FluidTrack: Investigating Child-Parent Collaborative Tracking for Pediatric Voiding Dysfunction Management

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Abstract

Daytime urinary frequency syndrome (DUFS) is a prevalent pediatric voiding dysfunction. Managing DUFS involves sufficient water intake and monitoring voiding and defecation behaviors, which can be challenging for preschool-aged patients to perform throughout the day for prolonged periods. To address this problem, we created FluidTrack, a semi-automated tracking system enabling child and parents to collaboratively track child's fluid intake, voiding, and defecation, while encouraging adequate water consumption. To examine preschoolers' engagement in behavior tracking with their parents, we conducted a 4-week deployment study with 14 DUFS patients (4–6 years) and their parents as part of DUFS management. The majority of patient participants enthusiastically engaged in semi-automated data capture, driven by their initial interest in FluidTrack. Sustaining the children's enthusiasm and behind-the-scenes parental assistance were critical for continuing semi-automated tracking. Our findings demonstrated the feasibility of children's semi-automated self-tracking in collaboration with their parents, and identified design suggestions for future work.

CCS Concepts

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**; **Empirical studies in collaborative and social computing**.

Keywords

pediatric patients, self-tracking, child-parent collaboration, water intake improvement, wearable device, daytime urinary frequency syndrome (DUFS)

ACM Reference Format:
Junhyung Moon, Sukhyun Lee, Youngchan Kim, Juhee Go, Han Mo Ku, Yeohyun Jung, Seonyeong Hwang, Bongshin Lee, Yong Seung Lee, Hyun-Kyung Lee, Kyoungwoo Lee, and Eun Kyoung Choe. 2025. FluidTrack: Investigating Child-Parent Collaborative Tracking for Pediatric Voiding Dysfunction Management. In *CHI Conference on Human Factors in Computing Systems (CHI '25), April 26–May 01, 2025, Yokohama, Japan.* ACM, New York, NY, USA, 18 pages. https://doi.org/10.1145/3706598.3713878

1 INTRODUCTION

Daytime urinary frequency syndrome (DUFS) is a common voiding dysfunction, typically occurring in children aged 4–10 years [21, 28, 84]. DUFS patients experience frequent voiding, e.g., 15–20 times a day. Per the standard guideline [62], clinicians typically recommend that patients drink enough water and monitor voiding and defecation behaviors for several weeks. However, during this period, DUFS patients and their caregivers lack specific and practical means to aid in following the DUFS management protocol. Given that children aged 2 to 7 years are still developing their memory, understanding, and concentration skills [11, 56, 57], maintaining consistent behaviors like drinking water and self-tracking over prolonged periods can be challenging. As such, their caregivers (typically parents) take the responsibility of managing DUFS. However, many parents work full-time, making it practically infeasible to consistently monitor their children's voiding and defecating behaviors and encourage water intake over extended periods.

In this work, we aim to assist DUFS patients and their caregivers in managing the condition through scaffolding self-tracking. Self-tracking involves data capture and reflection to support personal goals, such as progress monitoring and behavior change. This approach aligns well with the DUFS guidelines, which emphasize

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ACM ISBN 979-8-4007-1394-1/25/04
https://doi.org/10.1145/3706598.3713878

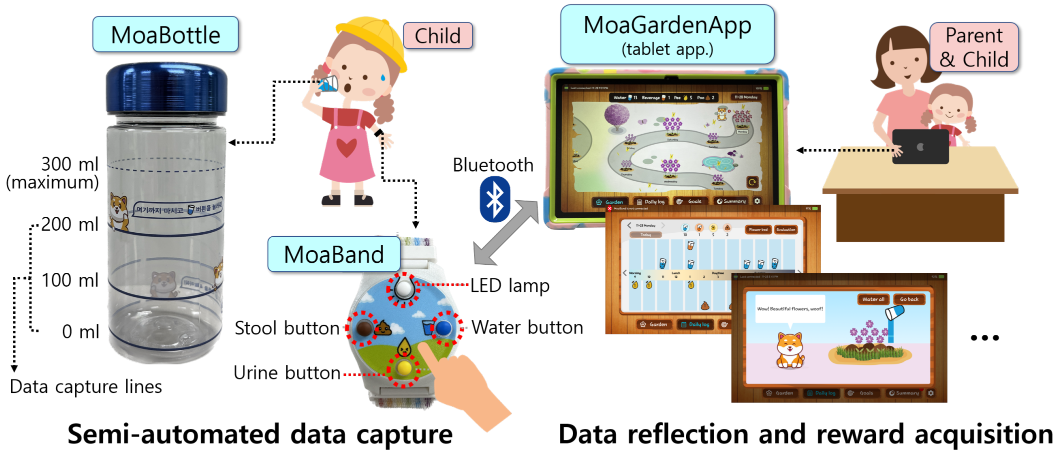


Figure 1: FluidTrack consists of MoaBand, MoaBottle, and MoaGardenApp. A child captures data by pressing the water, urine, and stool buttons on MoaBand, and gets feedback from an LED lamp for the successful button press. The child drinks water using MoaBottle and presses the water button on MoaBand when water level reaches or passes data capture lines printed on the bottle's wall. The captured data is automatically delivered to MoaGardenApp via the Bluetooth communication. The child and parent check the data and obtain flower rewards according to water intake achievements in MoaGardenApp.

monitoring patient's fluid intake, voiding, and defecation behaviors and improving their water intake habits. Given that children are in a critical period of learning and forming various behavioral habits, we aim to leverage the potential of self-tracking in enhancing self-awareness and ownership of their own behaviors [5, 78] with their caregivers' help. Among the typical age range of DUFS patients (4–10 years) spanning preschool and elementary school contexts, we target preschool-age children (4–6 years) who require greater assistance with managing DUFS and data capture, presenting a complex design challenge for introducing self-tracking. Although a few self-tracking technologies have been designed for use in child-caregiver dyads to support collaborative health management [58, 64, 65], they primarily rely on automated sensing. Instead of defaulting to automated solutions, we aim to explore how preschoolers can be involved in self-tracking, considering approaches that range from automated to manual. By meaningfully integrating manual tracking with necessary assistance to create semi-automated tracking systems [16], we can enhance the benefits of self-tracking for preschoolers. Manual self-tracking actively engages users in tracking their behaviors, fostering a sense of agency and promoting self-awareness [2, 6, 17, 39]. However, the potential and feasibility of integrating manual approaches for preschoolers remains underexplored, raising important questions about how to design self-tracking systems that align with their developmental and cognitive capabilities. Key questions include determining the appropriate mode of tracking technology for this age group, identifying the types of data they can reliably collect, and defining the roles caregivers should assume in supporting their children.

As we grapple with these questions, we designed and developed FluidTrack (Figure 1), a collaborative tracking system consisting of three components: (1) MoaBand, a wearable device that enables children to semi-automatically capture their water intake, voiding, and defecation behaviors; (2) MoaBottle, a water bottle to help children measure their water consumption amount; and (3) MoaGardenApp, a companion tablet application of MoaBand, to support the reflection and management of captured data. ("Moa" [moːɑ] is a variation of the Korean term, "moeda" that means "to collect.") The system employs a semi-automated data capture approach [16], requiring the user to press a button to record behavioral data, while the detailed timestamps and data types are automatically captured and transmitted via Bluetooth. The system was developed based on inputs from preschool-aged children, their parents, and a clinician.

Our study focuses on examining (1) the feasibility of preschool-aged children's data capture with FluidTrack system and (2) the dynamics of child-parent collaboration in the overall tracking process when the child is required to engage in the intense data capture. As part of conventional DUFS management, we conducted a 4-week deployment study with 14 DUFS pediatric patients (4–6 years) and their parents, using the FluidTrack system. All child-parent dyads successfully completed 4-week tracking of the child's fluid intake, voiding, and defecation behaviors, albeit with varying levels of engagement. Most children (10 out of 14) actively participated in semi-automated data capture using MoaBand. One child participant (C13), however, chose not to wear the MoaBand; this dyad instead used paper notes and later backfilled the data into the system at once every night. Some children showed reduced engagement over time, such as missing data entries, as their interest in the FluidTrack system waned. Parental assistance complemented the children's engagement in the overall tracking procedure, varying with the children's enthusiasm and the parents' availability. Based on the study results, we demonstrated the feasibility of preschool-aged children's semi-automated data capture —a significant step toward exploring young children's potential for active and manual engagement in self-tracking. We identified child-led, parent-assisted dynamics among our participating dyads, suggesting design improvements for future collaborative tracking systems incorporating complicated health management tasks. We also discovered the potential of FluidTrack in water intake encouragement among preschool-aged children.

The main research contributions of this work are: (1) the design and development of FluidTrack that supports children's fluid intake, voiding, and defecation tracking and their water intake improvement, and a detailed exploration of how we supported the collaborative involvement of pediatric patients and caregivers in the DUFS management process, (2) the demonstration of the feasibility of preschoolers' self-tracking and pediatric patient-caregiver collaboration in DUFS management through a 4-week deployment study with 14 DUFS patients and their families, and (3) the discussion of design implications for designing collaborative tracking systems for preschoolers and their family. Our research lays the groundwork for future designs of self-tracking systems that actively engage children as key participants in their health management.

2 Background and related work

We provide background information on DUFS including existing practices of behavior logging and promoting water intake. We then present a summary of previous works related to water intake intervention, highlighting gaps in the literature. Finally, we explore existing self-tracking approaches in managing children's health, integrating collaborative concepts among family members.

2.1 Behavior Tracking and Water Intake Promotion for DUFS Management

Children with DUFS, affecting about 16% of primary school-aged children [74, 75], experience short voiding intervals (e.g., 5–60 minutes [9, 18]). Frequent voiding interrupts daytime activities and could last for months to years [18]. History taking using a bladder diary is essential for diagnosing DUFS [49], as it provides DUFS-related data including the number of voiding, the degree of urgency, timestamp of defecation, stool shape, and the amount and distribution of fluid intake. Clinicians usually ask parents to record the data in a paper bladder diary for at least 2–3 consecutive days to gather comprehensive information on children's symptoms.

Following a diagnosis, children and their caregivers are advised to manage DUFS at home by ensuring sufficient hydration and monitoring voiding and defecation habits [62]. In general, children over 4 years should drink 1 liter of water daily [24, 50]. However, considering the developing attention spans and memory capacities of children aged 2 to 7 [11], caregivers often take on the responsibility for DUFS management tasks, such as ensuring consistent hydration and supporting self-monitoring. The lack of specific guidance or support for caregivers, combined with the burden this responsibility entails, warrants the development of engaging and age-appropriate interventions.

Our collaborating clinician[1] noted that during the DUFS management stage, healthcare providers often rely on caregivers' verbal self-reports for patient information. However, these self-reports, based on memory, may be less accurate than bladder diary records [71]. Although taking a history using bladder diaries for several weeks can provide clear insight into the patient's condition, this practice is rare due to its high burden [40, 77]. Mobile bladder diary apps (e.g., [44]) may offer a potential alternative, but these apps still place the burdensome task of data logging largely on parents. We propose that a semi-automated self-tracking approach, which balances the workload between patients and caregivers, can address current gaps in monitoring and managing DUFS. This approach specifically addresses the need for detailed tracking of water intake, voiding, and defecation events. Therefore, we explore the design of a self-tracking solution tailored for pediatric patients aged 4-6 years, facilitating collaboration with their caregivers.

[1] One of the authors of this paper, referred to as *the clinician*, is an expert in pediatric urology with over 10 years of experience at a university hospital in South Korea.

2.2 Water Intake Intervention for Children

Statistics [29, 50, 73] show that children across various countries often fall short of recommended water intake levels [24, 50]. In response, health science research has explored various interventions to enhance water consumption among preschool-aged children, including water delivery [26], water station installation [59], education programs [26, 30, 59], and social campaign or forums [26, 30]. While these approaches had varied impacts on children's water intake, ranging from 'significant' [26, 30] to 'limited' [59], they primarily focused on external factors such as water accessibility and information dissemination. Moreover, our survey found no literature specifically addressing inadequate hydration in pediatric DUFS patients.

We posit that addressing internal factors, such as personal engagement and self-awareness, could offer better outcomes. This is where the potential of self-tracking, which can inherently foster these internal factors, comes into play. Self-tracking enables users to collect and reflect on their behavioral data, providing opportunities for behavior improvement [48]. It can not only furnish a continuous and personalized feedback loop for the individuals but also potentially empower them with a sense of control and ownership over their health behaviors [5, 78]. We aim to leverage these potentials of self-tracking to positively influence young children's water intake behaviors.

In HCI research, self-tracking-based interventions have been proposed to promote water intake for adult users (e.g., [34, 37, 47]). SPLASH [47] is a smartphone app that enables users to set goals and track their liquid intake using a NFC-tagged cup. WaterCoaster [37] measures the water consumption with a weight sensor and provides game-like interactions through the accompanying app based on the measured consumption. GROW [34] is a smart bottle that displays aesthetic feedback, a tree image, on its surface according to water consumption. In general, the users responded positively to these systems, demonstrating the potential of self-tracking approaches in promoting water intake. Additionally, several strategies were discussed for further investigations in water intake intervention, including gamification [34, 37], reminders [34, 37, 47], and personalization [34, 47]. However, few studies have explored self-tracking interventions for children's water intake. Adapting tracking and motivational strategies from adults to young children presents a compelling research opportunity, as their developmental and usability needs differ from those of adults. For example, children aged 2 to 7 years may be preliterate and have difficulty grasping abstract concepts [11]. They tend to focus on only one aspect of an object or a single dimension of a problem at a time, limiting their understanding of hierarchies or complex structures [56, 57].

One of the most relevant studies to our work is Shin et al.'s interview study [68], which highlights the need for age-appropriate tracking system designs for children's fluid intake. They conducted semi-structured interviews with pediatric patients aged 5–15 years to explore fluid intake intervention ideas. The study found that children suggested incentives as motivation to drink water, though preferences varied with age. Younger children were satisfied with simple rewards like in-app gardening, while teenagers sought more complex rewards. Based on this finding, the authors noted the need to design intervention technologies tailored to specific age group.

Attending to young children as target users, several gamified features have been integrated into health interventions or accessibility support systems. For example, Cai et al. [12] designed Starrypia, a gamified Augmented Reality-based application for children on the autism spectrum. The app features cartoon characters, interactive activities, and rewards alongside AI-generated music therapy and sensory integration to create an engaging therapeutic experience. Gianotti et al. [27] designed the Associate Game to train hearing-impaired children in auditory perception through an interactive room with sound, light, motion sensors, and rewards (e.g., applause and bubbles). Dotch et al. [22] designed a smartwatch and smartphone app to assist noise-sensitive children in emotion regulation by integrating gamified elements like levels, challenges, and a point system. Khan et al. [36] designed T1D Buddy, a hybrid solution with a mobile app featuring gamified elements and a physical toy rabbit to help children newly diagnosed with Type 1 Diabetes (T1D) manage their condition and build routines. These works share a foundation in gamified interventions, yet each employs distinct strategies tailored to the unique needs and conditions of their target users. Building on these insights, our work focuses on designing a system that carefully considers the unique contexts and capabilities of preschool-age children with a specific condition, DUFS. We draw on relevant literature and incorporate feedback from preschoolers and their parents to create a self-tracking solution that effectively meets the needs of this younger age group with DUFS.

2.3 Collaborative Tracking of Children's Health within a Family Context

Previous research on self-tracking for children's health [58, 64, 65] has focused on the concept of child-parent collaboration, aiming to assist young children while sharing the tracking responsibilities between both parties. These studies shared valuable insights regarding the child-parent dynamics introduced by the designed tracking scenario. In the two separate studies of app-based physical activity promotion among families, Saksono et al. observed parents' perception on fulfilling psychological relatedness with children through competitions [65] and reflective communications [64]. Pina et al. explored the feasibility of collaborative sleep and mood tracking among children and parents using the developed app [58]. They noted the children's active contributions and the discomfort of parents in sharing their data with family members. In addition, these studies have adopted automated data capture approaches, such as step counting [64, 65] and sleep recording [58]. While sharing the goal of supporting health management through tracking in a family context, our work specifically targets much younger children, aged 4–6 years, and implements a semi-automated approach that involves intensive manual tracking.

Despite a high capture burden [16], manual data capture offers several benefits, including a greater sense of agency, empowered engagement with self-tracking data, and increased data awareness [2, 6, 17, 39]. However, few studies have examined the use of the manual approach in the context of children's behavior tracking. While Pina et al. [58] incorporated manual mood recording alongside automated sleep tracking, the extent of children's involvement in more intensive self-tracking, such as manually recording multiple data types several times a day, remains underexplored.

Building on the benefits of child-parent collaboration observed in previous studies [58, 64, 65], we hypothesize that similar advantages will enhance the feasibility of our tracking scenario. Our approach places a greater responsibility on young children, focusing on their self-tracking without the need to track parents' behavior. Under these conditions, we aim to explore the engagement and collaboration dynamics of pediatric DUFS patients and their parents, in the context of more intensive, semi-automated self-tracking.

3 FluidTrack: A Collaborative Tracking System for DUFS Pediatric Patients and Their Parents

We designed FluidTrack, a collaborative tracking system to facilitate conventional DUFS management for pediatric DUFS patients and their caregivers. FluidTrack supports the tracking of three key behaviors—fluid intake, voiding, and defecation—while promoting adequate water consumption. Through feedback sessions, We refined the design to ensure preschoolers could grasp its main concept and data capture rules, while also considering the caregivers' role in complementing preschoolers' participation in DUFS management.

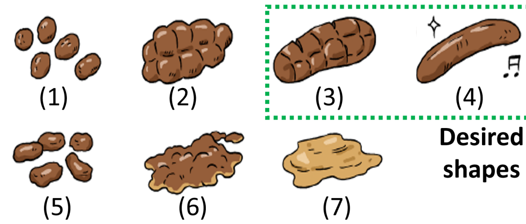
3.1 Design Goals

Through multiple iterations, feedback sessions, and insights from existing literature and clinical experts, we identified three design goals (DG1–3). Initially, we conceptualized these goals using literature and clinicians' input. Our design goals evolved and crystallized over time, shaped by early feedback from participants (see Section 3.2.4), which led to the addition and refinement of DG2 and DG3.

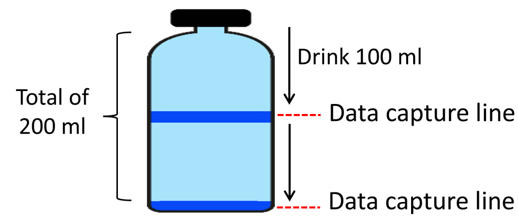
(DG1) Leverage the benefits of self-tracking in DUFS management for preschoolers. Self-tracking using pen and paper has proven helpful in diagnosing DUFS [49]. However, despite the importance of such data for managing DUFS, our clinical collaborator indicated that the foreseeable high burden of manual tracking discourages them from asking pediatric patients or caregivers to track data during the four-week period post-diagnosis. The literature on self-tracking suggests that manual data tracking can enhance a sense of agency, engagement with data, and awareness of the data [2, 6, 17, 39], thereby positively influencing behavior change. However, self-tracking in preschoolers (4–6 years) remains underexplored. In light of this, we believe that an appropriately designed semi-automated tracking approach [16], with a manageable user burden, can harness the potential of self-tracking in DUFS management. Therefore, our first design goal is to support semi-automated data capture that is both easy and playful, leveraging the benefits of self-tracking in DUFS management for preschoolers.

(DG2) Facilitate the collaboration between preschoolers and their parents. Given the developmental stage of preschool-aged children [11, 56, 57] (Section 2.2), we anticipated that children aged 4 to 6 might require support to complete all tracking tasks. Conversely, if parents were to take full responsibility for tracking, they would need to monitor their children continuously, which can be demanding. Thus, we aim to facilitate collaboration between preschoolers and their parents in self-tracking through FluidTrack. We seek to examine the roles that preschoolers and their parents assume during their collaborative tracking experience, particularly when several tasks require significant involvement from the preschoolers.

(DG3) Make the interaction engaging for the preschoolers with rewards. Given that our target users are 4 to 6 years old, it is crucial to make the technology engaging and playful. Using rewards to keep participants motivated is a common practice in self-tracking studies (e.g., flowers [19], rocket fuels [65]). However, in designing rewards for DUFS pediatric patients, we were concerned that inappropriate rewards could negatively affect their DUFS management. For example, if rewards for capturing voiding data become too enticing, children might try to void intentionally to earn more rewards, which conflicts with the goal of reducing daily voiding frequency in DUFS management. Thus, we need to carefully design rewards that motivate preschool-aged children to engage in tracking and water intake activities without disrupting DUFS management.



(a) Seven stool shapes determined in the Bristol Stool Chart [38, 51] that help children identify and capture their own stool shape



(b) MoaBottle design that supports data capture lines to help children capture the amount of water consumption

Figure 2: Bristol Stool Chart and MoaBottle images that were used to capture stool shape and the amount of water consumption, respectively in our data capture rules.

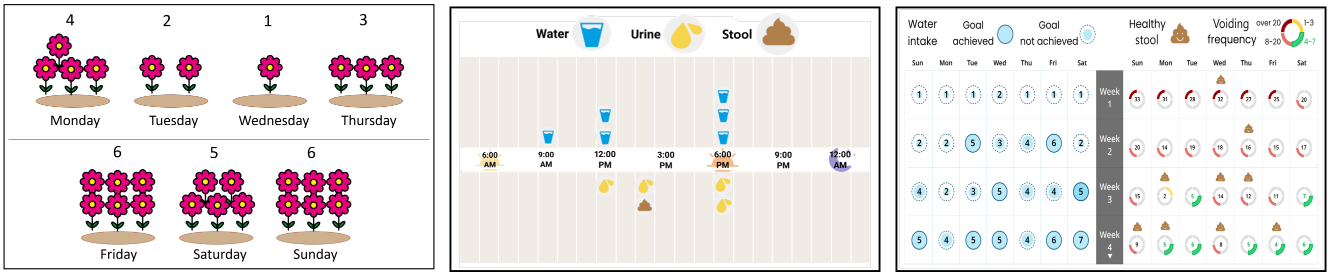
3.2 FluidTrack System Design

To identify the types of data to be collected, we first examined a bladder diary used in our collaborating hospital. To lower the capture burden, we selected a subset of diary items based on their importance to DUFS management, following the clinician's advice. The selected items capture three key behaviors—fluid intake, voiding, and defecation—along with the type (water, beverage) and amount of fluid consumption, and stool shape (Figure 2(a)). To support holistic data capture and management, the system included (1) MoaBand, a wristband device for preschoolers to capture the occurrence of three key behaviors (with automatically timestamped); (2) MoaBottle, a custom-designed water bottle to help preschoolers track water amount with a predetermined unit; and (3) MoaGardenApp, a companion tablet application to support the preschooler-parent dyad's collaborative management and reflection of data.

3.2.1 MoaBand. We examined several options to help preschool-aged children capture the three key behaviors. Initially, we considered fully manual methods such as sticker boards, and smartwatches for kids (e.g., Garmin vívofit® jr. 3 [42]), which can be engaging for children [53]. Smartwatches have also been suggested for children's health tracking and intervention in domains like autism [3], ADHD [20], and pain management [61]. However, parents and kindergarten teachers in our informal network expressed concerns about these tools. Some parents were worried about early exposure to smart devices leading to addiction, while teachers noted potential classroom distractions from stickers or smartwatches (e.g., sounds, visual effects). These concerns align with literature highlighting parental worries about young children's problematic smart device use [54, 55] and its negative impacts, such as increased risks of neurodevelopmental issues (e.g., ADHD) and physical problems (e.g., impaired vision) [1].

To alleviate these concerns, we decided to design a wristband device named MoaBand, which provides only tracking-related functions and lacks a display and a speaker. We chose the wristband form factor for its suitability for private use and its strong advantage in sending reminders to track behaviors. MoaBand adopts physical buttons because preschool-aged children tend to like pressing buttons (e.g., elevator buttons), and this action is simple and easy for them. We used three buttons (water, urine, and stool) mapped to water intake, voiding, and defecation behaviors respectively (Figure 1). When a user presses a button, the button type and timestamp are automatically stored on the device. To give feedback for successful button press, MoaBand uses an LED lamp and a vibration motor: the lamp gently emits one of three colors, each corresponding to a specific button, and the vibration motor is activated. MoaBand also vibrates to remind the user to drink water if the water button has not been pressed within an hour after the last press.

3.2.2 MoaBottle. Since MoaBand captures only the water intake along with timestamp, we needed a method to record the amount of water consumption. From popular online communities for preschoolers' parents hosted on the NAVER, a leading search engine in South Korea, we learned that preschool-aged children typically carry and use their own water containers, and designed MoaBottle to enable preschoolers to gauge their water consumption amount. MoaBottle is a 200 ml water bottle with two 100 ml unit lines (Figure 2(b)) to help children track their water consumption. Children were instructed to press the water button on MoaBand when the water level



(a) Garden page, which shows captured water intake data as flowers for each day of the week

(b) Daily Log page, which shows captured data in hour units on a 24-hour timeline in the middle

(c) Summary page, which shows captured data corresponding to 4-week DUFS management period

Figure 3: Images of main pages in MoaGardenApp that show captured data with different sizes of time window; Garden (7 days of a week), Daily Log (24 hours), and Summary (28 days of the entire DUFS management).

reaches or passes the 100 ml line. This allows them to track water consumption for each unit amount using the stored timestamps.

3.2.3 MoaGardenApp. We designed MoaGardenApp, a companion tablet application of MoaBand, to support preschoolers and their parents to collaboratively manage and reflect on captured data (DG2). We adopted growing flowers as the main metaphor, connecting water intake, voiding, and defecation data with water and fertilizer used to grow flowers. This design choice was based on the expectation that children would naturally associate their logged activities—drinking water, voiding, and defecation—with the real-world elements needed to help flowers bloom, making the process engaging and intuitive for them. MoaGardenApp includes three main pages: Garden, Daily Log, and Summary. The **Garden** page (Figure 3(a)) displays all the rewards children have received, featuring flowers on seven beds representing one week. Each flower symbolizes one instance of water intake, allowing easy comparison of water consumption throughout the week.

The **Daily Log** page (Figure 3(b)) is designed for children and their parents to collaboratively manage and reflect on captured data every day. It displays children's water intake, voiding, and defecation data for a single day, organized by type (intake or excretion) along a horizontal timeline in the middle: water and beverage intake data appear in the upper section, while voiding and defecation data are in the lower section. The timeline indicates only hours, simplifying data visualization for preschool-aged children while still providing sufficient information for clinicians. On this page, users can record beverage intake details (timestamp, amount, type) and select stool shape from options based on the Bristol Stool Chart [38, 51]: types 1 and 2 for constipation, types 3 and 4 as desirable shapes, and types 5, 6, and 7 for diarrhea (Figure 2(a)). When unsure, they can select the "Do not know" option. Parents can assist if these tasks are challenging for their children.

The **Summary** page (Figure 3(c)) provides an overview of children's captured behaviors, helping parents understand long-term trends. It shows water intake, voiding, and defecation data collected over four weeks of DUFS management. Beverage intake data is excluded to focus on how water intake affects voiding and defecation. Water intake data is arranged on the left, and voiding and defecation data is on the right. The circle surrounding the water intake number represents if the daily goal of 1 liter was achieved (solid line) or not (dotted line). This daily water intake goal was based on the recommendations [24, 50] mentioned in section 2.1. The number of voiding instances is shown with a doughnut chart, divided into four frequency ranges advised by the clinician: low (1-3; yellow), desired (4-7; green), high (8-20; bright red), and very high (over 20; dark red). "Healthy stool" icons are displayed only on the days when desired stool shapes (types 3 and 4) were recorded.

3.2.4 Design Feedback Sessions. Before fully implementing the FluidTrack system, we wanted to examine preschoolers' understanding and parents' perception on our design concepts. We conducted design feedback sessions with 10 child-parent dyads, consisting of children (5 girls and 5 boys) aged 5 to 6 years, and their parents (all happened to be mothers). Due to the COVID-19 pandemic, we conducted all sessions via Zoom, using PowerPoint slides to share study material. As a token of appreciation, each dyad received 40,000 KRW (about $31). The study was approved by the institutional review board of Yonsei University (7001988-202101-HR-1075-03).

Procedure. The design feedback session had two phases—one with the child and the other with the parent. In the first phase with a child, we began by explaining a short story about our tracking scenario with FluidTrack. We then covered three topics: (t1) the concept of behavior data capture with MoaBand, (t2) the mapping between water, urine, and stool icons to water intake, voiding, and defecation behaviors, and (t3) the mapping between water intake and a flower reward. After explaining each topic with an example, we asked the child to describe their understanding. We also assessed each child's understanding of the data capture protocol with MoaBottle (Figure 2(b)) using three water-consumption scenarios: *no capture* , *capture once*, and *capture twice*. Finally, we had the child complete three tasks: recognizing stool shapes, recalling a stool shape after a delay, and interpreting the flower reward metaphor. In the second phase with a parent, we collected feedback on FluidTrack's design, feasibility, and suggestions for improvement.

Results. Overall, most of 10 child participants correctly described their understanding about the design concepts and successfully completed the given tasks. However, three children missed several questions about the data capture rule with MoaBottle (Challenge 1), and one child had difficulty recalling a previously shown stool shape after a delay (Challenge 2). All parents remarked that

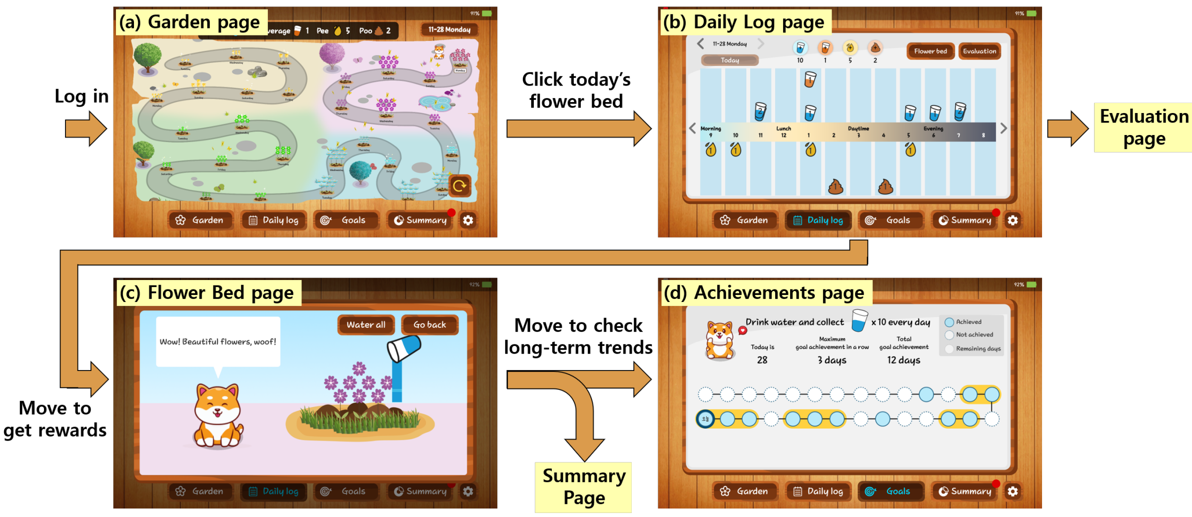


Figure 4: A revised design of the MoaGardenApp pages. A child-parent dyad sees Garden page (a) when they log in the app. On the page, they click today's flower bed to move to Daily Log page (b). After they refine captured data for the day, they move to Flower Bed page (c) to receive rewards. (The parent evaluates the subjective accuracy of the captured data on Evaluation page.) After getting rewards, they check the accumulated data in Achievements (d) and Summary (Figure 3(c)) pages.

they would be willing to help their children, with six being especially motivated if their children have health problems. From this study, we gained confidence that 5 to 6-year-old children can perform semi-automated tracking tasks using MoaBand, but tasks such as learning MoaBottle's data capture rule and recording stool shape require additional support.

3.3 FluidTrack System Design Refinement

3.3.1 Design Improvements in MoaBottle and MoaGardenApp. In response to the confusion of three children about how to capture data based on the printed lines on MoaBottle (Challenge 1), we introduced additional features to clarify the data capture rule and to encourage and remind correct tracking of water amount. We added brief text instructions alongside the lines, complemented by our designed character (introduced in section 3.3.1).

To better promote and sustain participants' motivation, we refined page designs, improved the rewarding mechanism, and created a puppy-like character named MongMong in MoaGardenApp. In the **Garden** page (Figure 4-(a)), we added a path of 28 beds that correspond to 28 days of DUFS management, encouraging users to think 28-day tracking as a journey.

We improved the **Daily Log** page (Figure 4-(b)) design to display beverage intake data together (shown as a cup of orange beverage). We then added the Evaluation and Flower Bed pages, which enable users to subjectively assess data accuracy and collect flower rewards, respectively. These pages are reachable from the Daily Log page, where they can complete data review and reflection. The **Evaluation** page, password-protected for parent use, enables parents to rate the captured data's accuracy (referred to as "subjective data accuracy") using a 7-point Likert scale (1: very inaccurate, 4: neutral, and 7: very accurate), or select the "Do not know" option. In the **Flower Bed** page (Figure 4-(c)), children can receive up to 10 flower rewards based on the number of times they press water button on MoaBand. To encourage daily goal achievement (100 ml x 10 times = 1L), we designed butterflies flying near flowers only in case they receive 10 flowers. Children can add special effects to flowers if they capture voiding and defecation data. Considering DG3, only a single reward is provided regardless of the amount of captured data for voiding and defecation; adding a glitter effect on flowers and growing flowers bigger, respectively.

The **Achievements** page (Figure 4-(d)) was newly added to enable users to see the daily goal achievement. This page shows 28 circles, each indicating whether the daily water intake goal is achieved. On the achieved day, a solid circle filled with sky blue appears, while an empty dotted circle appears otherwise. For consecutive days the goal was achieved, the circles are grouped with a yellow band to emphasize the streak.

MongMong, main character. According to design recommendations for children's touchscreen interface use [70], on-screen characters can improve children's learning outcomes [15, 25] and motivate their engagement in learning [25]. Thus, we designed a friendly puppy character named MongMong (the phonetic transcription of a puppy's barking in South Korea) to deliver instructions and tracking-related information to DUFS patients and to encourage their engagement. MongMong gives feedback with different postures and facial expressions according to data capture progress (e.g., Figure 4-(c)). MongMong also briefly explains the importance of drinking enough water.

3.3.2 Bi-weekly Summary Report Design for Parents. To address the challenges highlighted in the Design Feedback session (Section 3.2.4), we recognized parental support as a crucial factor to the success of the proposed tracking scenario. To offer perspectives distinct from those in MoaGardenApp and help parents' understanding of their children's data, we designed a bi-weekly report summarizing

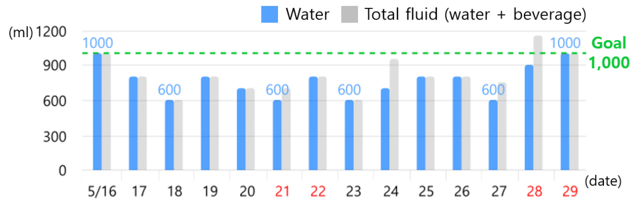


Figure 5: A bar chart of daily water and total fluid consumption for the previous two weeks in the designed bi-weekly report (data of a participant in the deployment study).

fluid intake, voiding, and defecation data captured during the previous two weeks. The clinician suggested that a two-week window is appropriate for observing changes in these behaviors. The report includes two weeks of tracked data including the data that were not presented in MoaGardenApp (e.g., beverage intake data in Figure 5), visualizing them with bar and line charts widely used in health tracking apps (e.g., Fitbit [41]).

3.4 FluidTrack System Development

With the improved MoaBottle and MoaGardenApp designs, we implemented the final version of the FluidTrack system as follows.

MoaBand was developed as a wearable device, whose dimensions are 40 mm (H) x 39 mm (W) x 11 mm (D), weighing 40g: it is smaller and lighter than MooMin Kids Watch (45.5 x 53 x 13.5 mm, 45g) [43], a popular product in South Korea. We carefully determined the height of each button and the required pressure for activation, considering both ease of use and potential for accidental activation by inanimate objects. We covered the LED lamp and water, urine, and stool buttons with rubber caps to provide better tactile feedback. MoaBand supports Bluetooth Low Energy (BLE) to communicate with MoaGardenApp. We attached a sticker on the device, which includes lamp, water cup, urine, and stool icons to indicate the meaning of the LED lamp and three buttons. We made four different sticker designs to let children choose their favorite.

MoaBottle is a Bisphenol A (BPA)-free bottle with a capacity of 330 ml. To track water consumption in 100 ml units (section 3.2.2), we printed three solid lines and one dotted line on MoaBottle's wall to indicate three data capture lines and the total capacity of 300 ml, respectively (Figure 1). We selected blue and pink colors for the bottle lid to enable children to select a preferred one.

We implemented **MoaGardenApp** on Samsung Galaxy Tab A7 (about 267 USD) [45] by using the Unity for Android OS [33]. Following the design considerations in TIDRC [70], we avoided small objects and fonts in all pages of MoaGardenApp to facilitate children's touchscreen interaction. To generate audio files of MongMong's words, we used Typecast [32], a free AI-based voice generator. MoaGardenApp can automatically connect to MoaBand and receive the data from it via BLE. MoaGardenApp periodically transmitted data to our Node JS-based web server that we implemented using an EC2 instance of Amazon Web Services.

4 Deployment Study

We conducted a deployment study with 14 DUFS patients and their parents for four weeks of DUFS management from October 2021 to

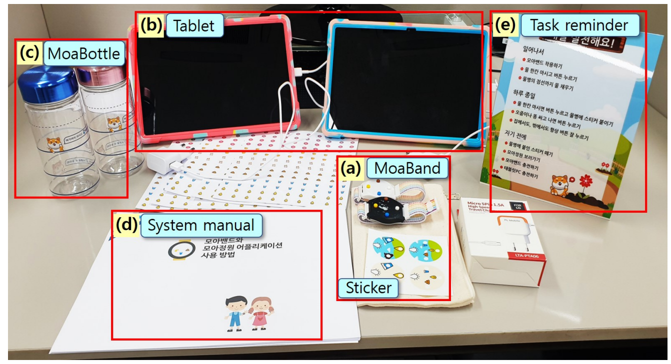


Figure 6: FluidTrack deployment kit consists of MoaBand with stickers (a), a tablet with MoaGardenApp (b), MoaBottle (c), a FluidTrack manual (d), and a key task reminder (e).

September 2022 in South Korea. Our goal was to investigate if and how DUFS patients aged 4–6 years capture data using FluidTrack, how patient-parent dyads collaborate through FluidTrack, and how they react to and perceive the overall FluidTrack design. This study was approved by the institutional review board of Severance Hospital (4-2021-0590).

4.1 Study Instrument (FluidTrack Kit) and Participants

We prepared a FluidTrack kit for our deployment study, consisting of MoaBand with stickers, a tablet with MoaGardenApp installed, MoaBottle, a paper manual for FluidTrack, and a key task reminder (Figure 6). The key task reminder, a standing board, listed the recommended tasks like wearing the MoaBand after waking up, pressing its buttons after each behavior, and charging devices before sleep.

We recruited dyads of a DUFS patient and a parent who visited the children's hospital where our collaborating clinician works. Our inclusion criteria for child participants were (1) a diagnosis of DUFS, (2) age between 4 and 6 years, and (3) current enrollment in preschool. For parent participants, the criterion was that they usually spend time with the participating child before bedtime.

Table 1 shows our participant demographics. Child participants (C1-C14; 8 females and 6 males) were on average 4.9 years old (*SD* = 0.5). Main participating parents of these children, who engaged in 4-week tracking and the exit interview, were 12 mothers and 2 fathers. Ten parents reported that other family members involved in the tracking procedure. All families resided in six different cities across South Korea.

4.2 Study Procedure

When DUFS patients and their parents visited the hospital, the clinician introduced our deployment study as an optional part of the conventional 4-week in-home management. For the patient-parent dyads who were interested in the participation, the clinician informed that the active engagement in the study could benefit DUFS management. As a conventional practice, he recommended the patients to drink enough water and hold voiding for a certain period of time, and he prescribed medication for those experiencing

Table 1: Overview of participating DUFS patients (C1-C14; C stands for child) and their family members who participated in our deployment study. For each family, we indicated a main participating parent first among two parents. All main participating parents (P1-P14) took the responsibility of engaging in the 4-week tracking procedure and the exit interview.

Family	DUFS patient	Parents	Other participating members
F1	C1 (4y, Female)	P1: Mother (Teacher) & Father (Employee)	Grandparents
F2	C2 (5y, Male)	P2: Mother (Homemaker) & Father (Employee)	-
F3	C3 (5y, Female)	P3: Mother (Business owner) & Father (Business owner)	Aunt
F4	C4 (5y, Female)	P4: Father (Employee) & Mother (Employee)	Grandmother & Twin brother (5y)
F5	C5 (5y, Female)	P5: Mother (Employee) & Father (Employee)	Grandmother
F6	C6 (4y, Male)	P6: Father (Employee) & Mother (Medical staff)	Grandmother & Brother (4y)
F7	C7 (6y, Female)	P7: Mother (Employee) & Father (Employee)	Sister (10y) & Brother (5y)
F8	C8 (5y, Female)	P8: Mother (Freelancer) & Father (Employee)	Sister (11y)
F9	C9 (5y, Female)	P9: Mother (Public officer) & Father (Public officer)	Grandmother
F10	C10 (5y, Female)	P10: Mother (Teacher) & Father (Highway patrol)	Grandmother
F11	C11 (5y, Male)	P11: Mother (Teacher) & Father (Teacher)	-
F12	C12 (5y, Male)	P12: Mother (Homemaker) & Father (Self-employed)	-
F13	C13 (5y, Male)	P13: Mother (Homemaker) & Father (Self-employed)	-
F14	C14 (5y, Male)	P14: Mother (Researcher) & Father (Employee)	Grandparents

constipation. Then, we informed the study details including drop-out conditions and audio-recording of exit interview. They could be dropped out (1) if they do not capture data for more than 3 days per week or (2) if the number of captured data is unrealistically high, such as 50 times of water intake per day, for more than 3 days among 28 days. Once they agreed to participate, we obtained consent from both the child and parent participants. After the participants signed the consent form, they began the three phases of our deployment study; (1) tutorial, (2) data collection, and (3) exit interview.

Tutorial. We provided a FluidTrack kit and explained the system's goals were tracking of patient's fluid intake, voiding, and defecation and patient's water intake improvement. We showed how to use FluidTrack, following the system manual. First, the patient wore MoaBand, and we checked if the patient was okay with wearing it. Then, we explained how to use MoaBand, and checked if the patient could press correct buttons on MoaBand while recalling the previous day's behaviors. Next, we informed how to use MoaBottle by consuming water with it and checked the patient's understanding. After confirming that all child participants understood how to use MoaBand and MoaBottle, we demonstrated MoaGardenApp to both the child and parent using example data, recommending an optimal flow for app usage (Figure 4). Three out of 14 patients did not visit the hospital, and only their parents met the clinician and agreed to participate in the study. For these three patients, we obtained consent via mail and conducted tutorials through video calls on KakaoTalk[2], a popular messenger app in South Korea. In appreciation of their participation, we provided 70,000 KRW (about 54 USD) to each dyad.

Data collection. We asked all participants to start tracking with FluidTrack the day after the tutorial. They used FluidTrack to capture patients' fluid intake, voiding, and defecation data for four weeks of DUFS management. We contacted parents at the end of every week to address any questions or issues, while being careful not to intervene in tracking. At the end of every two weeks, we sent a URL of a short survey to collect parents' subjective evaluation of changes in their children's water intake, voiding, and defecation behaviors. For example, we asked, "How did your child's voiding frequency change?" with a 7-point Likert scale (1: much worsened, 4: not changed, and 7: much improved). After the parents finished the survey, we emailed a PDF file of a bi-weekly report of their children's data, described in section 3.3.2.

Exit interview. After data collection, we conducted in-person, semi-structured interviews with each parent, averaging 66 minutes. We asked questions to explore various aspects: the contexts in which participants performed the tracking, their usage of MoaBand, MoaBottle, and MoaGardenApp, the effectiveness of these components, any changes in children's fluid intake, voiding, and defecation behaviors, and overall experience of using FluidTrack. To aid the parents in recalling their experiences, we referenced the participants' device and data during the interviews.

4.3 Data Analysis

Data collected in our deployment study consist of the behavior data and subjective data accuracy captured by the participants, the system log data, and the exit interview data. We analyzed these data to investigate participants' usage of FluidTrack, with a focus on data tracking and managing DUFS.

We calculated the descriptive statistics of FluidTrack system log data and capture data to examine participants' system use, capture activities, distribution of captured data, and subjective accuracy of the captured data. We also examined the trend of children's fluid intake, voiding, and defecation behaviors quantitatively. In the quantitative analysis, we excluded data collected during the *invalid days*, when participants could not use MoaBand or MoaGardenApp due to technical issues (e.g., accidental removal of MoaBand button caps or failure to retrieve data). The invalid days occurred in 4 out of 14 families and lasted no longer than 3 consecutive days.

[2] https://www.kakaocorp.com/page/service/service/KakaoTalk?lang=en

For the exit interview data, three authors collaborated to transcribe them to aid in qualitative analysis. We conducted a reflexive thematic analysis [10]. Initially, the three authors familiarized themselves with the first four transcriptions (P1–P4) and individually coded them using both inductive and deductive approaches. Together, they reviewed these codes to create an initial coding framework. During weekly research meetings, the whole group (three coders and PIs) discussed the coded data and refined the coding framework. This process continued as two of the three authors individually coded the remaining interviews (P5–P14). Subsequent meetings focused on refining the framework, resolving ambiguities, and finalizing themes, which included: preschool-aged DUFS patients' engagement with data capture, behind-the-scenes parents' assistance, and challenges and unexpected usages with FluidTrack.

5 Results

We first present our quantitative findings, detailing the participants' system usage and data capture behaviors. Then, we report the qualitative analysis results: (1) how preschool-aged DUFS patients engaged in the data capture; (2) how the parents collaborated with the child to achieve DUFS management tasks; (3) the challenges emerged during the 4-week tracking period, and (4) the parents' feedback about the overall tracking experiences with FluidTrack.

5.1 Descriptive Summary of System Usage and Captured Data

5.1.1 System Usage. We first examined how much our participants used FluidTrack system. We excluded F13's data in the quantitative data analysis reported in section 5.1 because P13 recorded the data throughout the day on paper, and C13 later pressed the buttons on MoaBand at night using P13's records. The remaining 13 families used MoaBand and MoaGardenApp for on average 25.5 days (*SD* = 2.7) and 21.6 days (*SD* = 5.1), respectively. Figure 7 illustrates the number of behavior instances captured by each family using these tools. On average, 13 families captured 13.7 instances using MoaBand (*SD* = 4.7) and 4.9 instances using MoaGardenApp (*SD* = 3.2) per day. Eleven out of the 13 families used MoaBand more than MoaGardenApp to capture data.

5.1.2 Captured Data. In total, the 13 families captured 6,429 behavior instances, with an average of 18.6 instances per day (*SD* = 3.5). Table 2 shows the amount of behavior instances captured by each family; on average 7.5 water intake (*SD* = 1.9), 1.0 beverage intake (*SD* = 0.6), 9.2 voiding (*SD* = 2.4), and 0.9 defecation instances (*SD* = 0.5) per day. In this calculation, we counted only the days when captured data existed, averaging 26.7 days (*SD* = 2.3). For the self-tracking data, the subjective data accuracy rated by the parents

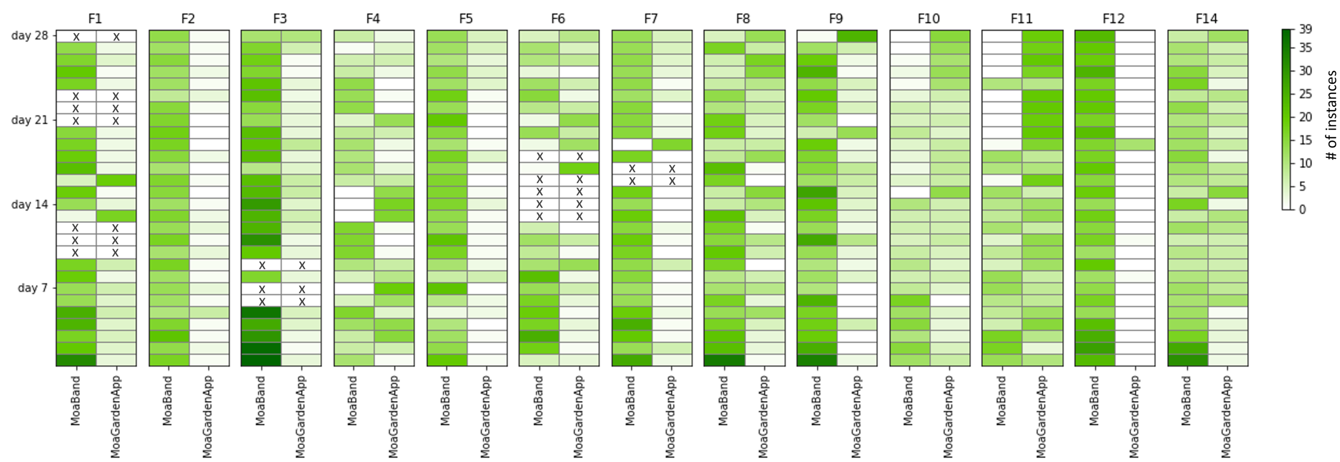
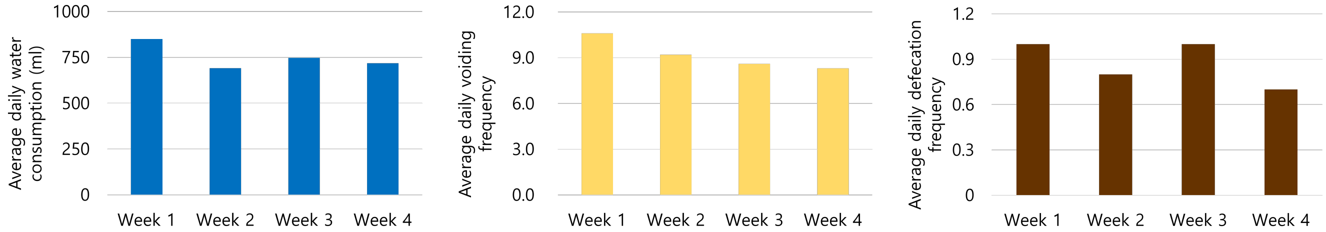


Figure 7: Heatmap of the number of data captured with MoaBand and MoaGardenApp, respectively, for each family. Color intensity of each cell becomes darker as the number of captured instances per day increases, ranging from 0 to 39. The largest number of the instances per day, that is 39, was captured by F3 with MoaBand on the first day. For the fair comparison, we excluded the data of the invalid days (denoted as 'x' in the cells) as explained in section 4.3 and F13's data as explained in section 5.1. Only F10 and F11 used MoaGardenApp more than MoaBand to capture data.

Table 2: The amount of data captured by each family. They captured water intake, voiding, and defecation data by using MoaBand and MoaGardenApp. They captured beverage intake data by using only MoaGardenApp, since MoaBand did not support a capturing function for beverage intake data.

Instance Type	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F14	Total
Water intake	221	210	200	100	156	165	217	257	195	144	225	242	252	2,584
Voiding	194	185	385	283	243	175	198	233	342	201	260	253	222	3,174
Defecation	30	22	20	11	14	26	33	61	9	10	18	36	17	307
Beverage intake	11	21	58	23	26	20	16	44	46	16	47	0	36	364



(a) Average daily water consumption. The largest amount appeared at the first week of the management.

(b) Average daily voiding frequency. Over the study periods, the average frequency steadily decreased.

(c) Average daily defecation frequency. The average frequency peaked in the first and third weeks.

Figure 8: Weekly trends of water consumption, voiding frequency, and defecation frequency for four weeks of DUFS management. (We excluded F13's data as explained in section 5.1.)

appeared high, with an average of 5.5 (where 1: very inaccurate, 4: neutral, and 7: very accurate; *SD* = 0.6). (We excluded P6 because he selected the "Do not know" option for all use days.)

We also investigated trends in water consumption, voiding frequency, and defecation frequency over the study periods (Figure 8). The average daily water consumption was 751 ml (*SD* = 187), peaking in Week 1 (Figure 8(a)). On average, the daily voiding frequency was 9.2 (*SD* = 2.4), declining steadily, while the daily defecation frequency was 0.9 (*SD* = 0.5).

5.2 Preschool-aged DUFS Patients' Active Engagement with Data Capture

All children had no difficulty pressing MoaBand's buttons after their water intake, voiding, and defecation. Ten out of the fourteen children were actively engaged in semi-automated data capture with MoaBand. Some parents noted that their child expressed a desire to capture data even when not wearing a MoaBand. For example, P3 said, *"While my child was in the bathroom [to defecate], she said 'mom, press the button please'."* Eleven out of 14 children were capable of following data capture rules using MoaBottle on their own. One of the remaining three children (C6) initially had difficulty deciding when to press the water button on MoaBand after using MoaBottle. However, C6 overcame this challenge early by ensuring that the water level reached one of the data capture lines on MoaBottle. Seven children, including C6, approached drinking water as if it were completing a mission in a game, ensuring that the water level reached the data capture lines. P1 mentioned, *"My child drank water while she kept checking if the water level reached the line, like doing a mission."*

Most children also contributed to stool shape recording using MoaGardenApp, mostly done retrospectively rather than at the time of defecation. Ten children were able to recall their stool shapes, selecting similar shapes on the app or informing their parents about the shapes. P7 mentioned, "My child selected her stool shape, and sometimes she asked, 'Why isn't it like this today?' I replied, 'That's because you didn't drink enough water.' [...] Later, after drinking more water, when she selected a shape, she said, 'Oh, so today, because I drank a lot of water, my poop came out well?' I responded, 'Yes.' Then she added, 'Since I drank a lot of water, it's easier to defecate.'" However, beverage data (excluding water) recording was carried out mainly by parents.

The children's active engagements in the data capture appear to be grounded on their initial positive reactions to using MoaBand (13 out of 14) and MoaGardenApp (all). P1 said, *"At first, my child was highly motivated to engage in [the tracking activities] by the joy of wearing a [special] device and button-pressing activities using it."* Similarly, P2 mentioned, *"MongMong [in MoaGardenApp] always said 'hello', and my child repeated it. He memorized almost all of what MongMong said... He is still learning Korean, so he knows them just partially, but he memorized all of them."* However, some parents noted a decline over time in their children's interest in MoaBand (7 out of 14) and MoaGardenApp (8 out of 14), potentially affecting the children's engagement in tracking activities. P3 remarked, "My child rarely skipped pressing the buttons, except for the last week. In the final week, her interest seemed to fade significantly, and she sometimes forgot to press."

5.3 Behind-the-Scenes Parents' Assistance

Most parents took two main roles: (1) supporting their child's data capture and reflection activities and (2) managing the child's behavioral data using various sources of information.

5.3.1 Supporting Children with Data Collection and Reflection. Parents complemented the children's data capture efforts, with varying levels of involvement. In the early phase, all parents except one actively reminded their children to use MoaBand for data capture. However, one parent (P13) assumed full responsibility for data capture because her child did not want to wear the MoaBand. All parents also managed MoaBand when their children were not wearing it, such as keeping it on the same spot for visibility and accessibility (12 out of 14). For example, P14 mentioned, "We designated the dining table as a fixed location because there's always water there, making it convenient for the child to pour and drink. Our dining table is quite spacious, and it's where the child reads books and spends most of his time engaging in various activities." Five parents sometimes carried MoaBand (e.g., two wore it themselves) not to miss data capture activities. For instance, C9 always asked her mother to wear MoaBand when going out together.

Beyond data collection, parents also assisted their children in reflecting on the recorded information, but only when the children showed interest in engaging with the data. While all children were eager to obtain rewards in MoaGardenApp (i.e., growing flowers), their level of engagement with the captured data varied. The exit interviews revealed that seven children often remained curious about captured data even after receiving the reward, and their parents guided the data reflection by explaining visual representations on the Summary page. For example, P7 described, *"I explained that if green button appears here (doughnut chart of voiding frequency in the Summary page (Figure 3(c))), it indicates the adequate voiding frequency, and if red button appears, it means that you went to the bathroom too often. Then she began to monitor the color indicators."* For six out of these seven children, their parents also highlighted the instances where they reflected on the captured data together using MoaGardenApp. P2 quoted C2's comment on the Garden page, *"I think I drank water a lot at that time, so the number [of flowers] is large here. I guess I drank little so the number is small there."* For the other half, parents had limited opportunities to facilitate their child's data understanding and reflection. These children seemed interested in receiving the rewards but less curious about the captured data. P11 described, *"We did not have many chances to have conversations [about the data], since [he] left immediately after receiving flower rewards."* For these seven children, their parents did not push them to learn the meaning of data and reflect on it.

5.3.2 Managing Data Using Multiple Sources. Most parents took responsibility for recording beverage intake data and managing overall data in MoaGardenApp. For beverage intake occurring outside the home, they verified the data by referencing the school lunch or snack menu and asking their children questions (e.g., 'How much did you drink at 3 p.m.?'). For beverage intake, all parents except for P12 primarily recorded the relevant data (on average once a day). (C12 did not drink beverages.) They relied on their own memories or notes, which included observations from other family caregivers and preschool teachers. In addition, all parents took the lead in modifying, deleting, and adding data in MoaGardenApp, referencing several sources of information: existing knowledge of their children's typical behaviors (7 out of 14), notes taken by themselves, other family caregivers or kindergarten teachers (11 out of 14), and the remaining amount of water in MoaBottle (3 out of 14). For instance, P1 mentioned, *"I usually filled MoaBottle with barley tea... if my child filled [MoaBottle] with water in kindergarten, I deduced [she drank at least 300 ml of barley tea] due to the color difference."*

Most (12 out of 14) parents often asked their children questions to ascertain behaviors occurred in their absence or to verify the accuracy of captured data. From these collaborations, a limited understanding of time was observed among seven children. In response, their parents tailored explanations of time by using broader timeframes (e.g., morning), specific contexts (e.g., while in the kindergarten), or visual cues. For instance, P7 described, *"(In the Daily Log page) I explained to my child that [one part of timeline] indicates morning, and color is bright because sun rises. After sun goes down, it becomes darker. So, this [dark] part indicates sleeping period. Then, [my child] understood that on the timeline: this is when she is in kindergarten and this is evening."*

5.4 Challenges and Unexpected Usages with FluidTrack

As the 4-week study progressed, various challenges and unexpected usages emerged due to peers and family influences, wearability and usage complications in the FluidTrack system, and children playing around with the device.

First, peers and family members sometimes interfered with or restricted the child's use of FluidTrack. For 10 children, peers in kindergarten occasionally pressed MoaBand's buttons for fun, causing inaccurate data capture. P1 described, *"Her friends were like, 'Can I press that?' ... One day, the stool button was pressed three times and too many voiding instances were captured."* Furthermore, P1 restricted her child's access to only the Garden page (Figure 4-(a)), to reduce the child's exposure to smart devices. This limited the child's opportunities to interact with the captured data. In addition, three children sometimes missed using MoaGardenApp due to their parents' schedules. For example, P10 typically left for work at 5 p.m. and returned home around midnight, missing the opportunity to interact with her child and review the data together. Similarly, P4 and P6 often arrived home late, and their child was already sleeping.

Second, the design and usability of MoaBand presented several challenges that impacted both data accuracy and user experience. The physical button interface of MoaBand caused data capture issues. MoaBand became unusable when the button's cap was accidentally removed (4 out of 14) and the buttons were inadvertently pressed (e.g., by clothing) (2 out of 14). For C11, MoaBand's single vibration was insufficient to inform the successful button press. C11 repeatedly pressed the same button after completing a single behavior because he was uncertain whether his press was registered. In addition, C13, who was averse to wearing accessories, rarely wore MoaBand. He simply pressed MoaBand's buttons, referencing his parent's notes of behavior instances, to use MoaGardenApp based on captured data. Additionally, nine children found it challenging to wear MoaBand for extended periods, citing discomfort from the strap's texture, warm weather, or its relatively large size. To address this, P2 and P5 modified MoaBand into a necklace, which their children found more comfortable. Missed reminders were identified as another challenge by eight of the 14 parents. We suspect that such cases occurred while their children were not wearing MoaBand or concentrating on other activities. P1 and P3 suggested increasing the frequency of reminders to address missed alerts, contrary to our initial design assumption that frequent reminders might lead to added stress and distraction. Beyond MoaBand usability, five parents reported that their children became bored with MoaGardenApp's components over time. To address this, they recommended making the app more engaging to promote sustained use. For instance, P11 proposed, *"If a daily mission is achieved, [children] can add items, such as a hat or gloves, to the character."*

Lastly, there were a few instances where children's intentional misuse of the MoaBand negatively affected the tracking process. At the start of the study, two children (C1 and C14) had recorded water intake to earn rewards without actually drinking. Fortunately, they stopped this behavior after their parents explained the importance of accurate data capture. In addition, C1 occasionally skipped the capture of voiding data to please P1, which was influenced by P1's positive reactions to lower voiding frequencies. P1 remarked, "Towards to the end, my child understood that the more water she drank and the fewer yellow buttons she pressed, the happier mom (P1) would be, and it would help the flower grow. [...] Over time, her voiding frequency seemed to decrease significantly. [...] I believed she had been pressing the button honestly at preschool during the week. But before returning the FluidTrack kit, I made a confirmation call to the teacher, and she mentioned that the child voided about five times a day." Meanwhile, C3 preferred using MoaGardenApp alone, which reduced collaborative data reflection sessions with P3.

5.5 Parents' Feedback about Overall Experiences with FluidTrack

While most parents reported positive experiences with FluidTrack in managing their children's DUFS, some noted the additional burden it placed on them. Additionally, several parents described unexpected yet positive effects on family dynamics that went beyond DUFS management.

5.5.1 Perceived Effects on DUFS Management. Eight out of 14 parents liked the collaborative tracking aspect of the FluidTrack system, as it enabled both parties to share responsibilities in DUFS management tasks. P7 shared, *"Seeing my child took the initiative and put in more effort [for behavior improvement] is highly encouraging. Before the study, no matter what I said or did, it did not work out well [for holding voiding or drinking water]."* Parents noted increased awareness in DUFS-related target behaviors among themselves and their children during the study period (nine parents; ten children). P3 mentioned, *"My child spends much of the day at kindergarten, where it was previously impossible for me to know how much water she drank [without FluidTrack]"* Furthermore, P9 described the child's behaviors during the study period, *"Before flushing, my child always checks the stool shape and makes comments like, 'Mom, does this look like a banana?'"*

Parents also reported children's enjoyment of getting rewards from the MoaGardenApp and their attachment to MoaBottle. P5 shared, *"At the beginning of the study, [my child] was very interested in [MoaGardenApp], so once she drank water, she logged in to the app and received a flower reward immediately."* P9 mentioned, *"My child really liked MoaBottle... So, she said 'I think water tastes better when I drink it with MoaBottle.'During the study period, she drank water mostly from MoaBottle even when we went out."*

While ten parents expressed a desire to continue using FluidTrack, the remaining four parents noted the significant burden placed on them despite their children's active involvement in the tracking. P9 detailed, *"After getting off work, I became already exhausted, but I had to go through the process of reviewing MoaGardenApp every day... For the things like beverages, I always had to manually input data, which was not easy."* That said, P9 also appreciated that what used to be "nagging" became a conversation mediated by the game [MoaGardenApp] and that it was positive to start and end the day with the child reflecting on the blossoming flowers together.

5.5.2 Positive Ripple Effects. For some families, the tracking experience with FluidTrack had a broader impact beyond DUFS management. Two parents (P8 and P9) experienced a notable change in their own drinking habits during the study, feeling inspired to maintain better hydration. P8 mentioned that C8's sister became motivated to improve her drinking behaviors, *"'Mom, I've been struggling with bowel movements lately, like her [C8].' ... She became motivated to increase water intake after observing C8's improvement in defecation, resulting from drinking more water."*

Two parents (P7 and P14) appreciated the increase in conversations with their children, not limited to topics regarding behavior tracking with FluidTrack. P14 said, *"Since I have a job, I rarely have chances to talk with my child during daytime... I'm grateful for the time [the study] has provided to have conversations with my child."*

Furthermore, four parents perceived that tracking with FluidTrack helped alleviate negative emotions related to DUFS within the family. P4 and P10 recalled their frustration with hospital visits prior to our study. P10 explained, *"Without prescribing any medication, [the doctor] said there was a psychological reason [for my child's condition]... Such explanations left us feeling helpless."* They appreciated that daily tracking with FluidTrack helped relieve their anxiety. Additionally, P9 described a positive shift in C9's perception of her frequent voiding, *"She seems to think that she contributes to managing her condition by engaging in tracking activities. So now, she just brushes off [a voiding instance] lightly like 'I peed again.' ... [Before the study,] she seemed to internalize our concerns, making herself emotionally burdened."* Similarly, P7 mentioned that the tension between C7 and her older sister eased after participating in our study. C7's sister, initially annoyed by the disruptions caused by C7's condition, became interested in FluidTrack. This led to a better understanding of C7's challenges, which in turn alleviated the pre-study tension.

6 Discussion and Future Work

6.1 Demonstrating the Feasibility of Preschool-aged Children's Semi-automated Data Capture

Our main goal was to investigate how to support preschool-aged children to engage in self-tracking for DUFS management and what roles their caregivers should play in facilitating data capture and reflection. We wanted to examine if MoaBand, a new wearable device we developed, along with a companion app and a water bottle, would be seamlessly integrated into children's daily routines and be accepted by their parents and kindergarten teachers. We were pleased to learn that MoaBand was generally well-received by participants, without significant annoyance or disruption to daily routines, such as excessive device use or classroom distractions. Rather, children enthusiastically used MoaBand, particularly during the initial phase of the study period, and most of them did not exhibit excessive usage patterns. This observation aligns with existing studies on children's experiences with smartwatches in the health domain. In Oygür et al.'s study [53], children (aged 7–12 years) often perceived using smartwatches as a fun activity. Similarly, in Ankrah et al.'s study [4], children (aged 10–15 years) with ADHD expressed excitement about using smartwatches, finding them engaging and helpful for self-regulation and understanding their health data.

We also observed a high level of engagement among 13 participants (excluding F13 as explained in section 5.1), who on average captured 13.7 instances per day of DUFS-related behaviors using MoaBand. Ten out of 14 parents expressed confidence that their children were more engaged in overall data capture with MoaBand than through caregiver involvement. Furthermore, most children successfully captured water consumption and stool shapes using MoaBottle and MoaGardenApp together. This research builds upon the findings of Pina et al. [58], who demonstrated the feasibility of simple manual tracking, such as daily mood tracking, in school-aged children (7–12 years old) with an average data capture rate of 0.77 entries per day. Our work takes this a step further by exploring the potential for even younger children (4–6 years old) to engage in more complex data capture using a semi-automated approach in collaboration with their parents.

In doing so, we identified two key areas for improvement—sustaining children's motivation and enhancing device reliability—to better support semi-automated data capture in the future. Our child participants' data capture appeared to moderately depend on their interests and enthusiasm with the FluidTrack system. Despite a nuanced difference, the initial enthusiasm of our child participants in using MoaBand to get in-app rewards seems to be aligned with Oygür et al.'s study [53], where the children were motivated in using a wearable device for quantifiable accomplishments (i.e., increasing number of step counts). However, the diminished engagement with MoaBand, as the enthusiasm decreased over time, indicates the need for more effective strategies for sustainable and intrinsic motivations [76]. As discussed in the literature [8, 83], giving children greater control over their activities and stimulating their curiosity can effectively enhance intrinsic motivation. Furthermore, providing salient and recognizable cosmetic customization options in wearable health trackers may enhance children's sense of identity, which in turn, improve their user engagement by fostering a more favorable attitude and stronger attachment towards the deviceas [35].

The design of data capture devices can be improved to enhance manual capture accuracy. To address MoaBand's button activations erroneously caused by inanimate objects, IMU sensors, commonly embedded in commercial smartwatches (e.g., Apple Watch Series 10 [31], Samsung Galaxy Watch 6 [46]), could be used. Given the potential of IMU sensors to capture various types of movements (e.g., arm motion [80] and body gestures [82]), analyzing IMU sensor data may help distinguish valid button presses from errors. For example, button activations occurring while a child is running are likely to be errors, as drinking water, voiding, or defecating are not typical activities while running. IMU sensors could help detect such contexts (e.g., running) and classify the activations accordingly. Furthermore, over time, IMU data may enable the identification of a child's unique button-pressing patterns, such as the strength of presses, the angle of the wrist, or the rhythm of pressing. These patterns, once learned, could help the system differentiate intentional activations from accidental ones. Additionally, considering the repeated button presses of C11 to ensure successful data recording, we need to devise a better feedback mechanism for MoaBand. For example, keeping the LED lamp activated for a few seconds after a button press could help.

In conclusion, this study provides compelling evidence of the feasibility and promise of semi-automated data capture in preschool-aged children, an age group underexplored in previous research. By demonstrating high engagement levels, extending findings from other age groups, and identifying actionable design improvements, our work lays a solid foundation for future explorations into child-centric wearable technologies and self-tracking systems.

6.2 Designing Child-led, Parent-assisted Collaboration Tool for Health Management

All 14 child-parent dyads completed the 4-week DUFS management period. Parents acknowledged substantial contributions from most children in data capture (section 5.2), enabling them to concentrate on device and data management tasks, such as verifying the captured data and reminding their child. This dynamic is similar to the collaboration strategy between children (aged 6 to 12 years) and their parents in managing T1D in Cha et al.'s interview study [14]. In their study, 'independent' type children, characterized by higher knowledge and motivation for self-care, took the lead in most self-care activities, while their parents played more of a reminding or monitoring role. Although we could not ascertain a high level of knowledge about DUFS management among our child participants, their high motivation led to high engagement in tracking, sharing responsibility with their parents. We believe that this showed the potential of younger children (aged 4 to 6 years) as 'independent' players in their health management.

However, although our FluidTrack system helped parents share the burden of tracking their children's behavior by encouraging active participation from the children, it also introduced new challenges that would not have arisen without the system. Parents now had to take on additional responsibilities, such as charging the devices, ensuring they were accessible to their children, and setting aside regular time for data reflection after returning from work. These findings align with Oygür et al.'s observations from user reviews of commercial children-oriented wearable trackers [52], which highlighted similar parental tasks. Additionally, missing data reflection time due to parents' busy schedules (as observed in three participants) may represent an emotional burden introduced by these new challenges, echoing findings from Shin et al.'s study [67]. Moreover, as children's interest in FluidTrack decreased, their data capture became less diligent, resulting in higher parental involvement and burden. Our findings suggest more work is still needed to effectively manage caregivers' burdens accounting for varying levels of children's independent engagement in child-parent collaborative health management. This aligns with the observations from existing deployment studies involving children with different conditions and age ranges, such as ADHD (9–15 years) [69] and T1D [13] (6–12 years).

As parental assistance was essential in data reflection with FluidTrack, when parents were too busy for this task, reflection opportunities for the child were very limited. When parents were available, the child's curiosity about captured data appeared to play a key role in fostering child-parent reflection opportunities. It was promising to observe instances of collaborative learning and reflection among curious children and their parents. We note that these engagements were not forced by the parents but rather initiated by the children. On the other hand, when children showed little interest in interpreting and reflecting on the captured data, their parents seemed uncertain about how to facilitate engagement. Additional features to facilitate data reflection, such as in-app reflection prompts and interactive questions demonstrated in previous works [58, 64, 66], could be helpful to address this challenge. For example, P14 noted a potential of using MongMong, the main character to facilitate data reflection discussions. In addition, providing visual aids may help parents initiate conversations with their children. Previous studies [23, 72] noted the importance of visual cues and graphical metaphors to better support children's use of apps or systems. Similarly, we observed that the timeline bar on the Daily Log page (Figure 4-(b)) proved helpful for a parent in explaining data over the timeline to her child.

This study highlights the potential of preschool-aged children to take on active, independent roles in their health management through family informatics systems like FluidTrack, while also shedding light on the critical, complementary role of parental assistance. While such systems enable a more balanced responsibility between children and parents, they also introduce challenges, such as sustaining engagement and reducing parental burden. These insights underscore the importance of designing systems that not only foster child-led participation but also support parents in managing their roles more efficiently.

6.3 Potentials of FluidTrack in Water Intake Promotion

Our study results showed that preschool-aged children can be motivated to drink water through the gamification strategy, employed in water intake intervention studies with adult users [34, 37, 47]. It was also encouraging that 11 out of 14 children tracked water consumption using MoaBottle without difficulties. An unexpected positive side effect was that seven children drank water to make the level meet the lines, as if setting and achieving a goal for each intake. Moreover, a goal-setting strategy employed by one child-parent pair (C1 and P1) was noteworthy. They divided the daily water intake goal of 1L into smaller, context-specific goals, such as 300ml at kindergarten and 200ml at the grandparents' home, making the goal more manageable and achievable for children.

Moving forward, future research could explore diverse features with novel goal-setting strategies for effective water intake promotion for preschool-aged children. In addition, the noted ineffectiveness of MoaBand's single vibration reminder, coupled with the finding that most children did not wear MoaBand throughout the day, highlights the need for improving the water intake reminder strategies. Increasing the reminder frequency could be a viable strategy, as suggested by P1 and P3. However, it is important to approach this cautiously to avoid potential negative outcomes, such as disengagement [7] and reduced intrinsic motivation [63]. Another strategy may involve using assistive tools like small reminder signs placed near locations where the target behaviors usually occur (e.g., near water station).

Finally, we suggest research directions for future water intake intervention studies, building on the observed interactions among peers and families. We could leverage the high interest of friends and siblings in MoaBand and MoaGardenApp to devise a water intake intervention design for preschool-aged children, with a classroom-level tracking. During our study design phase, we learned that most preschoolers use personal water bottles, teachers typically manage water bottles and monitor children's water intake, and provide a brief note to parents about children's daily activities. Thus, we believe that it is feasible to integrate group tracking for water intake in kindergarten or preschool settings. We expect that collective participation would not only make water consumption enjoyable but also enhance the data capture process. For example, peers could remind each other to capture drinking behaviors, as C8'sister often did. However, it is important to consider potential issues, such as unhealthy competition (e.g., being stressed from comparisons [81]) and increase of teachers' workloads, when leveraging peer dynamics in tracking system design for children.

6.4 Study Limitations and Future Work

Our study results have limitations in conclusively establishing the feasibility of behavior tracking with a semi-automated data capture approach among preschool-age children and their parents. Our participant group was limited to those highly motivated to manage DUFS, which might significantly influence their engagement in overall tracking activities. The clinician's advice and prescription, as described in section 4.2, could affect both their engagement in the tracking and behavioral changes in the patients. Additionally, all participating parents were adept at using smart devices, and their children had used the devices like smartphones, tablets, and laptops. This could contribute to their ease of using FluidTrack, a technology-mediated system. All families were also able to afford the time and resources required to visit one of the largest children's hospitals in South Korea. While most parents had jobs (11 out of 14), in their absence, other family caregivers or teachers were available to monitor their children and assist the tracking. The engagement levels and experiences with the FluidTrack system may differ in populations with different conditions. Broadening research to encompass a more varied demographic, along with longtudinal study designs, would yield deeper insights into the long-term effectiveness of the FluidTrack system.

After four weeks of DUFS management, our clinical collaborator determined that the treatment was successful for all 14 child participants (10 via hospital visit; 4 via phone call), based on parents' self-reports of their child's behavioral symptoms. We indeed observed a downward trend in voiding frequency among thirteen of the children (Figure 8(b)) based on the captured data. While this is an exciting outcome, our study was not designed to assess the extent to which these behavioral changes were attributable to the FluidTrack system compared to a traditional treatment protocol. Also, the absence of pre-study data and a ground truth of the captured data made it difficult to confirm any changes in the children's three key behaviors that may have been introduced by using FluidTrack. Nevertheless, we believe that our study is a crucial first step in evaluating the feasibility of the FluidTrack system before conducting a large-scale study.

In this study, we chose to design a wristband with physical-button interface after carefully considering backgrounds related to preschool-age children. However, this specific design choice posed several challenges, including discomfort due to the wristband strap's texture, the device's relatively large size for their thin wrists, and difficulty of wearing it for prolonged periods. Two families adapted MoaBand into a different form (i.e., necklace-style) for improved comfort, while two other children preferred using MoaGardenApp over MoaBand. These findings indicate that providing alternative options and customizable form factors for data capture tools might enhance children's engagement in behavior tracking with a semi-automated data capture approach.

The feedback pages on MoaGardenApp were meant for both parents and children, so we did not include any complex visualizations or details that child audiences would not understand. Thus, we designed a bi-weekly Summary Report (section 3.3.2), with the expectation that parents would appreciate receiving children's data in a new format offering perspectives distinct from those in MoaGardenApp. These reports were designed for adult viewers—for example, featuring more detailed data using traditional charts and facilitating comparisons across weeks. However, we received lukewarm responses to these summary reports. While six parents acknowledged some benefits when asked about their thoughts, two other parents never checked the reports, believing they already knew their children's behavior patterns through MoaGardenApp, and another four parents did not find the report's presentation significantly better. These findings suggest that such detailed reports may be perceived as an additional burden for busy parents, highlighting room for improving parental supervision experiences.

Among the cases where children misused FluidTrack, C1's behavior of occasionally skipping the capture of voiding data to please P1 highlights a potential limitation in the reliability of self-reported data. According to P1's remark, this behavior seems to stem from prosocial motivations, aligning with the findings by Warneken and Orlins [79] and Popliger et al. [60]. These studies demonstrated that children often tell white lies with the intent to improve or protect others' emotional states, even at the expense of truthfulness. In the context of FluidTrack, such motivations may inadvertently compromise data authenticity when children prioritize social harmony or parental approval over accurate reporting. This limitation underscores the need for future research to address the influence of prosocial motivations on data reliability in parent-child collaborations. Potential directions include integrating objective data collection methods alongside self-reports or designing system features that reduce the pressure to conform to perceived expectations.

7 Conclusion

We developed FluidTrack, a pediatric patient-parent collaborative tracking system, to support conventional DUFS management by facilitating the tracking of patient's behavior and encouraging water intake. Engaging preschool-aged children in capturing and reflecting on their behavioral data for health management poses significant challenges. Thus, we introduced a semi-automated tracking approach as a means to reliably track complex behavioral data while balancing the workload between pediatric patients and caregivers. Through a 4-week deployment study with 14 DUFS patients and their parents, we observed that the majority of participating families enthusiastically engaged in data capture and reflection. Our pediatric patients appeared to actively engage in tracking tasks, with behind-the-scenes assistance from their parents. Sustaining this collaborative tracking, which involved intensive data capture tasks, relied heavily on the children's interest and curiosity, as well as the availability and involvement of their parents. Overall, our study demonstrated the feasibility of semi-automated data capture in filling the current gaps in DUFS management and provided valuable insights for designing future tracking systems that incorporate children as active participants in health management.

Acknowledgments

We appreciate our research participants' valuable contributions and feedback. We are grateful to Sang Woon Kim and Jieun Park for their dedication to patient recruitment and their support for participants. This work was supported in part by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. RS-2024-00336466), the Institute of Information and Communications Technology Planning and Evaluation (IITP) Grant funded by the Korean Government (MSIT), Artificial Intelligence Graduate School Program, Yonsei University, under Grant RS-2020-II201361, and the Yonsei University Research Fund of 2024-22-0058.

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