES AND CURRENT PRACTICES

Overall, families in our study reported the sleep of their young children as the main factor affecting the family's sleep quality. During analysis, family processes around sleep emerged as a central

factor in the family's overall sleep quality, particularly processes focused on getting young children to bed and ensuring they sleep through the night. We report families' process-related challenges across three phases: bedtime, sleeping, and waking. We describe how these challenges affect the family as a system, and how families introduce new practices and artifacts to deal with sleep challenges.

4.1 Challenge: Bedtime forever

Bedtime is a key moment in the day for families with young children, and also the greatest source of challenges. During the critical hours before bed, parents in our study encouraged a daily routine of child-focused individual activities, such as bath-time, calming games, pre-bed TV, a final snack or beverage such as warm milk, and potty time. Families also prioritized collaborative 'family bonding' activities during this time, such as reading books together, singing, and evening prayer.

Families in our study all mentioned that they value this "magic time" as a core family activity. So much so, that none of them even considered using cancellation of shared bedtime activities as a punishment. However, the essential nature of bedtime rituals also posed a challenge for families in our study: many parents reported that children want bedtime activities to last as long as possible, frequently begging for one more story or one more treat. In the words of one parent, their children always want "the party to continue " –F2.

This transition, from 'party' to sleep, was the primary challenge to sleep quality for all families we spoke to. The switch from the reassurance and comfort of social bonding with siblings and parents to the solitude of sleep can be especially abrupt for young children, and every family told us its effects are felt by the family as a whole.

Some children, when the moment arises, are frequently afraid and require soothing. For example, the child in Family 6 often said "I'm scared and I need you" soon after his parents had left the room. Family 8, the most extreme example of this phenomenon, reported that their young child's emotional distress at suddenly being alone in the dark could sometimes last for hours if left unresolved. Families with multiple children also face the additional challenge of managing bedtime 'fairness' even if only one child is experiencing bedtime distress. As one parent said: "if you say yes to one, you will need to say yes to all three children, and bedtime will continue forever" –F9.

A late or extended kids' bedtime also impacts parents' own sleep quality. Parents told us they used post-bedtime hours to watch TV, read, complete chores or catch up on work. They valued this time to decompress, and would even extend their own bedtimes in order to retain it.

4.1.1 Solutions. Families tried a number of approaches to meet the challenges of bedtime. Some took the most direct route, allowing children to co-sleep with their parents. For example, the mother from F4, the only single parent we were able to recruit for the study, valued this time so much, she was willing to reduce her own sleep quality in order to spend time with her child at least at night and being close to her. "We usually fall asleep together with my daughter in my bed...[but] you know children in her age move a lot at night, so sometimes I don't have enough space and even can move to another bed. She falls asleep better with me and sleep is time when I can be actually together after my work day, so that's why I don't want to change it". –F4.

Figure 1: A home-based trampoline used for "jump minutes" in case a child is too excited and can't calm down before bedtime.

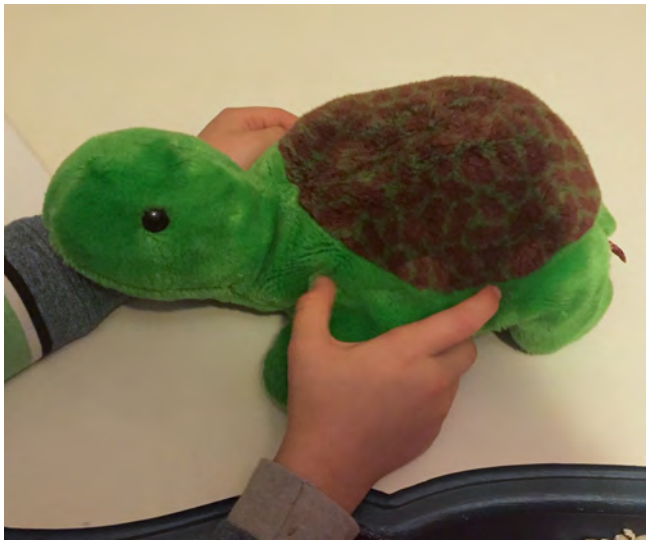

Figure 2: *Turtle*, a child's stuffed animal transitional object which he takes to bed and which helps him to sleep.

Most families, however, tried to resolve bedtime challenges without co-sleeping. These families employed two main strategies in order to support bedtime transitions: 1) tracking and managing daily activities, and 2) providing 'transitional' objects.

Many parents reported that their children were extremely energetic right before bedtime. Parents tried to prevent this 'supernova' by making adjustments to daily routines and practices. For example, the mother in Family 1 experimented with different nap times, noting that if her daughter napped at the wrong time or for the wrong duration, bedtime would be more challenging that night. For example, the mother from Family 1 told us that a late nap time would ruin their chances for an orderly bedtime. "If [our daughter]

wakes up from her nap at 4pm I just give up and don't push so hard for her to get to sleep...'cause I know it's going to take me an hour and a half to just get her to sleep."

Other solutions included adding walking time to their child's daily schedule, or encouraging other outdoor activites. However these solutions were dependent on external factors, such as the weather—a real concern during the time of our interview, when temperatures were near-freezing. One family (9) took a direct approach, installing an indoor trampoline and ask their children to use up energy by earning "jump minutes" throughout the day (see Figure 1).

Half of the families also described using *transitional objects*, artifacts which provide psychological comfort security to those children attached to them [35]. Transitional objects can be security blankets, stuffed animals, even pillowcases. transitional objects join children in their bed at night and help comfort them as they go to sleep. A typical example is shown in Figure 2: a child's favorite stuffed animal (simply called Turtle). Families reported that while these objects were no replacement for parents, they did help children feel comfortable and secure while falling asleep alone.

Figure 3: Sleeping solutions. Left: a sleep aid that glows orange when the room's temperature is appropriate for sound sleeping. Right: a video monitor for a 4-year-old's room.

4.2 Challenge: Sleeping soundly

While bedtime caused the most frequent sleep challenges for families, family members also encountered challenges staying asleep. Young children, still unused to sleeping independently, sometimes wake during the night. Parents also encountered difficulty staying asleep, both as a result of children's night waking and due to environmental factors and the sleep habits of the other parent.

Children's night waking happened either because of nightmares or bed-wetting, or child illness. Bed-wetting is occasionally extremely disruptive. As the mother from Family 7 told us: "Once, [our 5-year old] woke up from a wet bed which he shares with his sister and [a young dog]...so all of them—2 children and 1 dog—joined me, my husband, and my older dog in 1 bed'. The mother from Family 3 described a similar struggle with night-time bedwetting, which required her to not only get up during the night but perform the physical labor of removing and replacing her child's sheets. Nightmares were also a common reason of night waking, which some parents relate to difficulty falling asleep. As the mother from F10 told us: "My daughter [often] wakes up in the middle of the night, goes to my husband and wakes him up." Night waking could be extremely disruptive for families, particularly for parents. The mother from Family 3 told us that her heart was often racing after getting up to soothe her child during the night. The mother in Family 6 also recalled the first few years with her twin boys: "We were so sleep deprived that we lost our minds. We had no sleep, we slept maybe three hours at a time, and they were up every three hours all night long."

Family 6 was not alone. For example, Family 7 decided to co-sleep with their young children, but this caused sleep disruptions for both parents. Family 10 had a young baby, so the mother needed to get up to nurse the baby. Parents also described two additional distractors: environmental factors and their partner's sleep. The parents in Family 2 had different temperature preferences, with the husband preferring a colder bedroom. The parents in Family 3 and Family 6 had different biorythms, and their ideal waking times were rarely in sync.

For some parents, their child's sleep challenges impacted them even after the children had learned to sleep through the night. For example, the mother in Family 6 explained that "it took us like a year to feel like we were ourselves again from that sleep deprivation." The father in Family 6 still occasionally experiences insomnia two years later.

4.2.1 Solutions. In order to avoid night waking, families adjusted environmental factors to make the child's bedroom as calm and comfortable as possible. This included adjusting temperature, light levels, and providing soothing sounds to encourage sleep.

Almost every family used a noise machine or equivalent to provide comfort and reduce the chance of waking from nighttime noises such as parents' TV watching, or weather-related sounds (our study was conducted during a period of winter storms). Some families used humidifiers and heaters, but this was less common. One family had been using a humidifier but was currently running it without a water supply so it could serve as a soothing white noise device. One family even posted a sign on their child's door that read: "You wake him, you take him!"

Some families used dedicated temperature sensors (as seen in Figure 3 on the left). These devices glow orange when the temperature is in the best range for young children's sleep. Parents also monitored their children's sleep during the first few hours of sleep (while parents were awake) using baby monitors, featuring either video or audio. Some parents took these monitors to bed with them too, as seen on the right in Figure 3, on the bedside table next to an alarm clock and a lamp. This allowed parents to decide whether or not to get up to soothe the child, and gave them a sense of security and calm, knowing they could check up on their child remotely.

Parents also tried several solutions to their own sleep challenges. In two families, the fathers frequently slept in a separate room: the father in Family 6, on nights when he had trouble getting to sleep, and the father in Family 10, to allow for uninterrupted sleep

when his wife was nursing their baby during the night. The mother in Family 5 purchased a heated pillow to address differences in temperature preference.

4.3 Challenge: Waking up

All families talked about sleep challenges in the morning. Early waking was particularly disruptive; some children frequently woke up earlier than their parents expected or desired. For one family, early waking was a daily challenge, since their son consistently woke up at 5:45am no matter how they adjusted his bedtime or other factors. This case was more extreme than others, but early waking was a common challenge reported by all families in our study.

4.3.1 Solutions. Parents tried to address early waking through the establishment and enforcement of regular rituals and rules. Tracking and managing consistent bedtimes and daily activities (such as naps), which also helped children get to sleep more easily, also helped families with early waking challenges.

However, sometimes these rituals were not enough on their own. Several families purchased bedside clocks designed for this purpose (such as the clock in Figure 4). In addition to telling the time in numbers and clock hands, these clocks also display the different stages of night-time: sleeping time, and waking time. To help pre-numerate children, these clocks often include a visual state indicator. Family 3 used the clock in Figure 4 glows green when it's OK for the child to get up. Families also demonstrated a sense of humor about early waking.

Parents with different schedules also adjusted their schedules or practices so the early riser was able to wake up without disrupting their partner. As we described in the previous section, some parents slept in separate rooms either temporarily or full-time. However, parents also tried less drastic solutions. For example, the mother in Family 2 slept with her phone under her pillow at night, so that the vibration from the alarm would not wake her husband. The father in Family 3 regularly woke up with the children "and we usually are downstairs 'til about seven." The mother added: "and I stay upstairs and enjoy quiet!"

5 FINDINGS: PERCEPTIONS OF SLEEP TECHNOLOGIES

As part of our home-based interview, we asked participants to respond to a variety of existing sleep tracking solutions, and we also asked them questions about their views on technology in their home. In general, families were cautious about incorporating sensors and trackers into their everyday sleep routines, and parents were particularly concerned about adding additional 'screen time' or technology use into their child's routines, especially during sleep. Families evaluated the sleep tracking solutions we showed them based on their *intrusiveness*, and expressed skepticism about their accuracy. However, when we compared this discussion to the technology families discussed in the interview and home tour, we found reasons to be optimistic about the potential acceptability and adoption of family-centered sleep technology in the home.

Figure 4: A child-friendly clock which glows green when the child is allowed to come to their parents' room, and red when it's too early.

5.1 Perspectives on family-based technology

Families in our study were far from luddites, but none would be considered 'early adopters.' Several families in our study used Ring (internet-connected) doorbells and owned Alexa or other speaker-based voice assistants, and all families used televisions, home Internet, and cellphones. When it came to introducing *new* technology in their homes, families sought to avoid technology that makes their life more complicated. Both Family 7 and Family 10 had recently acquired voice assistant speakers as gifts, but reported mainly using them as speakers because it seemed too complicated to set up the assistants. Parents emphasized throughout the interviews that their time is limited, especially now that they have a family, and now almost all their waking hours are dedicated work and family. As the father in Family 3 shared: "You know, at some point, if technology is not an immediate assistance to me, I don't want to deal with it."

Parents preferred to avoid screen time for their children, and preferred to control the screen time they did allow. As the mother in Family 9 put it: "Our philosophy is that if he wants to be playing, he should be playing with toys are doing physical play, he doesn't need to be sitting and playing a computer based game." This concept of the digital world being artificial and the physical world being real came up frequently in our conversations with families. The father in Family 6 was more succinct: "I want to have more connection with physical world than virtual one".

5.2 Perceptions of current sleep trackers

As part of our interview, we showed families examples of several currently-available sleep technologies. When we presented descriptions of existing sleep trackers (wristband, eye mask, bed mat, and ring), opinions varied widely, especially *within* families. Parents, for example, had definite opinions about what technology might be better for their household and sometimes it didn't match with their children's opinions. However, a few common themes emerged.

Overwhelmingly, families in our study evaluated the sleep technologies we showed them based on the form factor's *intrusiveness*,

or how noticeable and cumbersome it would be. Because of the unobtrusive nature of mat-based bed sensors, in discussion families tended to prefer these over other form factors. Conversely, eyemask-based sensors were the least preferred option, especially when it came to children. As the mother from Family 9 put it, "I don't think they would ever keep a mask on." Band-based sensors were more popular; the son from Family 2 used our interview to plead for his parents to get him a superhero-themed wrist-based tracker. However, even then, the bar for such personal technologies, for families in our study, was quite high. As the father from Family 3 said: "I wear only underwear at night, so this means I have to wear something else!"

Families also expressed skepticism that sleep trackers could help them with their sleep challenges. Some families were suspicious of the trackers' ability to assess and monitor their sleep accurately. For example, the parents in one family wondered how a bed-based sensor could track multiple people sleeping in the same bed. The parents in another wondered how sensors might track a child who naturally rolls around a lot in their sleep. But some families were more definitive, finding few potential benefits and many clear costs. The father in Family 10 summarized an opinion we saw frequently during our interviews: "I just I think ultimately, I just wouldn't be super interested. Like, I kind of know why I wake up in the night. So I think I'm just probably not super interested in the data."

5.3 Existing sleep technology in the home

While families in our study were not particularly interested in the currently-available sleep *tracking* technologies we showed them, they did incorporate a wide variety of sleep-related technologies in their attempts to address the sleep challenges they faced as a family.

In children's rooms, we found devices to help children to fall asleep, to comfort them during sleep, and to allow them to get back to sleep. We also saw devices to help children understand their parents' preferred waking schedules. These took a variety of forms: cameras for baby monitors, night lights, clocks (both with and without dials), tabletop temperature sensors, sound machines, humidifiers (even ones which no longer produced steam but still provided comforting sounds), and heaters. We saw static artifacts such as story books, toys, and transitional objects, which helped to smooth the transition from 'party' to sleep.

In parents' rooms, we found devices to help parents care for their children during the night, protect the family from external threats, allow for emergency notifications from family and friends, wake up on time (sometimes without having to wake up their partner), provide comfort to help them get to sleep, as well as screen-based entertainment devices. These took the form of devices such as video and audio baby monitors, security monitor, phones, smartphones, tablets, TVs, alarm clocks, and adapters to charge devices overnight.

6 DESIGN OPPORTUNITIES: SOCIAL IMPLICATIONS

As described above, families in our study were not early adopters and not particularly excited by the existing sleep tracking technologies we showed them. They expressed reluctance to add more 'screen time' for their family and sought to protect their critical bedtime and sleeping practices from interference. And yet, in our interviews and home tours we saw many sleep 'technologies' already in use, especially when it came to ensuring their children got a good night's sleep. Families used artifacts to encourage independence, regulate family activities and rituals, and provide comfort. Parents used baby monitors to keep track of their children's sleep throughout the night. We believe these are all key opportunities for pervasive and ubiquitous computing technologies to support sleep at the family level.

However, our findings suggest that sleep technologies for families with young children may look quite different from individual-level sleep tracking or management tools available commercially and previously described in the research literature. Instead, we propose researchers and designers adopt a socio-technical approach to sleep tech, still incorporating environmental and individual factors but within a family-centered framework. That is, although sleep is a solitary activity, we believe a social computing approach is likely to result in technologies that help families sleep better. In this section, we describe four areas for further design and research: 1) technologies that support bedtime activities and rituals, 2) technologies that encourage children's independence, 3) technologies that provide comfort, and 4) technologies that encourage daily activities that ultimately aid with sleep.

6.1 Supporting family bedtime activities and rituals

Families uniformly agreed that bedtime was a key family event, allowing for bonding, relaxing, and fostering a sense of family togetherness. However, parents struggled to manage the tension between unifying bedtime rituals such as reading stories, playing games, and bathtime, and the ultimate function of bedtime: a smooth transition to individual sleep. That is, bedtime became simultaneously one of the most social times of the day, but then switched quickly to the most solitary. Parents found it challenging to keep to a bedtime schedule, to enforce rules about required activities (e.g. brushing teeth), and to stop the 'party' from continuing all night. Parents also encountered challenges managing their own bedtime. In many families we spoke to, the challenges of bedtime seemed almost like a domino cascade: issues with one child might extend to others; issues with children's bedtime propagated to parents' bedtime.

Family-centered sleep technologies could help support these bedtime activities through displaying and regulating activity sequences. For example, imagine a 'whereabouts clock' [3] for bedtime. Child A might be in the 'bath-time' phase, while Child B is 'reading stories' and Child C is 'sleeping.' Or imagine a 'sleep countdown' interface, which uses a space shuttle launch sequence metaphor to describe bedtime activities. In this system, the bedtime sequence would be more linear, and the 'launch time' would be visible and could slip (e.g. from 7:30pm to 8pm) if elements of the bedtime routine were taking too long.

6.2 Encouraging children's independence

While supporting family-level bedtime rituals is important, the individual needs of young children transitioning to independent sleeping and waking also present challenges to families. To address

bedtime concerns for these children, half of the families we interviewed provided 'transitional objects,' [35] such as teddy bears or blankets. These objects accompanied children on their journey to sleep, allowing them to gain independence without being alone. Children and their transitional objects slept alone together. Additionally, children in this developmental stage sometimes struggled to know when it was appropriate to wake up their parents. Two families provided clocks for their children that make a rule visual about when is allowed to come to their parents' room or too early.

Sleep technologies can help encourage children's independence through adopting strategies already used in 'analog' forms: embracing the transitional object as a form factor, and providing children with status and feedback about expected sleeping and waking norms. A child's transitional object is an important part of their childhood, which provides an opportunity and a challenge: sleep technologies that use the transitional object form factor are, if adopted, likely to become constant companions and valued objects, which improves their data-gathering and feedback-providing potential. However, as many parents told us, part of the appeal of a transitional object is that the child chooses it, so there would be no guarantee that a specific sleep system would be incorporated into the child's life. However, once adopted by the child, a transitional object could take on magical properties. This approach has seen success already: the Wakey system [9] takes the form of a rabbit doll. Imagine an interactive toy, like a smart version of the storytelling bear Teddy Ruxpin [6], which becomes a child's bedtime companion. Such a system could reinforce rules, support children in managing their sleep independently, and provide comfort.

6.3 Providing comfort at night

Technologies to provide comfort during the night have potential far beyond transitional objects, however. Most children in our study had devices in bedrooms to regulate their room's temperature and humidity level, provide a measure of night-time lighting, and broadcast soothing white noise. Parents also reported needing, using, or benefiting from such technologies for their own sleep.

Technologies that can more actively support night-time comfort and bring an additional sense of safety for all family members may improve overall family sleep quality. For example, it would now be possible for a system adopting the environmental sensing approach first used in the *Lullaby* system [17] or that of the *SleepTight* system [11] to be extended to a multi-user, multi-room approach that provides an overall environment-level view of a household's sleep environment. Existing devices used by our participants provide a set of form factor suggestions: artifacts that look less like computers and more like household infrastructure (night lights, humidifiers, etc.) may be more likely to be adopted by families. By networking these devices together, families could gain more control and a more holistic insight into their family-level sleep quality. Such technologies could also help with night waking, by—for example—sensing that a child is awake, and re-starting soothing lights and sounds to help guide the child to sleep without requiring parental intervention.

6.4 Promoting daytime habits to support sleep

In the same way that sleep quality at night affects people's lives the following day, families told us that daytime activities affected their sleep quality that night. Parents reported a strong correlation between their children's daytime exercise and children's tiredness that evening. Scheduling the right start time and duration of naptime was a constant challenge for many, and parents told us naptime had a big impact on bedtime. However, daytime habits and activities are not normally included in sleep technologies, which tend to focus on tracking things like sleep duration, waking events, and amount of REM sleep.

Family-based sleep technologies could help families track, manage, and schedule daytime activities to promote restful sleep. For these tasks, many existing personal informatics technologies could play a key role with minimal modifications. For example, a watch-based app could remind parents or other daytime caregivers when their child's ideal nap time is approaching. Family-based exercise interventions, such as *Spaceship Launch* [31], could be extended to reward activity for its sleep-enhancing qualities. Chore-tracking apps could incorporate sleep-promoting activities, and activity trackers could help families achieve insights about the right levels of activity for each family member to achieve their best sleep.

7 DISCUSSION: SUPPORTING FAMILY PROCESSES

Families in our study experienced a variety of sleep-related challenges, and sought to improve their sleep quality and regulate its duration. However, families told us that *tracking* their sleep was just one small piece of the puzzle. Indeed, when we presented them with existing sleep technologies—which predominantly focus on sleep tracking and individual-level management—both we and the families we interviewed could sense a disconnect. With each family, we spent at least an hour discussing their experiences and challenges with sleep. The stories they told us focused on *processes*: reading bedtime stories, taking baths, handling nightmares, breastfeeding, chasing the elusive perfect nap. Switching from that to a discussion of fitbits and bed sensors felt awkward. Instead, families told us that what they needed most was support for creating and maintaining healthy habits and practices, with technology in the background or in a supporting role.

An ecological systems approach to personal informatics technology, advocated compellingly by Murnane et al. [23], is enormously helpful in helping researchers and designers understand the scale of challenges and potential solutions. Using Bronfenbrenner's terminology, the family is one microsystem (on the same level as peers, schools, and churches) which is affected by actions at the individual level and the exosystem level (such as neighbors, media, industry, and politics) [2]. But in order to design family-level sleep technologies, we also need a better understanding of intra-family dynamics and the role of technology within those relations. We need a literature on *family process informatics*.

In order to understand how technologies could support family sleep processes, we can look to the family psychology and family therapy literatures. These disciplines have much to teach HCI about how families work, and the nuanced ways in which family dynamics impact the sleep of individuals. Family-level sleep concerns first

became of interest to family psychologists over a decade ago, demonstrating the ways in which "family contexts—including sleeping arrangements as well as stress, attitudes, and emotional environment— often have a marked influence on sleep" [12]. More broadly, the family sciences can provide useful theories of family functioning to help guide our sociotechnical research. One particularly promising area, *family resilience*, describes families as adaptive systems [33]. Within this approach, there are several sub-systems—meaning systems, emotion systems, control systems, maintenance systems, and family stress-response systems—each with their own distinct processes [15]. We believe that thinking about family-centered informatics this way will unlock many new avenues of research for HCI researchers, and will result in more salient family-centered health and wellbeing technologies.

8 LIMITATIONS & FUTURE WORK

Our participants represent limited diversity in sense of socioeconomic status, mostly representing middle class white families in central Indiana. We were unable to recruit participants with alternative domestic family structures, such as multi-generational families or LGBTQ families. The family interview method also introduced two limitations: because of the retrospective metacognition involved, parents provided much of the information used in analysis. Additionally, there is likely some selection bias due to the in-home nature of the interview: less-organized families or families with serious interpersonal challenges are less likely to participate in a 90-minute interview in their home. Finally, since our study focused on families for whom sleep was not a clinical issue, we did not hear from families facing more dramatic or disruptive sleep concerns. Our study was also conducted without the benefit of sleep experts on the study team. In our future work, we plan to work with families from a more diverse set of backgrounds through more purposeful sampling as well as larger-scale surveys to confirm our findings at a population scale. We plan to work with families in more child-friendly ways, such as participatory design studies. We plan to incorporate the participation of sleep experts and focus more specifically on evidence-based sleep hygiene. We also hope to extend our research into other domains in which technology could support family processes and resilience.

9 CONCLUSION

In this paper, we report design opportunities for family-based sleep technologies, drawn from an in-home interview study with 10 families with young children. We have shown a rich description of families' current practices, values, and perceived role for technology. We also provided design dimensions and implications for family-based sleep technologies. Overall, we believe family-based sleep technologies can have the greatest impact by supporting family bedtime activities and rituals, encouraging childrens' independence, providing comfort at night, and promoting daytime habits to support sleep. We also advocate for an approach to family-based technologies that focuses on family processes.

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