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ISBN
9781450394215

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Publication Date
2023-04-19

DOI
10.1145/3544548.3581316

Unpacking the Lived Experiences of Smartwatch Mediated Self and Co-Regulation with ADHD Children

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ABSTRACT

Challenges associated with ADHD affect children's daily routines and response to environmental stimuli, and support from parents is helpful in managing and overcoming behavior regulation challenges. Positive reinforcement is increasingly integrated into family technologies for teaching regulation skills, but typically support specific co-located activities. To better understand how technology can support co-regulation within families with ADHD children, we deployed CoolTaco, a smartwatch and phone system to support collaboration in creating tasks, gaining points for achieving them, and redeeming rewards. Ten families with ADHD children used CoolTaco in their daily routines. By qualitatively analyzing family interviews and usage logs, we find that smartwatches can help provide pervasive regulation support to children, but the division across devices and parent-child roles interfere with developing independence. We discuss how technology should support co-regulation while also fostering future self-regulation, such as by guiding children in goal setting and helping them reflect on progress and achievements.

*Both authors contributed equally to this research.

CHI '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9421-5/23/04.
https://doi.org/10.1145/3544548.3581316

CCS CONCEPTS

• **Human-centered computing** → **Interactive systems and tools**; **Empirical studies in ubiquitous and mobile computing**; **Ubiquitous and mobile devices**.

KEYWORDS

Smartwatch, wearable, co-regulation, ADHD, children

ACM Reference Format:
Lucas M. Silva, Franceli L. Cibrian, Elissa M. Monteiro, Arpita Bhattacharya, Jesus A. Beltran, Clarisse Bonang, Daniel A. Epstein, Sabrina E. B. Schuck, Kimberley D. Lakes, and Gillian R. Hayes. 2023. Unpacking the Lived Experiences of Smartwatch Mediated Self and Co-Regulation with ADHD Children. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23), April 23–28, 2023, Hamburg, Germany*. ACM, New York, NY, USA, 19 pages. https://doi.org/10.1145/3544548.3581316

1 INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is characterized by challenges with attention, organization, and impulsivity inconsistent with the child's developmental age [19]. Estimates indicate that about 1 in 10 children in the United States is affected by ADHD[1] [10, 21], and between 5.29% [68] and 7.2% [103] worldwide, making it one of the most common childhood mental health diagnoses [64, 109]. Challenges associated with ADHD affect how children self-regulate their behaviors in their daily routines and adapt to different environments and stimuli. For example, ADHD can make it challenging to plan and achieve goals due to higher risks of being distracted and difficulty with self-monitoring skills to assess

[1]Like others (e.g., [96]), we use both "ADHD children" and "children with ADHD" to show respect for the different views and preferences communities and ADHD people have expressed regarding the use of person-first language.

progress [19, 89]. Parental support is critical for social, emotional [70], and cognitive development [2, 100] of children. Parents can collaborate with children's regulation (i.e., co-regulate) by helping them manage tasks and goals, set boundaries, stay motivated, refocus, and much more [56, 104]. Parents are also important role models that help children regulate behaviors and emotions [33, 83]. Research in several disciplines, such as CSCW, HCI, and behavioral psychology, have investigated technology's roles in supporting parents or ADHD children (e.g., [16, 42]), but more rarely involving both as users for cooperative care in the same system [97].

Positive reinforcement strategies are cornerstones of many behavioral interventions [39, 47]. According to Self-Determination Theory (SDT), when people foster behaviors in others (e.g., parent's co-regulation), they can promote extrinsic motivation to do tasks [76]. In particular, people often use "token economies" as positive reinforcement strategies [47] to motivate children through rewards for achieved goals, such as to organize bedtime routines [94] or incentivize physical activity [61]. However, challenges remain in supporting co-regulation beyond specific routines taking place in settings in which children and adults are co-located, allowing for quick and relatively straightforward verification of goal completion. Interactive technologies provide an opportunity for positive reinforcement to support ADHD children and their parents in collaboration around co-regulation as they navigate lived experiences in multiple routines and contexts.

In this work, we examine the utility of smartwatches as a delivery platform for behavior support with ADHD children. While there is much room for improvement, especially around the inclusion of people with ADHD in their design [96, 97], a variety of mobile technology interventions show promise to promote cognition, social-emotional skills, behavior management, organizational skills, etc. (e.g., [16, 35, 42, 94]). Smartwatches can potentially expand on these approaches [16, 42] to improve accessibility in everyday life given that they are convenient and frequently available devices [15, 67]. Through co-design workshops with children with ADHD and caregivers, Cibrian et al. [17] identified that smartwatches can potentially mediate positive reinforcement strategies to support gradual autonomous and independent engagement for ADHD children. Such an approach can be scaffolded to support co-regulation with a caregiver and gradually decrease the caregiver's involvement. Although this prior work suggests that smartwatch-based strategies could help families co-regulate, we have limited understanding of how families might practically experience or perceive these technologies in their everyday lives. Gaining such understanding can provide important insights into the utility of the overall smartwatch mediated strategy and how it should be designed.

To understand how families perceive and use smartwatch mediated co-regulation in everyday life, we built and deployed CoolTaco (Cool Technology Assisting Co-regulation), a novel application on the phone and smartwatch, in the wild. Ten households with ADHD children aged 8-15 (10 ADHD children, 17 caregivers) used the system for 3 weeks to over 6 months (average 3 months). CoolTaco implements a basic task and reward strategy to support positive reinforcement for children's behavioral skills [39, 47]. With CoolTaco, parents and children create activities, children report activity completion, accumulate points, and redeem points for rewards. Our qualitative analysis of family's interviews and system logs indicate that CoolTaco helped structure routines and motivate some children towards goals while the smartwatch served as an always-available reminder for the child and a proxy for parent's collaboration even when not co-located. However, the multi-device nature of CoolTaco interfered with some family dynamics, such as supporting children in regulating their behaviors with limited parental involvement. In examining family's use of CoolTaco, we highlight tensions in family informatics systems between encouraging parental involvement and developing children's independence. The key contributions of our deployment study are the following:

- An understanding of smartwatch mediated collaboration strategies parents and children used to plan and stimulate children's regulation beyond when being together. Smartwatches were generally seen to be helpful for children to take on aspects of co-regulation work by executing tasks more independently with less parental presence.
- An empirical understanding of challenges, tensions, and labor that arise when families use a smartwatch mediated positive reinforcement system, such as the high technical and social dependency on parents' attitudes and actions, and efforts to reflect lived experiences to in-system data.
- Opportunities to support family co-regulation alongside children's autonomy. In particular, we discuss the need for coregulation technology to support moments of joint reflection in addition to asynchronous co-regulation, as well as the need to promote children's own self-regulation.

2 RELATED WORK

In this section, we review prior research on self and co-regulation concepts, technology mediated family collaboration, and use of smartwatches by children and families for well-being. Our study and CoolTaco's design build on these broad areas to explore opportunities for family collaboration mediated through the smartwatch to promote ADHD children's regulation.

2.1 Self-Regulation and Parental Co-Regulation

Self-regulation refers to the human ability to manage emotions, attention, behaviors, and cognition [28, 49, 98]. Self-regulation can also be described as a means for managing goal-directed behaviors [38]. Children tend to develop self-regulation throughout childhood, adolescence, and into early adulthood [48]. However, ADHD children can develop self-regulation at different rates or in different ways than their typically developing peers [22, 89]. Regulatory skills are associated with children's development of social competence, mental health, and academic learning outcomes [23]. Self-regulation development varies individually due to several factors, such as differences in temperament, beliefs, cognition, disabilities, self-control, expectations, and others [28, 38]. Self-regulation also builds on the dynamic interplay of environment, personal factors, and behavior [34]. An important aspect of self-regulation is being adaptive to the demands of the environment, but it also largely depends on self-efficacy [6].

ADHD children can experience difficulties in planning and achieving goals [22, 89], sometimes related to arousal levels that can inhibit adapting to situational needs [89]. Self-monitoring helps children to assess progress towards goals and regulating behaviors to reach them [89]. Developing self-regulation skills can have lasting positive effects on children by fostering independence and reflection on the long-term consequences of decisions and efforts [91].

Assistive technologies for self-regulation often follow design principles for behavior management, such as "digital nudging" [8] to influence judgment and choices, or learning through training and feedback (e.g., [52, 77, 87, 106, 110]). Within ADHD, assistive technologies have leveraged some of these design strategies to support children's regulation and skill development. For example, systems such as TangiPlan [107] have proposed the use of tangible objects representing tasks to help ADHD children plan and organize morning routines. Similarly, gamification techniques like storytelling and playfulness of self-regulation practices have been used to help children regulate stress and practice organizational skills, such as in Chillfish [93] and Plan-it [14]. Research has also sought to support ADHD children's learning in school settings, such as using wearables to encourage refocus when inattention is sensed [95], or cooperative positive behaviors through an ambient display of student's behavioral performance [46]. Other design strategies have been surfaced by recent literature reviews on assistive technologies for self-regulation, including involvement of emerging technologies [16] and their utility in digital health interventions [42]. Overall, evidence suggests that technology can offer some support for ADHD children's regulation but there is still need for systems to consider children's care ecosystems, such as the involvement of multiple stakeholders like parents and educators, given their importance in children's regulation and development [74, 97].

Parents[2] play an essential role in helping children regulate their behaviors [57, 83, 104]. Educating and guiding is a natural part of parenting, and parents use several co-regulation strategies to support their children [53]. Examples of such strategies include redirecting their attention, helping restart tasks, modeling, setting boundaries, and giving encouragement [33, 83]. A parent's warm and responsive relationship can also serve as support during stressful moments, influence emotional learning and regulation, foster effective communication, and give supervision while respecting autonomy [50, 54]. Finally, parents are the dominant forces in structuring the home environment with additional influence on community and school environments. Thus, parents can help children co-regulate while respecting their own journey toward independence and maturity for self-regulation.

Parents have a vital role in co-regulation with their children, and parenting is a demanding endeavor that requires self-regulation itself [83]. Parents might struggle with self-regulation too, especially in giving support to their children, when having challenges with mental health or being overburdened with work and family obligations [83]. ADHD is highly hereditary [26], hence many ADHD children have ADHD parents who are coping with their own self-regulation challenges. Even so, the parent-child relationship is a reciprocal bidirectional system through which both adapt their behaviors in response to each other and to the exchange itself [7]. Therefore, parents' self and co-regulation is influenced by children's demands and their personal characteristics.

[2]For ease of reading, we use here "parents" to include a wide variety of caregivers who may engage in "parenting" as primary caregivers of children, including biological, foster, and adoptive parents as well as siblings, grandparents, and other close family members acting in the primary caregiver and/or legal guardian role.

With CoolTaco, we explored how the smartwatch and app could mediate and contribute to parent-child collaborations. By incorporating aspects of co-regulation strategies in CoolTaco, we facilitated planning goals and assessing progress toward expected outcomes and rewards even when parents and children were not co-located.

2.2 Family Informatics and Technology Support for Co-Regulation

With the increased adoption of consumer-facing systems and devices for self-monitoring (e.g., physical activity, glucose), people have more access to personally generated data that can reflect their behaviors [24]. Recently, greater attention has been paid to the collaborative and contextualized nature of engaging with such technologies (e.g., [24, 27, 32, 65, 66, 90]).

In this work, we particularly build on the ideas of Pina et al. [66] described as "family informatics." With a focus on families composed of children and parents living together, their study highlighted how health management is collaborative and interconnected between each family member and how families approach tracking differently when coping with a chronic health condition [66]. Children can participate in tracking and collaborating with parents towards goals (e.g., [13, 58, 80]). When family members are all engaged, families are more likely to gain and maintain healthy behavior practices [32, 66].

Some family informatics research has sought ways to support co-regulation for healthy behaviors by supporting planning and or monitoring of behaviors alongside children, some specific to those with cognitive differences. Most relevant to our study, the MOBERO mobile system [94] supported children with ADHD and their parents in structuring morning and bedtime routines alongside the use of tokens and rewards. The Plan & Play [36] system implements a goal-oriented strategy to help parents and their young children co-regulate media engagement by creating plans for limiting and structuring play time on a tablet. Other studies, such as Spaceship Launch [81], StoryMap [78] and Snack Buddy [84] have focused on co-regulating for promoting specific activities, such as physical activity and healthy eating. Systems like GeniAuti [40] and Walden Monitor [35] supported regulation across different contexts by documenting a specialist's or caregiver's observation of children's behavior for later therapy interventions.

Research in family informatics has leveraged dashboards as a way to promote joint reflection through shared visualizations [65, 79, 81, 84]. Systems like Dreamcatcher [65] and Spaceship launch [81] make use of a shared interface for both parents and children to see each other's data (e.g., sleep and physical activity) to become more aware of each other's behaviors and health. Previous work has suggested that such moments of togetherness can be beneficial for learning, joint reflection of behaviors, and deciding on next actions to improve the family's health [20, 61]. However, these systems typically require joint use and can have limited support for when family members are not physically together.

Taken together, these studies indicate that technology can benefit parent-child co-regulation by supporting goal setting, monitoring triggers and setting events related to specific behaviors, and tracking progress of self-regulation in specific domains and activities. By focusing on regulating during specific moments or activities, studies of these systems limit our understanding of how technology can and should support co-regulation during everyday life circumstances. Further, children have largely not been involved in the application of such monitoring, limiting understanding of its utility towards co-regulation. We, therefore, need greater understanding of how families experience technology which supports co-regulation more flexibly for multiple goals and across different contexts.

2.3 Smartwatches for Self-Tracking and Wellbeing

Research has frequently examined smartwatches as a platform for implementing health and wellbeing interventions [29], with commercial features for sleep and physical activity tracking being particularly commonplace. Smartwatches have also been used for monitoring behaviors (e.g., scratching, eating) [72] and recently acknowledged as a potential mediator for regulation [18]. Much of the smartwatch's potential lies in its convenient and always available nature [15, 67] that might benefit children's rapid shifting contexts (e.g., from home to school, outdoors). For children with self-regulation challenges, the smartwatch's body-mounted nature might be less demanding of care and harder to lose than a phone.

In family informatics, wrist-worn devices have more often been used as a means to capture data (e.g., physical activity and sleep) (e.g., [51, 65, 80]) rather than a space for design, intervention, and reflection. Parents are often the drivers of smartwatch adoption by children in expectation that it will help instill a healthy lifestyle [61, 62]. However, most smartwatches used in research are still dependable on a parent's phone [67, 85] and Oygür et al. [61] have highlighted how this linkage can add invisible work for parents, such as for configuration and maintenance, which can undermine their original goal of facilitating parenting. Smartwatches also have limited battery life [72], which can require further regulation for maintenance or increased parental involvement.

Smartwatches have the potential to support self-monitoring and delivery of interventions by leveraging their sensors and their always available nature. They can also support in-the-moment reflection through glanceable visualizations [9, 31]. We built CoolTaco to leverage the smartwatch's portability, pervasiveness, and glanceability to facilitate access to daily goals, tracking progress of efforts, and expectations of rewards when achieving goals.

3 COOLTACO DESIGN

CoolTaco is a multi-device system for parents and children to use that comprises two apps, one for iPhone and one for Apple Watch. CoolTaco introduces novel design strategies for leveraging wearables for children to co-regulate asynchronously alongside their parents. CoolTaco is a phase in the larger CoolCraig project [3, 17, 92], a multidisciplinary effort to investigate technology support for ADHD children. The design of CoolTaco is based on the token economy behavior intervention [39, 47] and Cibrian et al.'s [17] co-design of smartwatches with ADHD children. In this section, we give an overview of the process which informed the design of CoolTaco, and detail CoolTaco's main features of supporting parents' and children's cooperation for regulation.

3.1 Design Foundation and Process

Our design is informed by Cibrian et al.'s [17] co-design research with ADHD children (N=24) and their caregivers (N=9 staff, N=4 parents). This prior work surfaced opportunities for smartwatches to support self-regulation by scaffolding consistent contact with tasks and rewards. The co-design work surfaced three categories of activities useful for planning and tracking via smartwatches: social, health, and school. Regarding the planning of activities, Cibrian et al.'s findings [17] indicated the interests of both children and parents in setting goals and monitoring progress. Figure 1a-c shows some of the sketches that informed the design of CoolTaco.

Informed by these design requirements and sketches, we considered multiple design directions through storyboarding [105]. For example, three sets of storyboards described the design idea of creating daily goals (e.g., Figure 1d) and receiving points for achieving them (e.g., Figure 1e). Other storyboards described mood tracking and dealing with stress (e.g., coaching, breathing exercise) via a smartwatch. We used these storyboards in a fun-sorter survey [71] with 24 children with ADHD about how much they liked them and thought them pretty, easy, and fun (more details in [102]). These design phases led us to identify four design objectives, which we included in CoolTaco: (1) include a *goal-reward dynamic* to enable positive reinforcement, (2) allow for *goal and reward flexibility* (i.e., not tied to a specific domain or setting), (3) enable *joint involvement of parents and children*, and (4) allow for *asynchronous collaboration* versus requiring family members be co-located. We describe below how these design objectives were achieved in CoolTaco.

Finally, before our study deployment, we piloted CoolTaco with 2 children and their parents for 2 weeks. These participants generally understood the flow of the smartphone and watch apps, but surfaced some bugs (e.g., database errors) and a need for clearer feedback for user actions (e.g., confirmation or error messages, indicator for synchronizing) that were then corrected prior to deployment. Pilot participants did not participate in the rest of the study.

The final version of CoolTaco implements a token economy for the *goal-reward strategy*, a well-established evidenced-based approach built on positive reinforcement [39, 47]. Token economies are purposely customizable and based on principles of collaboration for positively reinforcing behavior by awarding tokens in response to targeted actions. This method is commonly implemented in schools (e.g., handing out stickers or "school dollars" to be redeemed for rewards) [46, 59, 88] and has particular therapeutic effectiveness for some neurodivergent children [47, 86, 101]. Self-monitoring is a known strategy to foster self-regulation with ADHD children [73], thus combining positive reinforcement alongside tracking of progress has the potential to benefit regulation. Token-reward systems stimulate children's thinking about future consequences of their efforts, such as completing activities to accumulate points in expectations of future rewards (i.e., delaying gratification). Ideally, such artificial token economies created as part of behavioral interventions would eventually fade, being replaced by internal rewards or natural consequences [45] in ways that are ethical, empowering, and developmentally appropriate as children grow.

(a) Example of a social goal. **(b) Tracking goal completion.** **(c) Desire for rewards.** **(d) Storyboard sketch of available tasks.** **(e) Storyboard sketch of points being awarded.**

Figure 1: The design of CoolTaco is inspired by findings from Cibrian et al.'s co-design study [17] (sketches shared here with permission). Children ideated that the watch could show (a) goals for the day (b) tracking of goal completion, (c) and possible desired rewards. We also used storyboarding (d & e) as part of our design process for CoolTaco.

3.2 CoolTaco for Parents

In seeking to support *joint involvement* for parent's co-regulation role, we designed CoolTaco on the phone to enable positive reinforcement and motivational incentives through *flexible goals and rewards* (Figure 2). CoolTaco allows parents to manage activities (Figure 2a). Parents can flexibly create any activity by describing a name and choosing a category between wellness, school, social, and general (categories identified by children in Cibrian et al.'s [17] study). Parents also determine if the activity is a one time event, weekly, or daily (Figure 2b). Activities have a point value that ranges between 1 and 10; and a regularity, such as one time event, weekly, daily, or specific days of the week. Activities can later be modified or deleted. Once the child reports through the watch app that an activity has been done, it will appear in the "To be approved" screen (Figure 2c). This can happen *asynchronously*, without family members needing to be co-located. Parents then have the option to approve the completion report and award the point(s). Points can be earned each time the activity is completed.

The system allows parents to *flexibly create rewards* as motivational targets, with any description and between 1 and 10 point cost (Figure 2d). Rewards can be edited or removed (Figure 2e-top). When a child chooses to spend their available points to redeem a reward, these requests appear in the "Redeem" screen of the phone app, where parents can approve or decline the request (Figure 2e-bottom). Finally, parents can see a summary of the day's activities and their state alongside the child's point balance (Figure 2f).

3.3 CoolTaco for Children

In addition to involving parents in the technological care ecosystem [97], children play an active role in *jointly* managing CoolTaco, following advice from prior work [18, 42, 96, 97]. CoolTaco offers similar features for children to those of their parents, via a smartwatch app (Figure 3a). Parents and children can use CoolTaco *asynchronously for collaboration*, and data in the system is replicated between the phone and smartwatch apps. The "To Do" screen lists all activities available for the day (e.g., Figure 3b), and activities can be marked as complete (e.g., Figure 3c) and viewed later (Figure 3d). The Rewards screen displays the current point balance (Figure 3e) and available rewards which can be redeemed (e.g., Figure 3f, 3g). Finally, the child can add new activities themselves by selecting a category and description (Figure 3h) via voice-to-text, drawing each letter, or using emojis.

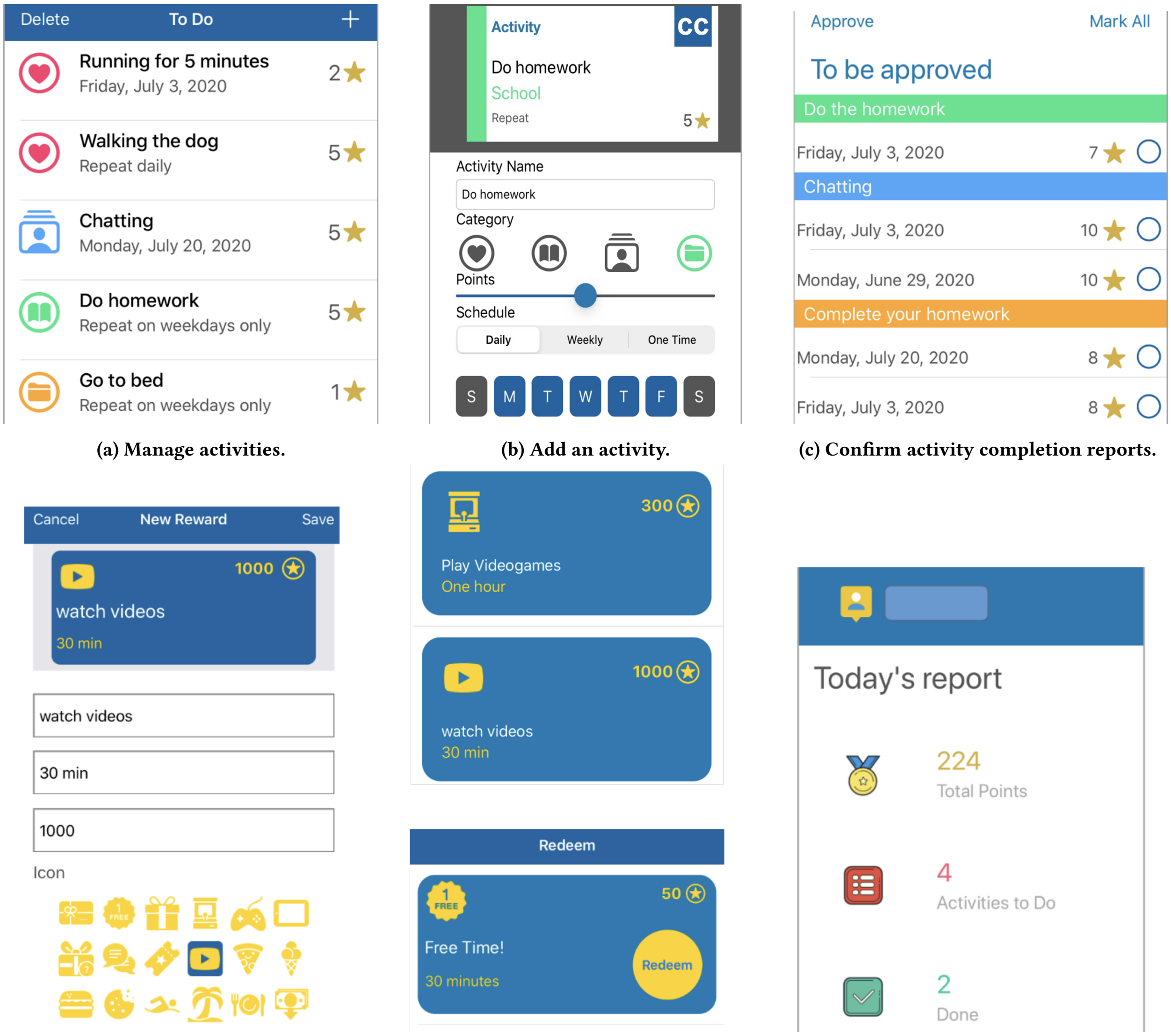
To offer children agency to *asynchronously collaborate* in the process, we enable them to create their own activities through the smartwatch. We opted for child-created activities to value zero points out of an abundance of caution to limit potential deleterious effects on the positive reinforcement related to "gaming the system." Long-term, there is interest in better exploring how child-generated goals could be used to even further engage and empower children in their own progress. Likewise, we did not enable rewards to be created by children. Therefore, child-created activities take the form of goals for the child's intrinsic motivation and the opportunity to internalize the reinforcements [76]. Aware of this design tension, we incorporated inquiries in our interviews with children and parents and report it in our findings. We also opted to not enable notifications on the smartwatch app. This decision recognizes the potential risk of notifications disrupting children with ADHD and exacerbating their attention challenges [17].

4 METHODS

We conducted a field deployment study to understand family's perspectives and uses of the novel smartwatch mediated co-regulation in their everyday setting, which is an effective methodological technique for eliciting feedback on a new kind of technology and providing new insights about how people's lives were impacted by its presence [75]. Our remote deployment study took place in the US for a minimum of three weeks (average 12 weeks, SD=4) with ten families with staggered enrollment during the COVID-19 pandemic. Our research was approved by our university's Institutional Review Board. In this section, we detail our study's recruitment and participants, procedures, data analysis, and limitations.

4.1 Participants

10 Children and 17 parents from 10 families participated in our deployment study between October 2020 and January 2022. To enroll in the study, parents consented by signing a form and children consented verbally. We were careful to be clear that both children or parents could decide to opt out of participating at any time. We recruited in collaboration with a local school that specializes in education for children with ADHD, but were severely impacted



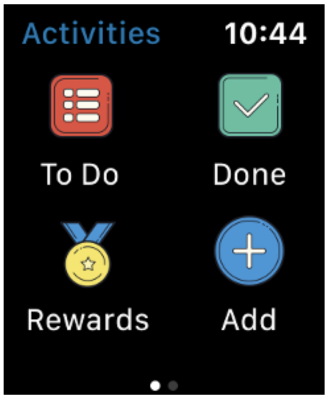
(a) Manage activities. (b) Add an activity. (c) Confirm activity completion reports.

(d) Create a new reward. (e) Manage rewards (top) and approve redeem request (bottom) (f) Daily report.

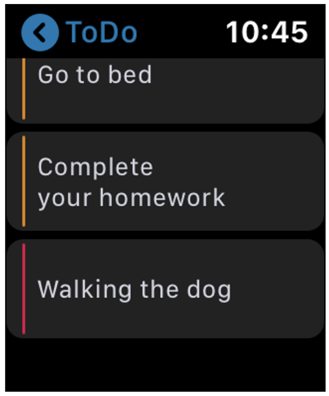
Figure 2: CoolTaco on phone enables parents to (a) manage activities, (b) specify activity details, (c) approve or deny a child's report of activities being completed, (d) add rewards, (e) manage rewards, and (f) view summary of a day's available and completed activities.

by health mandates for social distancing related to COVID-19 [92]. Parents became even more burdened with new routines of managing their remote work and their children's education. Consequently, many families that once consented to participate in our study opted to delay or cancel their involvement, including three families that had already consented and received loaned devices but later decided to opt out. Therefore, we expanded our recruitment efforts by word of mouth between friends of participants and clients of local behavioral clinics, and more flexibility in the child's age range. We initially aimed to recruit children between 10 and 15, but expanded to include those between 8 and 15. Despite these challenges, members of 10 families fully completed participation in our study deployment. Table 1 details participating families.

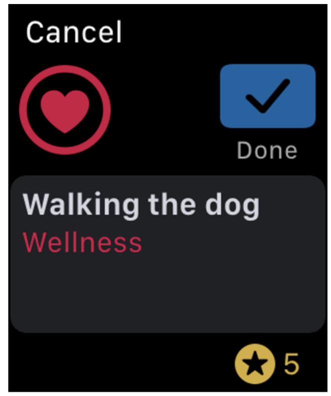
We enrolled 9 boys, 1 girl, and no one who identified as any other gender. This gender distribution aligns with the diagnostic ratio for ADHD [55, 108] and the student population in the collaborating school. The children were between the ages of 8 and 15 (mean age=10.8). Three families consisted of a single-parent household (F5, F8, F09), seven had mother and father caregivers, and four had non-participant sibling(s) (F02, F03, F06, F07).



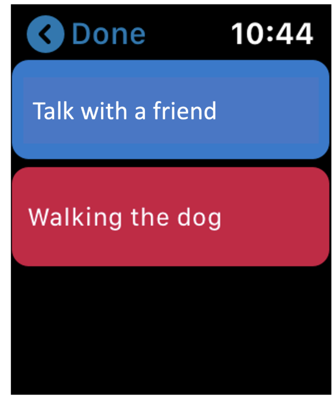
(a) Initial screen.



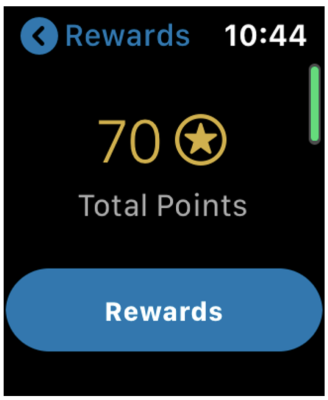
(b) Viewing activities.



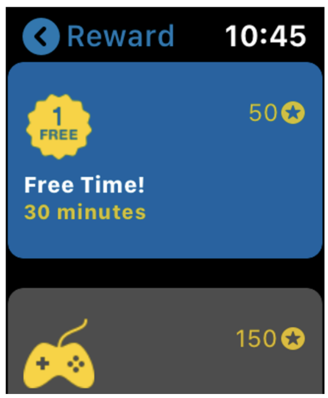
(c) Completing an activity.



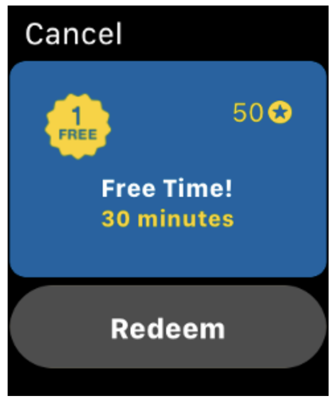
(d) Reviewing the day's finished activities.



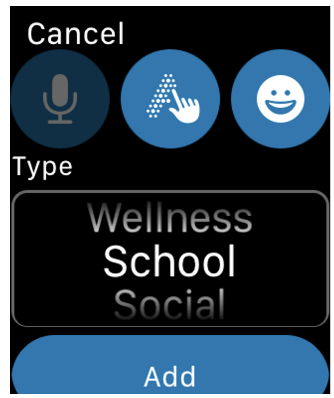
(e) Viewing point balance.



(f) Viewing available rewards.



(g) Spending points for a reward.



(h) Adding a new activity.

Figure 3: CoolTaco on Apple Watch had features analogous to the phone, and allowed children to (a) navigate between available activities for the day; (b) view and select an activity; (c) mark an activity as "done"; (d) view the day's activities already marked as completed; (e) view balance of points acquired and not spent; (f) view rewards; (g) use points to request a reward and (h) create their own activities without a point value.

All children presented ADHD symptoms according to parent reports. We additionally asked participants to complete two validated assessment tools: The Strengths and Weaknesses of ADHD symptoms and Normal-behaviors (SWAN; [99]) and the Behavior Assessment System for Children - Third Edition (BASC-3; [82]). The SWAN scale classifies the behavior dimensions of Attention and Hyperactivity/Impulsivity in a range of +3 (far below average) to -3 (far above average) and the BASC-3 classifies 12 behavior dimensions as average (41-59), at-risk (60-69) and clinically significant (above 70). The SWAN assessment indicated above average attention difficulties in 8 children (mean 1.69; SD=0.83) and hyperactivity/impulsivity in 5 children (mean 0.86; SD=0.65). On the BASC-3, 9 of 10 children scored at-risk (5) or clinically significant (4) for attention (mean 66.9; SD=6.51), and 7 out of 10 as at-risk (4) or clinically significant (3) for hyperactivity (mean 66.2; SD=8.91). A table with scores in other BASC-3 and SWAN dimensions is available in the supplementary material.

Three families (F01, F03, F06) concurrently used an analog token economy (e.g., jewel or coin token in a jar, points and rewards on a whiteboard) and three other families (F02, F05, and F08) had previously used one. Participating families received $100 and were offered the option of keeping or returning loaned phone and smartwatch devices after study procedures were concluded [92]. Throughout the rest of this paper, we use F# to refer to a specific family, C# to reference a participating child, and P# to reference a parent.

4.2 Study Procedures

CoolTaco runs on iPhone 8 and Apple Watch series 5. We also offered textile-type wristbands alongside the watch in response to some children's sensory sensitivity [30]. We originally planned to onboard participants in group workshops at the school to configure parents' phones alongside loaned Apple Watches and to give general instruction on study goals, participation, and app use. Due to the pandemic and social distance guidelines, we had to change plans and opted to deliver and loan pre-configured phones and watches to participants' porches [92]. We also included instruction manuals to the delivery package (see supplementary material).

Table 1: Participating families and summary of CoolTaco use

Family ID	Child's Gender, Age	Caregiver Participants	Activities Planned	Completed Activities	Rewards Available | Redeemed	Days with at Least one Activity Completion	Days Between First and Last Completed activity
1	M, 10	Mother, Father	8	39	2 | 0	15	41
2	M, 11	Mother, Father	32	153	5 | 2	12	107
3	F, 10	Mother, Father	29	203	10 | 2	37	93
4	M, 10	Mother, Father	3	0	2 | 0	0	0
5	M, 9	Father	6	13	1 | 0	6	13
6	M, 8	Mother, Father	6	19	4 | 0	12	62
7	M, 9	Mother, Father	24	321	5 | 21	48	235
8	M, 15	Mother	5	11	3 | 0	6	96
9	M, 15	Father	4	1	0	1	1
10	M, 11	Mother, Father	30	458	7 | 49	87	206

We offered 30-minute onboarding instruction over video calls. Families were not required to set up any particular number of activities, but the manual suggested 3-5 per day, that parents should monitor completion reports regularly, and reflect on the balance of activity's point value and reward's "costs." We pre-registered one activity ("wash your hands") as an example with a 1 point value, and pre-registered a 1000-point "surprise" reward as an example. Three families adopted this reward and others deleted it.

Participating families were asked to use CoolTaco for 3 weeks before being remotely interviewed. Families were allowed to keep using the system even after the final interview, averaging 12.2 weeks of usage (SD=28.3 days; min=6; max=87 days). While some families (F04, F09) engaged minimally with the system, others used it often and continued for much longer than requested (e.g., F10, F07), as detailed in Table 1. For example, F07 has continued to use the system a year after onboarding in the study. The final interview had two main phases. We first focused on talking with the child, with the parent present to act as a mediator to help maintain the video conferencing infrastructure and the child's attention. This phase lasted 20-30 minutes and aimed to understand the child's perspective on the smartwatch's affordances, their experiences with CoolTaco, their experiences with self and co-regulation, and desires or suggestions for an ideal version of CoolTaco. For the second phase, we interviewed only the parent(s). Like with the child, this phase was aimed at understanding the parent's perspective and experiences around the use of CoolTaco, supporting co-regulation with their child, potential and shortcomings of the smartwatch, and suggestions for future designs of CoolTaco. During this phase parents also clarified or complemented the interview with the child. For example, P01 sometimes helped *"fill in the gaps regarding [C01]'s questions. Obviously, part of it is that he's shy"* (P01). At least two researchers were present during interviews, with one leading and the other being in a supporting role and taking observational memos.

4.3 Data Analysis

Interview recordings were automatically transcribed by the video conferencing tool and later reviewed and corrected by one member of the research team. Our qualitative analysis of interviews followed reflexive thematic analysis [11, 12]. Our analysis approach was primarily inductive and conducted through several iterations to roughly follow Braun & Clarke's six phases: familiarization, coding, generating initial themes, reviewing themes, defining and naming themes, and writing up. First, five researchers read interview observational notes and inductively separated excerpts they deemed representative of participants' reported experiences. The researchers then met virtually and used Miro[3], an online digital whiteboard tool, to discuss interviews and conduct affinity diagramming with the excerpts. The outcome of this iteration was a group of topics that became codes in an initial codebook. The same researchers then used the initial codebook to independently code one full interview transcript. The research team met weekly to discuss and review the codebook, eventually agreeing upon a final codebook. The final codebook consisted of 11 parent codes and 42 sub-codes. For example, the parent code "strengths of CoolTaco" had "supporting regulation," "role modeling," "negotiations," "checking task completion," and more. The final version of the codebook was then used to code all ten interview transcripts. We used coded data and the codebook to inform the thematic mapping [11] of CoolTaco's impact on children's self and co-regulation, the perspectives of parents and children about the system design, smartwatch mediation, and desires for future technology design. Themes were further refined during the writing process of this paper to highlight the potential and shortcomings of technology intervention for cooperative care for ADHD children and the families' *in-situ* experiences.

In addition to the interview analysis, two researchers analyzed children's and parents' registered activities and rewards, following a semantic and latent approach [11, 12]. The two researchers jointly reviewed each activity and reward registered in the logs to discuss the underlying meanings and intentions for their creation. Although the system provided four categories of activities to the users (i.e., wellness, school, social, and general; Figure 1a), we identified additional nuances in how activities were described, coding them as chores, educational, desired behaviors, exercise, or routine. Likewise, rewards were coded as familial or individual, and either material, event, or screen-based.

[3]https://miro.com/

4.4 Limitations

Circumstances surrounding the COVID-19 pandemic deeply impacted onboarding of participants and data collection procedures. In particular, it became challenging to meet parents to install CoolTaco on their own phone due to social distancing requirements. This led us to lend a separate phone to families with the app already installed as a workaround. The requirement of using CoolTaco on a phone not truly personal might have impacted the regularity of parent's engagement with our system, as it is less convenient than using their own phones (e.g., in-between opening their other apps).

The pandemic also impacted our recruitment [92], with us needing to broaden our original age range target. Involving neurodivergent children is a known challenge in the field due to recruitment challenges and it is "generally acceptable to have 5-10" participants with a disability [44]. We sought to mitigate this limitation by involving the caregivers and for an extended period. Our participant cohort, therefore, offered breadth of experiences, and we would not have observed some system and family dynamics had we only enrolled older children. For example, the broad pool enabled observing how families managed ADHD differently, particularly around expectations for independence. Future work could add further understanding on use and perspectives of a particular age group.

We acknowledge that our findings might not represent perspectives of dissimilar family dynamics and household makeups. Participants were typically middle and upper-middle-class and with likely access to educational, material, and behavior therapy resources. Families with lower socioeconomic status can have different perspectives on smartwatch-driven behavior support. For example, Saksono et al., [80] have identified that concerns and neighborhood safety can limit efficacy of physical activity trackers and efforts for healthy behaviors, which may extend to other smartwatch-based well-being interventions. It is also likely that cultural backgrounds influence perspectives and attitudes for co-regulation and preferences and practices in adopting smartwatches-mediated support. For example, research has indicated that emotion co-regulation is affected by different socialization practices among cultural groups, and parents and children who react, discuss, and express emotions more may lead to more social and regulation competence [70].

5 FINDINGS

Overall, most participants used CoolTaco extensively, even if not every day. Participants varied greatly in the number of days they used CoolTaco (Table 1). Families that engaged with CoolTaco averaged 27 days of actively completing activities in the system (SD=28.3; min=6; max=87 days). Families averaged 106 days between the first and last completed activities (SD=77.2; min=13; max=235 days). Most families reported benefits from using CoolTaco and described seeing the potential of smartwatch meditation to help with the self and co-regulation of children with ADHD.

Participants created a total of 39 rewards and 147 planned activities, out of which 92 were recurring activities and 55 were one-time activities. Parents created 93 of the activities (mean=9.3 per family), and 6 children (C04, C10, C09, C03, C07) created activities themselves (54 activities; mean=9). Parent-created activities averaged 4.4 points (SD=2.7). C04 did not complete any activity using the app, and C09 completed one. The other children averaged 152 reports of activity completions (SD=166.7; min=11; max=458), combining for a total of 1218 reports. Nonetheless, 224 of these have not yet been approved by parents, indicating some disagreement about their completion or parents forgetting to approve them. As for rewards, parents other than P09 combined for 39 rewards, averaging 4.3 rewards per family (SD=2.8; min=1; max=10). Rewards cost an average of 249 points (SD=325.9; min=10; max=1050). Surprisingly, most children (N=6) did not redeem any rewards using the CoolTaco, with C07 and C10 redeeming rewards routinely (21, 49), and C02 and C03 redeeming only two each.

CoolTaco was perceived as providing useful asynchronous co-regulation support, with children having a persistent reminder for daily goals via the smartwatch component. This empowered children to take on some of the co-regulation work themselves and be more actively involved. Conversely, families faced challenges using the system due to a high technical and social dependency on parents' attitudes and actions, labor and expectations for documenting lived experiences in the system, and integrating with analog token economy systems some already had in place.

5.1 Benefits of Co-Regulation Via a Smartwatch

CoolTaco's use of open-ended activities allowed families to use multiple strategies to structure daily habits and responsibilities for self-regulation with the smartwatch. Both children and parents used activities to organize children's self-care and contributions to the family environment by setting goals for daily functioning (e.g., chores, routine tasks) and expectations of desired positive behaviors (e.g., healthy habits, positive social interactions). Activities like *"Hug mom"* (C10), *"Tantrum free day"* (P07), *"Followed directions from adult on the 1st time"* (P02), and *"Show getting along"* (P01) emphasize the desired behaviors that promote well-being and need not be constrained to a specific time. Similarly, routine and physical exercise activities reflected desires for a healthy way of life (e.g., *"Practice Soccer for 20 minutes"*, P02) and necessary habits (e.g., *"Hygiene- shower by 8:30pm"*, P08). Parents generally used these strategies to *"teach them responsibility"* (P08) and life skills. Overall, activities highlight desired goals for regulating good behaviors and healthy routines for children's shifting contexts and independence of parental presence (Table 2).

Most families (N=8), described the smartwatch component of CoolTaco as useful to expand co-regulation to moments which children and parents were apart. Families reported several ways that the smartwatch was beneficial: as a persistent reminder and co-regulation support while children moved across multiple contexts, enabling children to keep track of daily goals for themselves, and taking on some of the *"blame"* of enforcing parenting rules.

5.1.1 The Smartwatch Went with the Child, Enabling Persistent Reminder for Goals and Support in Different Contexts. With CoolTaco, the smartwatch helped assist parents in co-regulation by supporting children in becoming more independently organized. Several participants (N=06; F01, F02, F03, F06, F07, F10) reported that the persistently-available list of activities helped the smartwatch serve as a pervasive reminder. They also reported that being able to acquire points and *"watch all my stars just grow and see how much I get"* (C10) at any time through the smartwatch component of CoolTaco motivated executing planned activities. For example, C03 said she

Table 2: Examples of activities created by parents and children, organized by our inductive categorization.

Category of activity	Example: Parent	Example: Child	Total #
Desired Social Behavior	"Act of kindness to Daddy" (P07)	"Be Accepting." (C07)	37
Educational	"Homework 2pm" (P05)	"Do math" (C02)	31
Chores	"Feed cat's dinner" (P01)	"Walk Finley" (C10)	23
Unclear	-	"Poop Face" (C07), "Q" (C02)	21
Routine	"Brush Teeth (morning)" (P06)	"Take bedtime pill" (C10)	22
Exercise	"10 Squats /10 Push-ups /10 sit-ups" (P08)	"Ride New BiKe" (C03); "🛴" (C10)	13
Total #	93	54	147

liked *"the ability for you to add a task so that you can remind yourself to do things that you want to do,"* and her mother agreed, saying that the list of activities was useful *"to be a reminder for her [C03] to do it"* alongside the star points for reinforcement. Similarly, C02 said that CoolTaco *"it kinda reminded me"*, with P02 complimenting that *"having that reminder on him is helpful."*

Families often wished the smartwatch component of CoolTaco contained additional self-monitoring or reminder functionality to support the children. Some parents thought that activity notifications could offer additional support for timely reminders. For example, P01 said that *"an advantage would be to set the alarm system so there's a prompt"*. Similarly, P05 pondered:

> P05: *"The main addition I would make is, if you could build in reminder times, [for example,] if it has something that said at seven in the morning: 'take medicine' or 'you're supposed to be doing your chores' at three o'clock, and a little alarm went off on the watch to remind them. I think that would probably be the best addition."*

Ultimately, the smartwatch combined with positive reinforcement strategies was seen as a useful pervasive intermediary for children to benefit from co-regulation efforts with less need of parental presence and their active nudging of reminding each goal.

Some participants described that the smartwatch going with the child helped lower the burden of tracking activities in CoolTaco, enabling co-regulation across a range of different contexts than if it had to occur with the parent present. For example, children were still receiving co-regulation *"in the other room"* (P05), and while *"outdoors playing"* (C03), and parents valued *"being able to remotely set up certain goals and prizes that would then sync up with something that's on his [C06] wrist"* (P06). Support could also be across bigger shifts in contexts, such as for longer stays in a different home. For example, C08's parents were divorced, and P08 mentioned that CoolTaco could help with co-regulation even with separate households. P08 contrasted the digital and pervasiveness of the smartwatch could be an advantage over their previous analog token system:

> P08: *"[My previous system] was manual, and you have to be always on top of stuff and noticing things. And especially [when] C08 is with his dad, it was hard to manage something in both households that was manual like that. CoolTaco seems to be the easiest to manage and setup and to keep track of."*

Likewise, F02 had similarly compared with their previous system that used coins: *"It's hard to keep track of that coin token, I always had some in my pocket [...], but it requires you to be a very hands-on present parent."* Some families also prepared different activities for different contexts. For example, F03 explained how they planned specific activities for when C03 went to a sleepover at the grandparents' house, with some input from the grandmother:

> P03: *"We changed CoolTaco to be specific for grandmother's house. I called grandma to ask what sort of things [C03] would want to help with around the house or what kind of tasks. Normally it was walking and training 'Blue', that's our dog, so we changed it to walking grandparent's dog."*

Families appreciated preparing activities in advance for children to leverage the smartwatch and execute on their own later (e.g., *"take medicine 7am"*, P05), or to track on their own (e.g., *"20 minutes reading"*, P03; *"Close all three [Apple Watch] rings"*, P02).

Overall, families enjoyed how the smartwatch was easily integrated with everyday life shifts of contexts, from big changes in location (like houses) to nuanced movements in the home, such as being in separate rooms from the parents or while they are at work.

5.1.2 Enabling Children to Take on Some of the Co-Regulation Work. Alongside serving as a persistent reminder, the smartwatch enabled children to take on some of the responsibilities associated with co-regulation. For example, the children frequently used the smartwatch to assess their progress and pending goals. C10 appreciated that he could *"check off tasks [...][the CoolTaco app] it helps me get my work done"* even when his parents are *"at work"* (P10). C10's parents added that he *"has challenges with executive functioning, having difficulty structuring tasks, being organized,"* but CoolTaco helped because *"he pays so much attention to getting the points, that the list becomes routine, and the routine becomes habit."* (P10). C02 similarly mentioned that he *"wanted to get a lot of points."*, with P02 adding that *"he was very motivated to check off [activity completions]."* Thus, having persistent access helped some children become more empowered to reflect on goals and behaviors on their own.

Some families, particularly those with younger children (N=08), reported that CoolTaco invited their children to be shared owners of the co-regulation process, lowering the burden on the parents. For example, P02 said, *"I like that it transfers the responsibility for me to* *him."* Parents mentioned that much of their previous co-regulation work went into mentally keeping track of activities, observing if children did the activity, or manually maintaining tangible token economy systems (e.g., on a whiteboard or paper, via a jar with coins). The smartwatch helped the children contribute some of this tracking and observation, making them more active participants in co-regulation. For example, P07 said:

> P07: *"In our own [analog token] system I was very inconsistent in keeping track of things and had to just really simplify for myself. I love that the watch is just all on there and on it's him [C07], he requests, I approve [reports]. It's so nice I don't have to have a chart on the wall and I don't have to remember anything. I don't have to remember to mark stuff. It's him being accountable."*

P02 similarly reflected that the smartwatch in CoolTaco helped their child be more responsive to co-regulation. She said that C02 would monitor their own tasks like *"get up in the morning, … brush your teeth, … eating healthy food and snacks, getting along with your family... having [CoolTaco] would help us be able to do all of those things." The family would then review what he did "at the end of the day, sitting down with him even and saying 'oh you did all this stuff you've had a great day today', like, this is good!"*

Families described the smartwatch component of CoolTaco as valuable in involving children to take on some of the work in evaluating pending activities, doing and reporting them, and requesting rewards themselves. In summary, most families perceived the digital and cooperative nature of CoolTaco as easing some of their physical and mental efforts, and increasing the child's involvement, empowerment, and accountability in the co-regulation process.

5.1.3 The Smartwatch Could Become the Focus of Regulation. Parents reported that the smartwatch could take some of the attention for "haggling" and "blame" for a child to reach a desired outcome. For example, several parents (N=4; P01, P06, P07, P10) sought to leverage CoolTaco as an entertainment mediator: *"when he wants to play video games, I say 'okay take a look at your [CoolTaco] app, see if there's anything that you can accomplish to earn screen time"'* (P06). This allowed some offloading of the burdens that often surround family technology use [37] and other kinds of family conflicts.

Thus, offloading moderation to the smartwatch could reduce some family strife. For example, P07 said that *"It just made things go a little bit smoother for us [...] He always used to fight me over taking out the trash. Now he doesn't fight it."* Similarly, P05 had confiscated his son's phone due to undesired behaviors. He then added a reward, *"Earn phone"* (10 points), as an attempt to offload to the system the motivation and mediation to CoolTaco of C05 acquiring it back. This is similar to how previous work has indicated technology mediation can reduce family conflict (e.g., technology moderating behavior instead of parents being the ones saying "no") [36, 37]. However, parents noted that they still need to help their children internalize the smartwatch as a tool to help them become more independent from their parents while still being responsible for their tasks and role within the family. For example, P04 described: *"I think the watch would help him, but we have to teach him too that the watch is a helpful thing. If the watch is asking me to do something, then I should do it, not like 'oh, let me turn it off', you know?"* Ignoring the smartwatch's prompts might ultimately result in returning to a state of heavy parental interaction and oversight, which may not be desirable for parent or child.

5.2 Challenges and Tensions to Co-Regulate with Technology

Despite overall perceived benefits from using CoolTaco, participants encountered difficulties surrounding high technical and social dependency on the parents to drive system use and information veracity, maintaining system data true and consistent with lived experiences, providing positive reinforcement during shared moments or when time-sensitivity was important, and challenges with integrating with tangible systems already in use.

5.2.1 Technical Dependency on Parents for the System to Work. While some aspects of CoolTaco supported children in contributing towards their co-regulation (see Section 5.1.2), other components interfered with their ability to do so. One major tension was that only parent-created activities in CoolTaco would provide points. Our original decision for children's activities not awarding points was based on it possibly undermining the parent's role in positive reinforcement. Consequently, children had mixed perspectives about their self-created activities being useful. Most children acknowledged that self-assigning points could circumvent the role of rewards and parenting support. For example, C03 said, *"You don't want me to give myself 200 points."* Still, others were frustrated with this limitation, such as C10, who understood the reasoning but complained: *"something I don't like about the [CoolTaco] App is when I add the activity it [gives] zero points, not one single point!"* He then suggested that a balanced alternative could be that *"the parent can set the maximum of what points you can add. It would be great to get like 100 points, but there should be, like, a maximum."* Still, C10 created several activities for his self-regulation: *"I added the 'get the mail' because that reminds them [parents] that I love them, and the 'science studies' to enrich my work."* As for the parents, they generally understood these constraints, but some sought to give children more initiative within the system. For example:

> P10: *"There is merit to the discussion of the child coming up with a task, and then we have a discussion saying okay well is that [activity] really one that should be on there, or is it not? And if so, how many points? That whole negotiation process of how many points that should be worth and all of this has led to some interesting discussions."*

P10 appreciated the control over deciding whether and how many points an activity was worth, but decided to collaborate with C10 on tweaking some of them. Family discussions sometimes led to mirroring a child's activities with ones worth points. P03 explained that *"because it was created by her, she couldn't make it worth any points, and so I went and created one [similar activity]."* For example, the "🐠 *water*" (C03) activity became *"Fish water"* (P03) (clean the aquarium) worth 1 point, and *"Language arts"* (C10) was mirrored to be worth 3 points. Overall, despite the constraints on children's self-created activities, it proved useful for some parents and children to jointly reflect on self-regulation necessities and responsibilities, engaging in reflexive analysis stimulated through CoolTaco's iterative use. Still, since *"there's no follow up, other than approving [activities]"* (P06) much of this joint reflection was not directly system driven thereby potentially limiting how much families might stimulate and support child-led engagements and reflection on data together to evaluate goals, progress, and regulation outcomes.

Although remote reporting of activity completion benefited co-regulation and empowered some children, CoolTaco's use brought new labor for parents to maintain consistency and veracity between in-system data and families' lived experiences. Some parents took upon themselves to evaluate whether activities were actually done noting *"it's so easy to click 'yes' without [actually] doing it"* (P04). Further, families often struggled to use CoolTaco when family members disagreed about whether an activity was completed. For example, P06 mentioned that some activities were not in a binary state of done and not done. P06 stated, *"sometimes he does the task but not completely. It [CoolTaco] could maybe [allow to] give part of the points [...] You know, something is worth 10 points and you only get 7, but [CoolTaco] doesn't have an option for that."* In this scenario, children could thus execute a task and receive points for it, but if the result is not up to their parents' expectations, the points are reduced. Filtering between these situations could then introduce further monitoring and evaluation efforts for the parent. For example, P03 mentioned that:

> P03: *"There are times that she [C03] would check off a task as completed, and it would be accidental or she didn't actually do it [...] [and] when I have to approve a list I had to keep trying to remember what she actually didn't get points for."*

These reports indicate a need for higher flexibility in evaluating and rewarding efforts towards completing activities, such as assigning points and allowing feedback for activity completion reports. However, care must be taken not to create complex back-and-forth flows of requests and resubmit between parents and children, which would add significant parental burdens.

Parents also desired flexibility for awarding points for unplanned positive reinforcement. The structured and multi-device flow of CoolTaco led to rewarding planned goals, but was less adequate for regulation mediation during shared moments or to reinforce spontaneous positive behaviors after the act. For example, P05 said *"The only time [CoolTaco] wouldn't be useful is if you had something you wanted to do in a time sensitive manner."* Likewise, P06 mentioned that *"if we're on a car trip or something, you know, and I'm telling him hey I'm going to award you 30 points later, you know that doesn't quite work, he needs to see it like right now."* Sometimes parents thought back about past situations and wished to give points as rewards after the fact, such as after the child displayed a warm social interaction (e.g., *"If I see him [C07] do a random kind of act of kindness"*, P07). Similarly, P02 said that she would like to be able to give *"some extra bonus points, like [for] 'you were kind to your brother', or so."* Parents reported that higher flexibility for assigning points in CoolTaco could be useful to reward children's more autonomous positive behaviors. P03 sought to circumvent this limitation by creating a one-time *"free points"* activity. Overall, families desired more flexibility in the activity-reward workflow so they could adapt positive reinforcement to their different lived experiences beyond depending only on parents' planning beforehand.

In some families, parents had to drive system use to ensure that children were able to receive their rewards. For example, P07 noticed that their child sometimes did not report on their school-related reading, *"but [C07] does read, [C07] just sometimes doesn't put it in [CoolTaco] right, so I said, 'you should probably put it in so you can get your points,' so we do have conversations when I notice things."* Conversely, activity completion reports were also dependent on parent approval and some children reported being upset when their parents did not put in the labor for approvals and point handouts. For example, P06 reported on C06 demanding them to check the system on pending reports: *"I did get chewed out. I got chewed out a couple days ago because he's like 'I did those things [activities] and my points didn't change!' So [I responded] 'Oh, I know, honey, I have to approve them' so yeah." P06 considered that their labor could be decreased if "there was a way to just automatically, you know, give them points you know, like a quick reward."* These practices indicate that CoolTaco, while mediating some co-regulation, also involved a level of effort and tedium that must be balanced with the benefits families receive and should be improved in future designs.

5.2.2 Social Dependency on Parents for the System to Work. Relative to children-driven interventions, closely involving parents in the workflow of CoolTaco resulted in the need to be motivated and involved for system-mediated co-regulation to happen. However, parents had different expectations for how involved they wanted to be in CoolTaco, and families in which parents wanted to engage less benefited less. Older children (age=15; F08, F09), in particular, often had parents who sought to limit their co-regulation efforts as a means of *"pushing"* (P09) their children for more independence. P08 said that her intention was grounded in her desire for C08 to *"not rely on us as much, or on other people."* She explained that C08 is *"almost 16 so he doesn't have too many more years before he is an adult."* P09 took a more radical approach to *"being hands-off on purpose"* and avoided co-regulation through CoolTaco altogether:

> P09: *"As much as possible, I am trying to push him away. I wanted to see to what extent he could adopt it [CoolTaco] as his own thing and use it to his own benefit without being force-fed. I didn't check in on him or constantly remind him to put the watch on. I had accepted that he was responsible to do it. again, [C09] is 15 [years old]."*

C09 perceived himself as fairly regulated in regards to chores and said, *"the [chores] ones I do every day because those are habits, I already formed habits for most of my chores."* Yet, P09 said that C09 has challenges with time management and emotion regulation. P09 pondered that if he was to change his parenting approach to provide more co-regulation, he:

> P09: *"I would certainly invest time and energy to do it. For example, [C09] is in a martial arts class and supposed to be practicing on his own but I could certainly see myself creating a schedule with him so that he works out 5 days a week for 30 minutes. That would help organize things."*

These experiences illustrate how family co-regulation is subject to expectations of independence and parental involvement that establish boundaries of supporting roles in the family. As children grow and are expected to be more responsible, parents might be less inclined to be involved and drive system use. Systems will have to adapt to these types of changes to be successful over the long-term.

Some children might need to be more actively supported by parents and have challenges with independent use of systems like CoolTaco even when parents are more involved. For example, C05 had trouble using the smartwatch independently in addition to difficulties with being motivated by co-regulation, with P05 saying that he needs much effort and involvement to *"make him start. [...] once he gets into it, he'll get it done, schoolwork and everything."* C05 receives both parental and specialist support daily beyond organizational structure and motivational incentives.

In addition, some parents reflected that it was dependent on them to gradually adapt activities and rewards in CoolTaco over time for children's growth. For example, P06 said:

> P06: *"[Activities] needs to be revamped because it's [currently] geared more towards where he [C06] was at last year versus now that I need to add some responsibilities. Because it's great that he can now brush his teeth, but you need to get your clothes, you can now get your own glass of milk. So, I'm gonna add more stuff."*

Parents then had to adapt and create rewards to motivate their children. For example, P10 said *"we need to spend more time on the rewards system to make them more meaningful."* Similarly, P02 said they would routinely ask themselves *"'what can we give him [C02] as a daily award that is not electronic?'"* but *"it became hard to come up with [CoolTaco] rewards that wouldn't be electronics based [because] we had an incident where he 'stole' electronics in the middle of the night, we'd catch him and he just got into a lot of trouble. So he lost all electronics..."* In summary, parents found it burdensome to think through meaningful ways of engaging their children with the system, such as setting motivational rewards.

Some situations further required social coordination among multiple adults, which had limits within CoolTaco. As previously mentioned, C03's sleepover at her grandmother's house prompted adaptation of tasks, but the grandmother was not able to engage with the system herself and needed to do it via P03. In another example, the mother of C07 mentioned a communication breakdown with her husband about requiring points for rewards, and he *"freely"* awarded a trip to *"Chuck E. Cheese,"* an entertainment and food center, without C07 using his points. She concluded that *"my husband and I need to be on the same page."* P05 had a more permanent communication challenge, having limited interaction with his ex-wife after gaining custody of their son, and because *"[C05] is not allowed to bring any of his technology to her house."* These reports highlight the social labor required to coordinate co-regulation beyond what CoolTaco enabled in-system and that depended on the adults.

5.2.3 Not Every Co-Regulation Needs System Mediation and Tracking. Some families' positive reinforcement routines, which previously happened outside of any form of digital mediation, now became routinized by the structured creation of activities, checking them off as completed, and claiming rewards. For some of these situations, families did not always perceive enough benefit to balance the labor of using the CoolTaco system.

Families often questioned whether particular activities or rewards needed to be documented in CoolTaco, such as tasks and rewards that were considered to be normal parts of family daily life. For example, F03 tended to offer screen time as an immediate reward for timely prep in the morning, not needing to enter the task and its completion in CoolTaco: *"So in the morning I wake up and I get ready for the day. I brush my teeth, I put on clothes and all that. Once I'm ready I'll tell mom and she will say I can have screen time."* (C03). Routines like these are reinforcement strategies deeply ingrained in the family's structure and that successfully modeled children's behaviors. Children still needed co-regulation in these situations, but there were no perceived benefits in doing it through the smartwatch mediation nor documenting it for later reflection.

Families also often avoided the labor of documenting reward redemptions, largely underusing the in-system redemption feature in CoolTaco. In practice, parents often pragmatically used activity completions and amount of points as a threshold to evaluate handout of rewards while not necessarily being strict about them documenting point expenditure in the system. For example, P04 said, *"we give him the awards because he's doing it [activities], not because he's really accomplished it."* Similarly, during the interview with F10 and discussing the use of rewards, C10 whispered to P10 about not spending points for their visit to a restaurant the previous day, to which P10 answered *"it's ok, that's on me."* Similarly, P07 explained that they were more *"used to say 'Okay, if you got green [achieving goals] all week' than come Friday, that's when C07 would get something [reward]."* Thus, families were mostly concerned with the system reflecting their lived experiences regarding activities, and used rewards mostly as a *"motivation and a purpose"* (P07) rather than for keeping a detailed record.

Families further had conflicting attitudes about whether to redeem certain in-system rewards because they were seen as more family-oriented than individual. Although most registered rewards were for the child's individual use (N=24) (e.g., a toy, screen time), many were to be enjoyed as a family (N=12) (e.g., family meals, playtime with parents). Rewards were also typically material (e.g., money, food) or events (e.g., *"go bowling"*, F02; *"Manicure by Mom"*, F03). Parents still wanted to encourage these family events and were more lenient with point expenditures or having to document their redemption. For example, P04 explained that establishing rewards was challenging *"because he does get a lot of stuff as a family,like going camping and eating ice cream."* Routinely redeeming individual-level rewards was an exception, and mostly done by C10 and C07 for screen time. Parents also could deem it not worth enforcing some smaller in-system reward redemptions, because children could be *"hesitant to spend points"* (P10) and feel a sense of loss while *"saving up for the most priceless thing"* (C02). Overall, these reports illustrate that the redeeming process could be counterproductive for parents' goals of enjoying the smaller rewards alongside the child (i.e., family time) or children's longer term targets (i.e., higher costing rewards). Consequently, families were flexible with handing out family level awards (e.g., *"dinner with Mom or Dad"*, F03) and less rigorously enforcing redeeming through the system, even if that part of the data became inconsistent with lived experiences.

5.2.4 Integration with Concurrent Physical Token Systems, Which Have other Benefits. When families used existing tangible token systems (N=04; F01, F03, F06), they sought to use CoolTaco concurrently with their established systems due to the perceived benefits of tangible interactions. They saw benefits in using CoolTaco (see Section 5.1), but reported that their tangible systems had the unique benefits of being *"palpable"* (P01) and *"flexible"* (P06), indicating that multimodal interactions should be explored in the future. For P06, the main advantage of the tangible economy system is the ease of reinforcing good behaviors and unpredicted events by *"easily adding [a] handful of jewels"* to the jar. P01 believed that the physical nature of tokens going into a jar was *"more collaborative"*:

> P06: *"It's also the feedback that we have for encouragement, like 'okay good job!' CoolTaco is more for the routine tasks to get that on a regular basis, like brush your teeth, get dressed. That's a little different than how our reward system is. What we have is more for recognition for something positive, spontaneously, or redirecting what happened at the moment."*

P01's report indicates that their analog system could help with emotional co-regulation. Nonetheless, they wished to integrate with CoolTaco to *"keep track of the tokens when we don't have physical tokens"* and vice-versa to *"translate over that more palpable and motivating"* visualization of digitally attained tokens. Both P03 and P01 wished to use CoolTaco to bolster their systems so that *"it might actually remind [the child] to do them [activities]"* (P03) and to *"set the alarm system, so there's a prompt on the watch."* (P01), also indicating expectations for notifications for time-bound goals.

Overall, these reports indicate the potential benefits of integrating tangible and pervasive systems. Co-located and shared visualizations of tracking activities could also benefit shared moments to reflect on behaviors and responsibilities together.

6 DISCUSSION

The results of our deployment of CoolTaco with ten households indicate that smartwatch mediated co-regulation provides benefits to families by being able to structure responsibilities and set expectations of healthy habits without having to be co-located. Most participants saw CoolTaco's use as a way to stimulate children to be responsible and be more involved in the co-regulation process on their own. However, the high dependency on parents' involvement interfered with enabling children's independence, and increased social and technical burdens on the parents for the system to be useful. Participants' experiences also highlight the need for flexible delivery of positive reinforcement and better support for children to increase autonomy gradually. We now discuss (1) tensions families faced to collaborate in a multi-device system to co-regulate, (2) design opportunities for better joint reflection and reassessments, and (3) to foster children's self-regulation with gradual independence.

6.1 Tension Between Fostering Parental Involvement and Independence

The involvement of a smartwatch worn by children helped them to be more active participants in co-regulation, monitoring their activities and points as they went about their days. In designing for asynchronous and pervasive co-regulation, we found that the smartwatch was able to serve as a proxy for parental assistance, while enabling children to be more autonomous and responsible for part of the process. Autonomy is important for children to internalize the extrinsic motivation from positive reinforcement [76], and the smartwatch allowed children to receive guidance from parents while gaining some independence to execute tasks, review goals, and assess progress on their own. CoolTaco's support for autonomy was valued by some families, and those with older children were interested in using the system to foster self-regulation.

However, our results further indicate that the multi-device nature of CoolTaco led parents to experience tension between wanting to foster this sense of independence with wanting to be highly involved in CoolTaco's use to assist with co-regulation. Some parents who were interested in being more highly involved in their family's use of CoolTaco used the system for joint reflection activities typical of family informatics systems [66], discussing how to improve activities, point values, and rewards. These families valued how joint reflection led to discussions about the importance of particular behaviors and negotiations about point amounts or future rewards, and even wished that CoolTaco did more to encourage them to come together. But for families who did want children to be more independent, the design of CoolTaco sometimes hampered children's self-regulation by needing parents to create point-worthy activities or approve completed ones. For these families, the requirement that parents be involved in these decisions made the system a gatekeeper that limited higher levels of autonomy.

Even when desiring to be more involved, parents reported challenges, such as creating effective goals and rewards, and remembering to review reports. While CoolTaco's open-ended nature enabled families to tailor tasks and goals however they wanted, parents were sometimes at a loss on how to co-regulate efficiently (e.g., unsure what activities and rewards to suggest) or could have self-regulation challenges themselves for consistent system use (e.g., forgetting to approve completed goals).

6.1.1 Design recommendations. In light of these tensions, we see the opportunity to tailor or offer different co-regulation systems to accommodate families' varying desires for more or less involvement and control. **Such accommodation could be made possible by allowing families to choose which aspects of co-regulation tasks are completed by the parent, the child, or a mixture of both.** Much like how personal informatics research has indicated benefits in allowing people to adapt systems on what and how to track personal health parameters [4, 41], family informatics for co-regulation could allow families to choose flavors of roles in positive reinforcement each family member can have. For example, such systems could allow children to suggest rewards or create them, request additional points or self-assign them, require parental approvals or be automatic. This could support children's developmental stages, such as shifting to more autonomy focus as children grow. However, designing for changes in roles and levels of control between family members, particularly as families better understand their needs [66], requires further research.

Since parents that wish to be more involved in co-regulation might need more structured guidance on doing so, we envision that systems could provide education and structured suggestions for how to better support their children. For example, systems could give more suggestions on regulation strategies alongside coaching parents about coping with ADHD. Often parents of ADHD children might be struggling with their own self-regulation and be undiagnosed themselves [26]. Therefore, parent coaching could be paired with notifications and be adaptive to enable real-time collaborative suggestions based on parent's or children's contexts as they go about their day (e.g., reminders to check children's daily goals, suggesting parents congratulate or help the child refocus). Future research is also needed on how systems can deliver such parental support concurrently to assist the children without overburdening the family with complex and constant technology dependence.

6.2 Better Supporting Joint Reflection

A challenge for parents who wished to be heavily involved in using CoolTaco was that the multi-device approach required them to consciously and intentionally think about jointly coming together as a family to review and discuss activities, points, and how co-regulation was going. By separating interaction with CoolTaco into separate parent-centric (e.g., phone) and child-centric (e.g., smartwatch) interfaces and interactions, the system tended not to encourage joint use. While separation helped children to be more independent and both stakeholders to participate in co-regulation while apart, it missed out on moments for joint reflection found in other family informatics systems where interaction is largely with a shared device, such as an ambient display on a tablet [65] or a shared conversational voice interface in a public space in the home [63, 69]. A valuable direction for future co-regulation and family informatics systems could be integrating both approaches, with separate devices supporting collection and everyday monitoring with a shared device for joint reflection.

Our findings also highlight that technology can limit the ability to involve multiple and diverse caregivers in coordinating co-regulation. CoolTaco's design supported some parent-child collaboration, but was limited in coordinating efforts from different people in the child's care ecosystems, such as grandparents and parents, and between parents. Communication and coordination between caregivers is important to establish consistent co-regulation support with the child [74]. When there are communication breakdowns and lack of coordinated reflection, caregiving mediated by systems can be hindered and lead to ineffective co-regulation. Since coordination between children's care ecosystem is crucial for technology to better enable them to thrive [97], there is a need for systems to better stimulate shared reflection and integration between stakeholders that are part of the co-regulation.

6.2.1 Design recommendations. Coordinating review of co-regulation data for meaningful understanding and action can be challenging [25, 65, 74]. One specific improvement opportunity is around joint reflection about rewards, as parents mostly leaned on point acquisition for positive reinforcement and gauged out-of-system reward handouts by looking at the point amounts. **Explicit reflection prompts after spending points for rewards might help children make sense of their regulation, expand on the reward from a prize to a deeper understanding of the positive consequences of persistence and delayed gratification.** Similar to how prior work has used reflective questions to stimulate reflection about physical activity [79], co-regulation systems could stimulate reflection by highlighting or summarizing goals that were achieved alongside question prompts about the consequences of regulated behaviors. Such support can potentially help internalize motivations by children's self-efficacy and sense of competence [76]. It can also be a moment to coordinate what activities and rewards should be system mediated versus a family-level effort and reward.

Joint reflection can also be a means of synchronizing efforts and perspectives from multiple caregivers involved in the child's co-regulation. For example, systems could stimulate coordination by supporting increased awareness between stakeholders via notifications of goals completed and rewards requests, activities created, pending report approval, etc. Reminders could also be sent to multiple caregivers to stimulate them to discuss joint collaborative efforts and necessities. Coordinating efforts from caregivers not living together (e.g., some grandparents or divorced parents) could also be supported by asynchronous shared dashboards working on their personal devices. However, our findings indicate several tensions between parent-child dyads, and such tensions can potentially be even more complex as more stakeholders are directly involved. Additionally, technical challenges emerge when involving multiple users, roles, and devices.

Joint reflection for regulation could also benefit from integrating tangible and digital positive reinforcement systems, as families often perceived analog systems as more flexible (e.g., can quickly give jewels/coins after a spontaneous positive behavior) and appreciated their physicality (e.g., a physical jar's volume gradually filling up). Parents also imagined that integration would also benefit them to lower the mental and physical labor of maintaining analog tokens while children moved through different contexts. This physical and digital integration resonates with prior personal informatics work suggesting that digital solutions can be useful to extend analog self-tracking (e.g., pictures of a paper journal) for recordkeeping and to share with others online, while enabling people to still benefit from interacting with physical materials [1, 5, 107]. Some participants similarly reported enjoying the benefits of the physical materiality of palpable tokens as they filled a container to represent progress and goal achievement. Therefore, there is opportunity for co-regulation systems to benefit from digital and asynchronous support via smartwatches alongside the physicality of analog tokens. One potential approach is for digital systems to encourage joint reflection moments at the end of the day, and guide families by giving credit for physical tokens in accordance with activities completed when family members were apart. More advanced approaches could use mechanized devices to add to jars, similar to playful prize/toy vending machines.

Mirroring analog systems, digital co-regulation systems could remove some rigidity by allowing more flexible point and award assignments so families can reinforce positive behaviors under different and less planned out situations that still benefit from co-regulation. Further, the digital binary of activities and goals being "done" or "not done" interfered with the spontaneity of life events, where goals and behaviors have room for interpretation and different ranges of outcomes in face of expectations. Therefore, digital co-regulation systems would benefit from more ways to award points in-the-moment and more flexibly.

6.3 Designing for Children's Gradual Independent Self-Regulation

To support families working towards greater autonomy and independence for their children, digital systems could allow the balance of co-regulation to shift by enabling children to incentivize and reward their self-driven efforts themselves. For technology to enable more independent regulation for ADHD children, it would be helpful for it to serve as a co-regulation partner that substitutes some parental practices [17]. Much has been discussed how systems for improving children's wellbeing might introduce additional parental labor that is counter to its supporting role (e.g., [61]). The design of such a system could largely follow principles of goal-setting technology for independent use, such as including the ability to (1) self-set goals, (2) help track progress and review summary feedback, and (3) stimulate self-reflection and sensemaking for internalizing efforts and assessing their behaviors, possibly alongside self-driven positive reinforcement. Understanding how to tailor these approaches to support children, particularly those with ADHD, is a valuable direction for future research.

Furthermore, as children grow and potentially increase their technology ecosystems (e.g., acquire a phone of their own) there is opportunity to further increase technology mediated support alongside the smartwatch for increased autonomy. While parents are generally concerned with perceived risks on increased technology use for young children [60], particularly with phones [43], our parents were generally comfortable with the smartwatch for younger children given some limitations in the form factor (e.g., limited internet browsing). Still, for our older child participants, use of phone and other devices was less constrained. Contact with multiple devices and modalities of technology interaction is an opportunity for regulation support [16].

6.3.1 Design recommendations. In many families, the move from co-regulation towards self-regulation requires greater scaffolding that technology could assist with. To foster children's gradual independence, parents could be involved in setting parameters for some aspects of self-monitoring, such as setting default limits to point values. Another potential approach is to separate parent and children tokens and rewards, allowing children's tokens to be spent to acquire self-created rewards which are more hedonistic (e.g., digital stickers) while parental rewards are more material (e.g., purchases, family activities). While family involvement can be beneficial in these steps, some of them could be automated, such as automatically approving or acknowledging some goals when using the smartwatch's stopwatch (e.g., "reading for 20 minutes"), or captured through it's sensors (e.g., physical activity goals). Designing effective strategies for balancing desires children might have for digitally reinforcing their own motivation, automation, and family constraints requires further research and understanding.

Future systems could make use of children's growing technology ecosystem, providing them greater abilities to configure and use such systems for gradual independence. Our study indicated that the body-mounted nature of the watch helped with pervasive regulation support, but the more complex system manipulation (e.g., setting recurring activities and configuring rewards) relied on features made available on parent's phones. If systems gradually allow for children to manipulate and configure their own self-reinforcement strategies (e.g., manage their points and rewards), some features and interaction modalities can be added to their phone, tablet, voice assistant, etc., to be used alongside the smartwatch. Thus, systems could evolve from more dependent on parents and their devices, to more independent when children acquire their own. Still, not every family will be able to or will wish to acquire multiple devices or child-specific devices, and care must be taken to still provide gradual independence support for children in families of different economic means or social practices.

There are still open questions about measured efficacy of interventions like CoolTaco towards promoting children's self-regulation. There is a particular need to further investigate how efficacy might be impacted by varying levels of parental involvement. There is opportunity to think about how measured improvement in self-regulation could be incorporated into the function of systems themselves, such as adaptively suggesting or stimulating parental involvement. For example, adaptability could gradually support children's independence as they grow, while allowing additional caregiver help to return when self-regulation via technology is insufficient or otherwise lacking.

7 CONCLUSION

Multi-device family informatics systems can support fostering independence as well as joint reflection. In our study of such a system, families generally leveraged the smartwatch to bolster children in becoming more autonomous, receiving co-regulation support even when parents were not present. However, participants' experiences highlighted how children's autonomy could be diminished by high dependency on parents. As expectations and desires for parental involvement might vary by family and the children's developmental stage, we envision future systems that support selecting what co-regulation tasks are completed by parents, children, or a mix of both. Adaptation as the child grows and develops would allow for additional progress while being developmentally appropriate and respectful towards the ADHD person. Furthermore, there is an opportunity to improve technology for co-regulation in environments of high parental involvement through promoting joint reflection, while supporting those who prefer or need lower parental involvement through system-driven co-regulation support.

ACKNOWLEDGMENTS

We thank our participants for their involvement in the study even during the pandemic. We thank Dr. Stephanie M. Reich for her support and feedback on an earlier version of this paper. We also thank the PIE and STAR labs for This work was supported by AHRQ under award number 1R21HS026058-01A1, and the Jacobs Foundation CERES network. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding organizations.

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