Ubiquitous Mobile Application for Conducting Occupational Therapy in Children with ADHD

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Abstract. Attention Deficit Hyperactivity Disorder (ADHD) is a prevalent neurodevelopmental disorder that affects a significant number of children worldwide. It represents learning challenges, profoundly impacting the child's attention and behavior. Occupational therapies face these challenges by involving the child in mirroring activities of daily life.

This article presents the creation and assessment of a mobile application that assists therapists in remotely observing children's behavior during occupational therapy at home. This mobile application belongs to a smart-home environment designed to conduct occupational therapies for children with ADHD. It uses Firebase to acquire and manipulate data from this environment. Therapists can obtain clear details about the children's behavior, better than in a conventional clinical setting. The 16-week experiment reveals that therapists find the application useful for decision-making in therapeutic matters and lets parents be more involved in the therapy. This leads to new ideas on how to use the app.

Keywords: Ubiquitous occupational therapy · Mobile application development · Cloud computing · Remote monitoring · Behavior tracking · Therapeutic Decision-Making

1 Introduction

Attention Deficit Hyperactivity Disorder (ADHD), recognized as the most common Neurodevelopmental Disorder (NDD), poses significant challenges to children worldwide. It is typified by a triad of characteristic symptoms: inattention, hyperactivity, and impulsivity. Despite extensive research in the field, the origin of ADHD remains enigmatic, with the precise underlying mechanisms yet to be fully clarified [1].

The clinical manifestations of ADHD frequently endure into adulthood and often exhibit comorbidity with other disorders, such as Autism Spectrum Disorder (ASD) or Anxiety Disorder. The presence of ADHD can have a detrimental impact on an individual's daily functioning, academic accomplishments,

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and productivity in the workplace [2]. Empirical studies indicate a potential correlation between ADHD in childhood and subsequent success in adulthood, underscoring the necessity for early detection and efficacious treatment strategies [3]. Therapeutic interventions span from pharmacological remedies to behavioral approaches like occupational therapy [4–6]. Therefore, ensuring accessibility to these treatment options is primary for enhancing the quality of life for children with ADHD and their families.

The main goal of occupational therapy is to help children become more independent in their daily tasks. This includes things they do at home and school, especially homework [7]. Nevertheless, many children with ADHD find doing homework on their own very hard. Because it takes a lot of effort and there's no immediate reward, they often get frustrated and give up. This can hurt their school performance over time [8].

This paper introduces an Android mobile application as part of a smart-home environment intended to monitor children with ADHD during in-home occupational therapies. The application delivers meaningful information to therapists and parents using cloud-centric data processing by Firebase.

The organization of this paper is articulated as follows: Sect. 2 reviews related literature and projects, highlighting what makes our study different and unique compared to others. Section 3 gives a brief look at the smart-home system from earlier research. This helps readers understand why we made this mobile application. Section 4 delineates the research methodology employed in this study, and gives details about the application's features, its role in the smart-home system, and how data was handled. In Sect. 5, we describe the main parts of our experiments and the test methods we used. This section also explains how the app might help children with ADHD, their parents, and therapists. Section 6 wraps up the paper by summarizing the main findings and suggesting future research directions in this area.

2 Related Work

In the healthcare field, Pozo-Guzman et al. introduced an IoT system within a cyber-physical setup to monitor COVID-19 patients in hard-to-reach areas, allowing for timely medical check-ins [12]. This system uses the Firebase real-time database for two-way communication: 1. Doctors can see patient data (like heart rate and blood oxygen levels) from online devices on a web application. This application shows patient recovery trends with clear charts. 2. Through the same app, doctors can send important advice and medicine details to the patient or their family. This technology helped reduce hospital crowding by keeping patient numbers manageable. Patients could recover at home, while healthcare workers closely monitored for any problems.

In ADHD diagnostics, Chandrasena et al. created a mobile application that incorporates a questionnaire and gaming activities designed to identify and diagnose symptoms indicative of ADHD, including hyperactivity, impulsivity, inattention, and organizational disorders. Firebase serves as the central server facilitating information processing within the application. While the system's precision may not currently meet optimal standards, the authors believe using machine learning can make it better. This would improve diagnosis accuracy [13].

In the area of ADHD treatment, Doan et al. described CoolCraig, a mobile app to help children with ADHD and their caregivers manage behaviors and emotions. The app works on two devices: a smartwatch for children and a smartphone for caregivers. The authors illustrate a usage scenario delineating how CoolCraig supports children and their caregivers using goals, rewards, and tracking emotions and behavior. A key part of the application is its notifications, reminding children to note their feelings and actions. Results show that using the app regularly has helped children behave better in different settings [14].

Relatedly, Dolon-Poza et al. created a machine learning system using Firebase to see how well occupational therapy works on a child with ADHD over time. This system takes data from a smart home setup to check behavior. It also predicts how a child might progress with their treatment with an accuracy above 80 %. This helps therapists adjust the therapy to better fit the child's needs [15].

Out of the mentioned studies, [12] is most similar to our work, but it centers on clinical settings. Meanwhile, [13,14] mainly create apps for ADHD diagnosis. On the other hand, [15] does not make an app, instead, it uses an algorithm in Firebase to predict how well occupational therapies might work.

Consequently, the application presented in this study encompasses distinct functionalities tailored to enhance occupational therapies for children diagnosed with ADHD, thereby complementing the previous work [15,16]. A comprehensive exposition of these functionalities can be found in the methodology and experiments sections of this paper.

3 Background

This mobile application acts as the primary interface in delivering occupational therapy to children with ADHD within a smart-home setting. It streamlines the monitoring process for therapists and parents, allowing them to oversee the therapeutic progress of their charges. The application not only grants access to data sourced from the smart-home environment and processed via Firebase but also enables customization of the smart-home settings to ensure ideal conditions for therapy sessions [16].

In previous research, we designed a smart-home setting characterized by a sensor network specifically placed in the children's study space at home for real-time behavioral tracking. This network incorporates various sensors-including pressure, motion, and distance-fitted into the child's desk and chair. These sensors detect behaviors like distraction, fidgeting, or leaving the workspace [17].

Additionally, we introduced a robotic assistant to this sensor network. Equipped with a camera, the robot uses shape recognition algorithms to identify other signs of distraction. Such behaviors might involve the child stopping their writing tasks or misusing their study materials, actions therapists often refer to as 'playing on the table' [18].

The robotic assistant performs two main functions: it acts as a bridge between the child and therapist and serves as a tool for behavior change. Using pre-recorded voice commands, it directs the child to adjust their actions during homework, offering useful feedback and encouragement similar to a therapist's guidance [19]. Moreover, the robot has interactive features via its built-in touch screen. This interface shows various menu options, allowing the child to convey needs like needing a bathroom break, asking for a pause, and seeking help, among others.

Figure 1 depicts the arrangement of the smart environment, highlighting the position and function of key components like the smart chair and smart desk, essential for evaluating the child's behavior. The integration of the robotic assistant in this setup is also showcased. Additionally, the figure visually represents how the mobile application connects and interacts with the smart-home environment. This application is crucial for real-time communication, data handling, and carrying out commands within this smart framework.

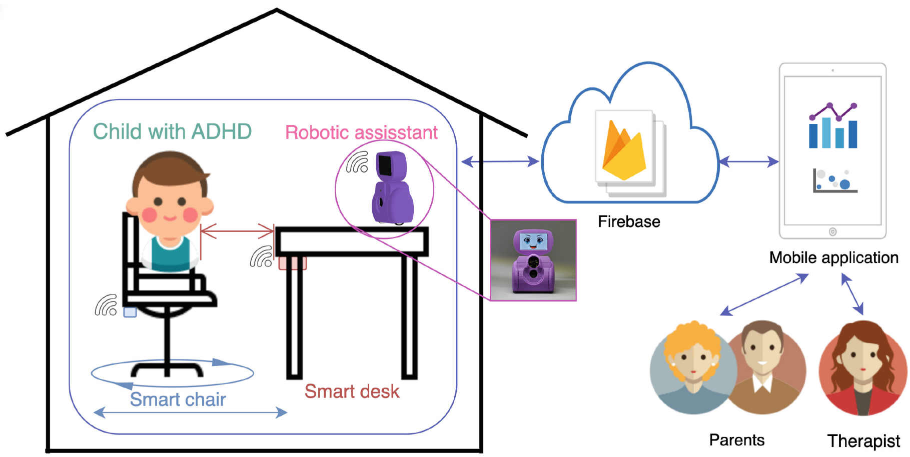

Fig. 1. Schematic of the SmartHome environment designed for pervasive occupational therapy for children with ADHD. This depiction shows the placement of various sensor devices and the robotic assistant within the house. These tools capture detailed information about the workspace, which is then relayed to Firebase for processing. The processed data can subsequently be accessed and visualized by therapists and parents via the mobile application developed in the course of this research.

4 Methodology

The application we developed incorporates four main features, as shown in Fig. 2. First, it supports real-time tracking of behavior and relevant therapy data. Second, it provides therapists with vital data from different therapy sessions. Third, it allows for remote customization of the smart environment and robotic assistant based on the child's unique requirements. Finally, it includes an authentication feature, ensuring only specific users, like parents and therapists, can access it.

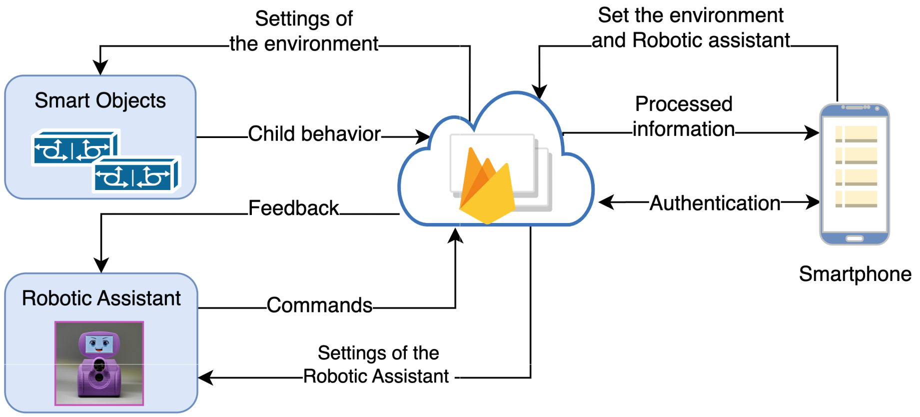

Fig. 2. Illustration of the interaction mechanism among the smart objects, the robotic assistant, and the mobile application, facilitated via Firebase. This diagram underscores the communication flow and data exchange among these entities in the context of the SmartHome environment.

We utilized Firebase[1] for the development of the smart home environment and the application presented in this paper. Here, we briefly discuss how Firebase facilitates the establishment of the smart environment and, in turn, the mobile application described in this article.

Feature 1. Remote Monitoring: The 'smart chair' and 'smart desk' are equipped with WiFi-enabled sensor devices, and a Raspberry Pi-based robotic assistant gathers acceleration, positional, and visual data during therapeutic sessions. After an initial pre-processing phase, significant distraction events are sent to Firebase. Moreover, children can engage with the robotic assistant to log task updates, request breaks, or seek help, and these interactions are recorded as events. Real-time synchronization with Firebase ensures that all events are thoroughly logged by the session's conclusion.

To tap into the real-time database, one must first establish a DatabaseReference instance, enabling data reading or writing. Data references can then have listeners attached to them, allowing for real-time data change tracking. Figure 3 depicts how data from Firebase's real-time database is mirrored in the mobile

[1] A platform owned by Google designed to streamline web and mobile application development. It offers various services such as real-time data storage, processing, user authentication, and push notifications. Moreover, it is compatible with many programming languages and integrates smoothly with Google tools [9–11].

application, facilitating child behavior monitoring. While Firebase's real-time database organizes the data alphabetically, the app offers flexibility in data presentation, allowing for custom ordering.

Feature 2. Information Processing in Firebase: Data stored in Firebase's real-time database is transformed into valuable therapeutic insights through protocols set by therapists for each child diagnosed with ADHD. These protocols are actioned by the Firebase cloud functions [18].

To deploy Cloud Functions, specific functions are written and triggered by events, such as updates in the real-time database. As demonstrated in Fig. 3 (Right), one distraction is labeled as "good". This suggests that a single distraction during the duration of the homework might not be detrimental. Cloud functions determine other such labels.

The valuable insights derived from the cloud functions are updated in the real-time database. Therapists then view these within the mobile application through graphical displays. These graphs chart the behavioral trends of each child during therapy sessions, for different tasks, or over specified durations.

Various behavioral patterns manifested by children diagnosed with ADHD can be identified and tracked. These include:

- **Hyperactivity.** This is discerned when the events recorded by the smart chair during task execution show unusual movements such as spinning, sudden bouncing, or acceleration in any direction. Therapists perceive these movements as indications of distraction stemming from playfulness.
- **Impulsivity**. This behavior is detected when events captured by both the smart chair and smart desk during the task indicate that the child often and for extended periods, leaves the workspace.
- **Wandering**. Even in the absence of hyperactive or impulsive events, if the image recognition by the robotic assistant determines that the child isn't actively participating in his/her task, it is termed wandering. Therapists label this state of disengagement as "the child is wandering".

The child's interaction with the robotic assistant, made possible through its touch-sensitive interface, generates crucial data. After each session, this data is sent to and analyzed by cloud services on the server side.

The generated data offers insights into three primary dimensions:

1. **Distraction Metrics:** Events categorized as distractions are numerically evaluated, accompanied by the duration from the initial distraction point until the child refocuses. A post-session analysis is carried out to assess the percentage of the session time wherein the child was distracted.
2. **Pause Metrics:** Situations in which the child signals the robotic assistant to pause are recorded, including the duration of each pause. These metrics are then contextualized as a fraction of the total session time, serving as a reference for comparison.

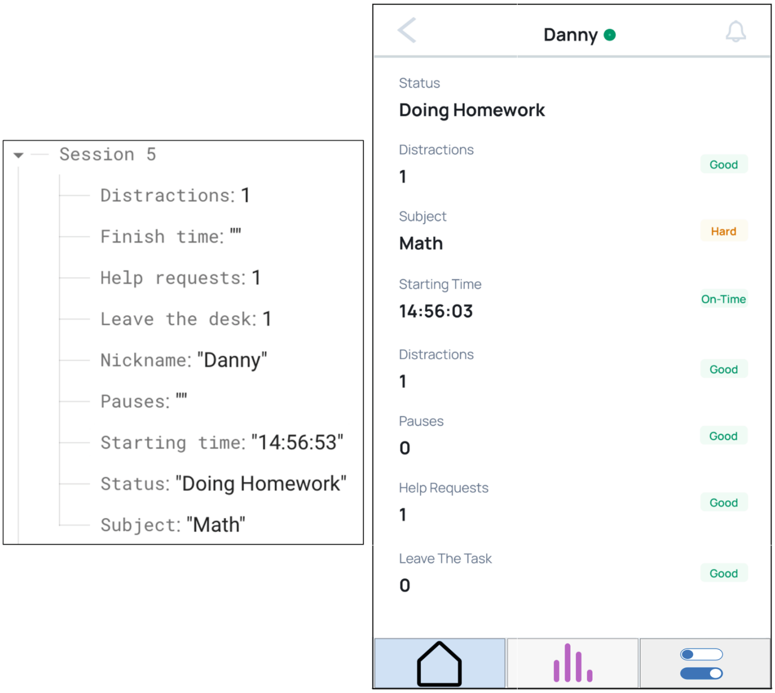

Fig. 3. (Left) Depiction of real-time data acquisition as represented within the Firebase real-time database, demonstrating the process of sensor reading collection. (Right) Visualization of the processed information within the mobile application, structured for easy comprehension and practical use by therapists and parents.

3. **Assistance Request Metrics:** When a child encounters obstacles that prevent task continuation, they can initiate an assistance request. This action triggers a specific cloud function, which, in turn, sends real-time push notifications to the parents via the designated application, ensuring they are updated about their child's needs. Moreover, the child can reach out to their therapists if necessary. Based on this request, the therapist can plan a follow-up session, providing interim feedback through the mobile app. This feedback is subsequently conveyed to the child through the robotic assistant.

In Fig. 4 (center), we illustrate the analytical findings of a homework session held on November 22, 2022. This compilation amalgamates data sourced from the integrated sensors of the smart environment as well as the interactive components of the robotic assistant.

Feature 3. Environment and Robotic Assistant Configuration: Distraction criteria vary, reflecting the unique attributes of each child. Hence, an initial calibration of the environment becomes imperative. The mobile application caters to personalized child profile adjustments, facilitating the meticulous configuration of both the smart devices and the robotic assistant. Such customizations can be carried out seamlessly through the application interface, without necessitating changes to the inherent code of the smart objects. Figure 4 (right) delineates how therapists can modulate sensitivity levels using predefined categories: highly sensitive, sensitive, normally sensitive, less sensitive, and non-sensitive, represented as intuitive sliding scales. This obviates the need for entering specific acceleration or distance metrics. A parallel approach is employed to tweak the response delay of the robotic assistant's feedback mechanism.

Feature 4. Authentication and Security: Firebase's security framework ensures that access to the application and individual child data is limited to authenticated users: specifically, therapists and the pertinent parents. The registration process mandates a two-step verification process executed through email. The extent of access granted to each user is inherently governed by their association with the child. Parents are granted access exclusively to their child's data. Conversely, therapists have the prerogative to both access and modify the data for all children under their professional supervision. For enhanced user convenience, the option to register via existing Google accounts is also incorporated. In facilitating these authentication dynamics, our application leverages Firebase Authentication APIs to effectively manage user registrations, log-ins, and user data management. The visual representation of the user account creation interface can be perused in Fig. 4 (left).

Through our endeavors, we have ascertained that Firebase furnishes an all-encompassing array of four salient features, all of which are seamlessly navigable through its intuitive console interface. These four distinct features were seamlessly embedded within the Android application by leveraging Firebase's Android-specific libraries. The assimilation procedure encompasses the integration of dependencies pertinent to Firebase libraries within the 'build.gradle' file, the subsequent initialization of Firebase within the application's milieu, and the definitive execution of the inherent capabilities of each respective service within the application's foundational code.

By harnessing Firebase's robust capabilities, we succeeded in crafting a versatile, highly scalable Android application that amalgamates an array of intricate functionalities. These include but are not limited to user authentication protocols, adept real-time data orchestration, cloud-centric functions, expansive data repository management, and dynamic user interactive modules. This application underwent rigorous evaluation through three distinct experimental methodologies, conclusively demonstrating its efficacy as an instrumental tool in facilitating occupational therapy for children diagnosed with ADHD.

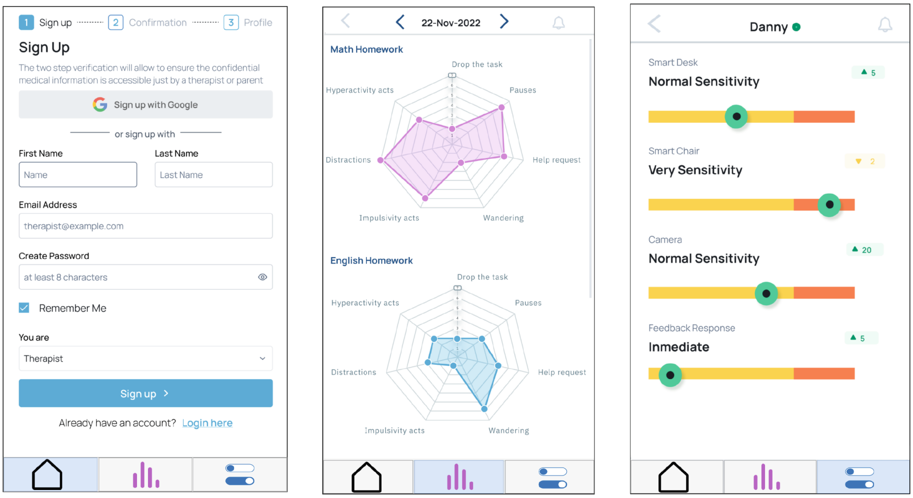

Fig. 4. (Left) The graphical user interface exhibited assists in the registration process for new accounts via the mobile application. (Center) The interface displayed here presents a detailed analysis of data gathered during a specific math and English homework session. This particular session illustrates the varying impacts of different homework assignments on a child, leading therapists to infer that math tasks necessitate a significant degree of exertion from the child. (Right) This interface enables the tuning of sensitivity parameters associated with the smart objects, in addition to the adjustment of feedback response latency in the robotic assistant.

5 Experiment and Results

The mobile application's effectiveness, when integrated with the smart environment, underwent rigorous validation across three distinct experiments over a 16-week duration. These experiments involved the collaboration of six seasoned therapists who meticulously selected a sample group of 32 children aged between 4 to 8 years, each exhibiting potential ADHD diagnostic indicators. Notably, to mitigate any experimental biases, the selected cohort exclusively comprised children without any comorbidities related to other disorders such as ASD (Autism Spectrum Disorder) or ODD (Oppositional Defiant Disorder). Before the onset of these experiments, informed consent was duly acquired from the parents, thereby ensuring the voluntary participation of their children in the study.

Table 1. Categorization of children into age-specific groups. Tasks have been allotted to each group by their cognitive developmental stage. For each group, two therapists are designated to observe and document the children's behavior, the first one with the mobile application and the second one without it.

Group	Age	Children	Task	Session time	Therapists	Period
1	4	2	Drawing	40 min	2	Week 1-2
2	5	2	Drawing	40 min	2	Week 1-2
3	6	4	Language homework	1 h	4	Week 3-4
4	7	5	Math and English homework	1 h	2	Week 5-6
5	8	3	Math and English homework	1 h	2	Week 5-6

5.1 The Experiments

During each experimental session, two groups were closely observed as they carried out their respective tasks. While one therapist utilized the application to monitor real-time results, the other conducted traditional monitoring, making manual notes on their observations. Post-session, the application's results were presented by the first therapist, and the second therapist shared their notes.

As depicted in Table 1, the initial two weeks saw both therapists overseeing activities involving 4 and 5-year-old children, who were assigned drawing tasks. Drawing, though seemingly simple, demands sustained attention-a quality often challenging for ADHD-diagnosed children. The therapist's roles alternated between weeks. In the initial week, Therapist 1 employed the application, leaving Therapist 2 with traditional monitoring. In the subsequent week, they switched roles.

Key observed behaviors included acts of impulsivity, instances of distraction, signs of hyperactivity, wandering, calls for assistance, pauses, and instances where tasks were abandoned. Yet, there remains potential for therapists to identify additional parameters to further refine the model's accuracy.

Notably, the therapists refrained from directly intervening or providing feedback to the children. The robotic assistant was solely responsible for this. While the first therapist's primary duty was passive observation, the second therapist meticulously documented interactions for post-session review.

5.2 Results from the Initial Experiment (Weeks 1 and 2)

During the initial experimental phase, we evaluated both the application's effectiveness in setting up the environment and establishing children's profiles and the accuracy of the smart objects compared to therapist observations.

From Fig. 5, it's clear that therapists not using the application had a reduced ability to record distraction events in the first week. In a role reversal in the second week, therapists who had previously used the application were less accurate than their counterparts. Their feedback suggested that having used the application, they found manual note-taking during standard monitoring to be redundant.

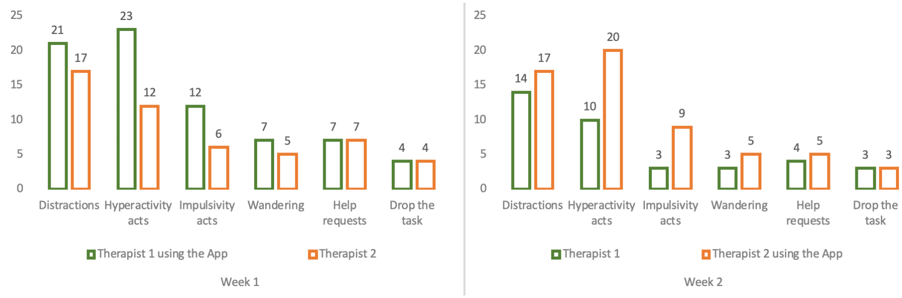

Fig. 5. Comparative analysis of the accuracy in identifying distraction parameters during sessions, between therapists employing the application and those not using it. The results depicted within the application are deemed to be the most accurate, as inferred from prior clinical validations of the smart-home environment [19].

At the end of each therapy session week, therapists' conclusions and reports varied noticeably. However, those utilizing the application consistently provided a more detailed and holistic overview of the children's progress in occupational therapy.

Finally, the therapists did not provide any feedback on enhancements for the application or the smart environment.

5.3 Results from the Second Experiment (Weeks 3 and 4)

During weeks 3 and 4, an identical experimental approach was applied to a sample of four 6-year-old children focusing on language tasks. Each child read three uniform short texts and discussed their interpretations post-reading with individual therapists to avoid fatigue; four therapists in total participated. Half of these therapists used the application for monitoring during the reading, while the others relied on traditional note-taking methods.

The experiment aimed to discern correlations between children's distraction metrics, as determined by both the app and manual therapist reports, and their comprehension of the readings. Responses to the text were graded on a scale from 1 to 5, with 1 indicating a poor response and 5 indicating a perfect understanding. While therapists were encouraged to remain objective in evaluations, a standardized rubric was provided to ensure consistent assessment across the board.

We cannot suggest that the children's performance is affected by the monitoring technique (with or without the use of the mobile application). However, it can be observed that therapists who used the application were more capable of drawing correlations between the children's performance during evaluations and the application's generated report.

Analyzing Fig. 6, it's evident that children monitored without the application displayed fewer distractions, implying better performance. However, Table 2 shows that the average grades across all children are relatively consistent. This

Table 2. Compilation of the average grades secured during the therapy sessions in the second experiment (weeks 3 and 4).

Child	Grade Text 1	Grade Text 2	Grade Text 3	Average grade
1	2.5	3.2	3.1	2,9
2	3.5	2.8	3.0	3,1
3	2,9	4.1	2.9	3,3
4	3.0	2.3	3.1	2,8

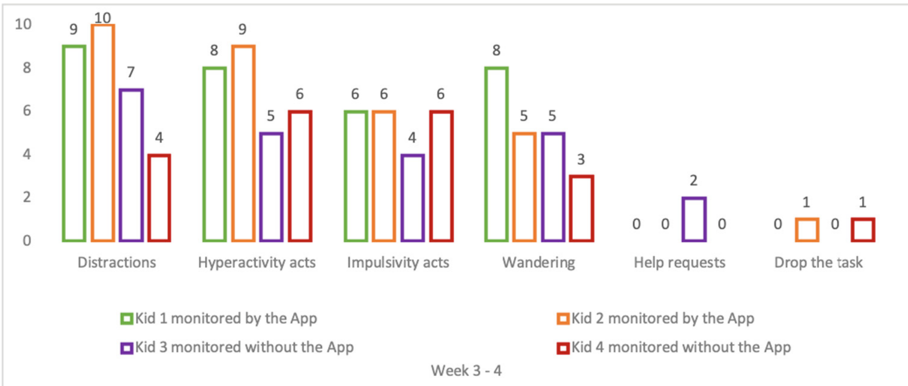

Fig. 6. Comparative analysis of the accuracy in detecting distraction parameters during sessions, contrasting between therapists employing the application and those abstaining from its use. The results presented within the application are regarded as the most accurate, backed by prior clinical validations of the smart-home environment [19].

suggests that therapists using the application could more effectively convey and support their observations about performance in each reading session's final evaluations. In contrast, therapists relying on traditional monitoring methods had limited data to validate these findings.

5.4 Results of the Final Experiment (Weeks 5 and 6)

The third and concluding experiment focused on the remote monitoring of eight children, all aged between 7 and 8 years, as they undertook their math and English homework assignments. Additionally, this trial involved the active participation of the children's parents, summing up to eight involved parents in total.

Our primary aim with this experiment was to gauge the application's clarity and understandability to parents, particularly those unacquainted with the nuances of occupational therapy. Following every therapy session, parents were presented with a questionnaire to assess their ability to comprehend and interpret the data and insights shared by the application.

The ensuing results were promising. Parents demonstrated a comprehensive understanding of their children's behavior. They were notably adept at recognizing instances when their children were becoming distracted during tasks. Of particular interest to the parents was the data about the time their children took to finish their homework and the weekly count of distractions they faced. This newfound knowledge inspired parents to be more proactive in aiding their children with their tasks and engaging in conversations to pinpoint potential domestic sources of distraction.

This trial served to reaffirm the outcomes of the first two experiments, where therapists employed the mobile application. The app proved instrumental in offering a detailed insight into the children's behavior, paving the way for a more refined and tailored approach to subsequent occupational therapies.

5.5 Findings

In our study, after careful experiments and analysis, we identified several key findings. These insights showed the effectiveness of the application and its impact on therapists and parents, highlighting the potential of technology to enhance ADHD therapies.

> **Finding 1:** The app enables effective remote tracking, showing a child's behavior during tasks. This simplifies therapy planning and improves timely decisions, including ADHD medication adjustments.

From a usability standpoint, our research brought to light a significant discovery. This observation not only underscored the importance of user experience but also highlighted the effectiveness and ease with which therapists and parents interacted with the application.

> **Finding 2:** Users found the app easy to use without facing any errors or issues. Parents have become more involved in their child's therapy and therapists could set up and personalize the smart-home environment, even without technical expertise.

The findings prove that the app is a transformative tool for managing ADHD challenges during occupational therapies at home. Its capacity for effective remote monitoring provides real-time insights into a child's behavior, streamlining therapy planning and enabling prompt therapeutic decisions, including medication adjustments. Its user-friendly interface ensures that parents engage more deeply in their child's therapy, and therapists, irrespective of their technical acumen, can seamlessly configure the smart-home environment. This cohesive integration of technology, parents, and professionals suggests a promising future for ADHD management.

6 Conclusions

The developed mobile application contributes as a critical tool enabling the ubiquitous execution of occupational therapies. It delivers real-time data capabilities, granting therapists and parents the necessary means to observe a child's behavior during tasks, and critically evaluate their progress promptly.

To enable comprehensive data interpretation, the application incorporates advanced visualization features that generate structured and categorized graphs and tables. These sophisticated tools provide a high-resolution view of the therapeutic journey for each child, tracing their progress over a designated time frame and allowing for a detailed longitudinal analysis.

This systematically collated information is stored within individual child profiles. Utilizing this accumulated data, therapists are better equipped to make informed decisions about the therapy's course, thereby promoting dynamic adjustments based on a child's demonstrated progress and immediate needs.

The application also offers robust customization capabilities for therapists, enabling them to calibrate the smart-home environment and robotic assistant according to specific requirements. This includes the capacity to fine-tune the sensitivity of smart objects, such as the chair and desk, to detect events like distraction or abandonment of the workstation. Additionally, therapists can define how the robotic assistant processes the actions captured through its camera, allowing for greater discernment between distraction, brief pauses, or the emergence of novel behavioral patterns.

Following experimental trials, the application has received favorable responses from both therapists and parents, who view it as an invaluable resource in therapeutic analysis. Its ability to simplify the acquisition and interpretation of data, tailor insights to individual child profiles, and present outcomes derived from therapy sessions, underscore its utility.

Regarding scalability, the application exhibits potential for adaptation across varied therapy scenarios, transcending the constraints of a home environment. Therefore, the utilization of Firebase as a robust and scalable platform for the application seems highly appropriate. Future work should focus on broadening the application's functionality to cater to a wider range of therapeutic needs, including the treatment of conditions like ASD and Anxiety Disorder.

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