Initial Validation of an Assistive Technology to Enhance Executive Functioning Among Children with ADHD

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ABSTRACT
Children with Attention Deficit and Hyperactivity Disorder (ADHD) experience a deficit in cognitive processes responsible for goal-directed behaviors, known as executive functioning (EF). In an effort to assist them, we developed TangiPlan – a prototype of a tangible assistive technology intended to improve EF during morning routines. TangiPlan was designed based on the following guidelines: implement intervention techniques recommended by experts; reduce conflicts with caregivers; avoid intrusion; support flexibility and autonomy. These design guidelines were implemented in a prototype consisting of six tangible objects, each representing a task that needs to be completed during a child's morning routine, and a tablet application for planning tasks and matching them with objects. An initial evaluation of the prototype with two case studies resulted in improved organization and time management, increased satisfaction, and fewer conflicts with parents during morning routines.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Prototyping, User-centered design.* K.4.2 [**Computers and Society**]: Social Issues – *Assistive technologies for persons with disabilities.*

General Terms
Design, Human Factors.

Keywords
ADHD; Executive Functions; Time Management; Children; Tangible Interface; Assistive Technology.

1. INTRODUCTION
"I set the alarm clock to go off every two minutes, but after the first alarm I just… turn off all the alarms without even opening my eyes. I go back to sleep until my parents wake me up… then I have to really quickly brush my hair and get dressed… and then I realize I forgot to put some things in my bag, and I have to eat something before I take my Ritalin, so my parents yell at me 'we're late, we're late'. I go out with my shoes in one hand, with my bag still open and a lot of things I need to put in it".

(Girl, 13.5, diagnosed with ADHD).

Attention Deficit and Hyperactivity Disorder (ADHD) is reflected in a persistent pattern of inattention and/or hyperactivity-impulsivity [2]. Individuals with this disorder, estimated at 3%-7% of school-age children, may have difficulties sustaining attention, and often find it hard to persist with a task until completion. They are easily distracted and often forgetful in daily activities [2].

Central to the meaning of ADHD is a deficit in Executive Functioning (EF) – cognitive processes responsible for ongoing, purposeful, goal-based behaviors [6, 10]. As the testimonial opening this paper implies, behavioral manifestations of poor EF include difficulties with Organization, Time Management, and Planning (OTMP), which adversely affect children's everyday functioning [3]. OTMP difficulties reflect a performance rather than a skill deficit. Therefore, interventions that encourage goal-based behaviors could potentially increase the occurrence of these behaviors [5].

We developed an assistive technology to help middle school children with ADHD improve EF during morning routines, particularly OTMP. Our prototype, called TangiPlan, is comprised of six tangible objects and an application for tablets. In this paper we describe the prototype, and report findings from an initial evaluation with two case studies.

2. RELATED WORK
Several technologies aimed to improve EF were developed in recent years. For example, TaskTracker [7] is a smartphone application enabling users to define tasks, set alarms and motivational messages, and then track actual progress. ProcedurePal [4] is an application for rehearsing common daily tasks. Tasks are defined and divided into smaller steps, each represented by an image. Users view the images to learn how to perform the task. Basic Calendar [8] is an application that enables task-tracking through a customized calendar interface. Technologies beyond the smartphone include Time Timer (http://www.timetimer.com) – a physical timer with a red disc that disappears as time elapses, making it easier to visualize how much time is left for completing a task; and Watchminder (http://watchminder.com) – a wrist watch for setting vibrating alarms. Time Machine [1] utilizes marbles to represent time. Users fill a cylinder with marbles according to their estimation of time required to complete a task. Every 30 minutes, a motor drops

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one marble from the cylinder into a collection rail, which serves as a visual graph of how users spend their time.

While these systems address various aspects of EF, most were not designed for children with ADHD, therefore it is unclear how suited they are for this population. In contrast, our prototype was tailored to the unique needs of children with ADHD.

3. THE TANGIPLAN PROTOTYPE

TangiPlan is a prototype aimed to improve middle school children's OTMP skills. TangiPlan was designed according to guidelines suggested by Weisberg et al. [9] specifically for an assistive technology for children with ADHD. These guidelines were based on interviews with experts and representatives of the target population: (1) implement intervention techniques recommended by experts (e.g., divide complicated tasks into smaller ones, plan a daily schedule and allocate time for each activity, write to-do lists and reminders, use a stop-watch to track task completion time); (2) reduce conflict between caregivers and children; (3) avoid intrusion; (4) support flexibility and autonomy. In addition, we opted to use a tangible interface, in line with the "Objects for Change" framework [11], suggesting that tangible interfaces are particularly suited for supporting behavior change.

TangiPlan is comprised of six tangible objects, and an application for tablets. Each object represents a task that needs to be performed by the child during the morning routine. Using TangiPlan consists of two main stages: planning and execution. During the planning stage, which occurs the previous evening, the child uses a tablet application to divide tomorrow's morning routine into small tasks, and allocate time for completing each one (in accordance with design guideline 1 mentioned above). The child then pairs each task with a tangible object, and places each object at the location where the task is supposed to be performed (e.g., an object representing the "brush teeth" task is placed near the sink). It is important to note that children define their own tasks, set their own target times, and place objects at locations of their choosing (in accordance with design guideline 4). During the execution stage, which occurs the next morning, objects serve as physical reminders for performing corresponding tasks. The child presses a button on each object before starting a task. As time elapses, green light flows in a downward direction across the front panel, resembling a "digital hourglass". Each individual light represents 30 seconds. When the allocated time per task is up, red light begins to flow in an upward direction, signaling a delay. When the task is completed, the child presses the button again. Lights can be easily observed from several angles, and they are relatively non-intrusive (in accordance with design guideline 3). The order in which tasks are performed is flexible, a certain task can be performed first one day, and last another day. This enables children to adapt to external circumstances, as well as maintain a sense of autonomy (in accordance with design guideline 4).

The tangible objects are connected to a web server to enable real-time monitoring through the tablet application. Real-time monitoring can remind children to complete overlooked tasks before they leave the house. In that manner, TangiPlan enables children to monitor their own behavior, releasing caregivers from "policing" duties. However, TangiPlan does enable parents to track their child's progress from their own device, if they wish to do so (in accordance with design guideline 2). Since the main goal of the system is improving OTMP, and repetition helps improve skills, children are required to update their tasks every evening. The screen for updating tasks indicates how long it took to complete each task yesterday. If completion time for a certain task was equivalent to or shorter than allocated time, the task is highlighted in green. If completion time was longer than allocated time, the task is highlighted in red (see Figure 2). Time between tasks is calculated as well, and highlighted in red if longer than one minute. Based on this information, the child can choose to allocate more or less time to a certain task. To minimize negative feedback, delays under 30 seconds are overlooked.

3.1 The Tangible Objects

TangiPlan objects are 3D-printed in the shape of a truncated square pyramid. The electronic components embedded inside the objects include a Spark Core board with an on-board WiFi capability, a NeoPixel RGB LED Stick, and a Lithium Ion cylinder-shaped battery. The entire front panel is transparent to allow LED lights to be easily observed from several angles (see Figure 1). Each object communicates individually with the server to receive updated task time, and to report task completion time.

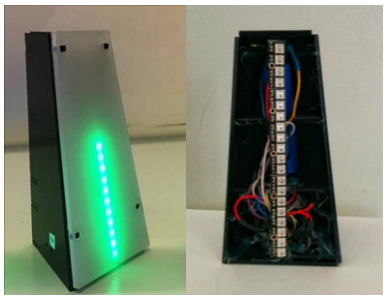

Figure 1. Left: active object. Right: uncovered object.

3.2 The Tablet Application

The TangiPlan application is a web-based HTML5 service, designed to run on 11 inch tablets. The application guides children through the planning stage. On the first screen they are asked to set "wake up" and "ready to leave" times. On the second screen they are asked to define tasks (up to six), and allocate time for completing each one. On the third screen they are asked to match each task with an object. During the execution stage, the application serves as a virtual check list, enabling children to track task completion in real-time.

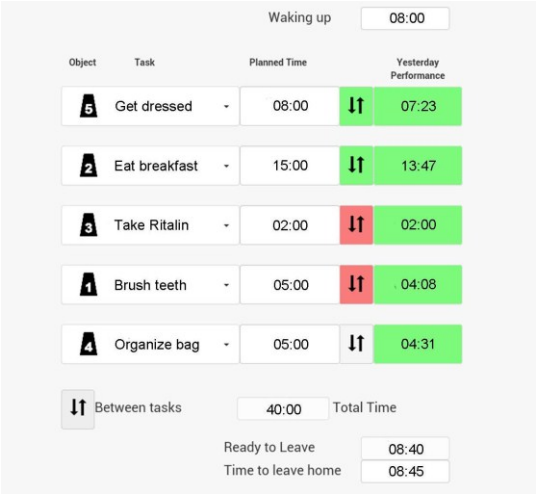

Figure 2. The tablet application after one day of use.

4. CASE STUDIES

As a preliminary evaluation of TangiPlan, we conducted two field deployments, aimed at gauging the response of both children and parents to the prototype.

4.1.1 Participants

Child 1 was a boy, 13 years old. Child 2 was a girl, 13.5 years old. Both were previously diagnosed with ADHD, and have been receiving medicinal treatment for their symptoms. They were referred to the study by their psychologist; their participation was approved by a parent.

4.1.2 Measures

Both children and parents answered questionnaires on the first and last day of the study. The questionnaires for the children included items regarding satisfaction with the current morning routine, and level of parental involvement during the morning routine. The parental questionnaires included background questions regarding the child's ADHD diagnosis, as well as items regarding satisfaction with the child's current morning routine, and level of parental involvement during the child's morning routine. All items were rated on a 5-point Likert scale. A more in-depth examination of subjective experiences while using TangiPlan was achieved through semi-structured interviews with the child and their parent on the last day of the study. Participants were encouraged to express their views regarding their morning routine, and the different components of the TangiPlan prototype.

4.1.3 Procedure

On the first day of the study, a research assistant visited each family at their home. She asked both the child and the parent to fill out questionnaires, and then explained to the child how TangiPlan works. She left the prototype at the family's home (2 weeks in the case of family 1; 4 weeks in the case of family 2, to compensate for non-routine days due to class trip and sickness). On the last day of the study, the research assistant visited each family again. She asked both the child and the parent to fill out questionnaires, took pictures of locations in which the tangible objects were placed, and interviewed the parent and child together for approximately 30 minutes. The interviews were recorded; the recordings were later transcribed. Two researchers independently analyzed the transcriptions to identify emerging common themes.

4.1.4 Results and Discussion

Before using TangiPlan, both children encountered difficulties during their morning routine. For Child1, time management was the greatest difficulty, whereas for Child2 time management and organization were both difficult. The testimonial that opened this paper described the typical morning routine of Child2. As a result, parents had to be highly involved in their child's morning routine.

After they started using TangiPlan, both children implemented techniques recommended by experts for improving OTMP (Child2: *"Usually I lie to myself that I'm on time, but then I run late because I don't know how to organize things, and {TangiPlan} organized my time so I wouldn't waste it"*). Children and parents alike noticed an improvement in OTMP, resulting in the child arriving at school on time (Child1: *"I concentrated on organization, I had a goal to be on time"*. Mother1: *"It made him think about movement through space, organization in the morning, what to do before, what to do after, it gave him structure"*. Child2: *"There's something that tells me 'here, press', now you need to be active, you need to {meet goals}, you need to look at it, you can't say 'I'll get dressed in bed because I'm cold' and then fall asleep"*). Tasks defined by Child1: brush teeth, get dressed, wear shoes, eat and take Ritalin, do physiotherapy, take cellphone. Tasks defined by Child2: shower, brush teeth, get dressed, organize things, eat and take Ritalin, verify I have everything. Both children reported that the order of performing tasks changed daily. The list of tasks or time allocated per task were edited during the course of the study, though not often, because routines remained fairly consistent (Child1: *"If I didn't finish a task on time, I increased the time a bit. If I was on time, I left it the same, unless there was a big gap and then I decreased it"*. Child2: *"When it became less warm I stopped showering in the morning, so I removed this task and the times changed a bit"*).

The children had fewer conflicts with parents and siblings while using TangiPlan (Mother1: *"He bothered {his little brother} less, he had less time and he was focused on the goal"*. Child2: *"I didn't bother my mother in the morning that I don't have anything to wear… and I had time to eat before taking Ritalin, so she didn't have to yell at me… I think I used to ruin their mornings. {With TangiPlan} my morning was much more pleasant"*. Mother2: *"I could let go a bit, instead of 'get up, get up, get up, how long does it take to get dressed?'... Our mornings were quiet and fun, for everybody"*). Parents did not monitor their child's progress in real-time, even though the system enabled them to do so (Mother1: *"I didn't use the link even once… I don't like parental monitoring"*).

Similar results were reflected in questionnaire ratings, which showed increased satisfaction and decreased parental involvement in morning routines while using TangiPlan (see Table 1).

Table 1. Ratings (1-5) of satisfaction with morning routine, and level of parental involvement in morning routine, prior to and while using the TangiPlan (TP) prototype

	Satisfaction		Parental Involvement	
I.D.	**Before**	**TP**	**Before**	**TP**
Child1	3	4	4	2
Mother1	3	4	3	2
Child2	3	5	4	1
Mother2	2	5	5	2

Interestingly, Child1 placed each object at the location of the corresponding task, whereas Child2 placed all objects at the same location (*"I simply put them all on my desk… it was more convenient when they were all in a row… everything is rather close to my room after all, so I press, I go brush my teeth, I come back and press again"*) (see Figure 3). She turned each object to its side upon completion of the corresponding task.

Figure 3. Left: Child1 placed each object at a different location. Right: Child2 placed all objects at the same location.

It seems that the physical design of the object was intuitive (Child2: "*The button is on top and convenient to press, simple and easy… not too many buttons and things, just press and there are lights"*). However, the objects were perceived as fragile by all participants, as too big by Child1, and as somewhat dull by Child2. The children were not satisfied with the representation of elapsing time in a non-detailed form through lights; neither child understood how much time they had left for completing a task just by looking at the lights. For that reason, Child1 wished to replace the lights with digits (*"It's better to write the exact time, no lights, just minutes")*. The representation of elapsing time ought to be further investigated. However, participants did understand that a change in the color of the lights from green to red indicated they were running late (Child2: *"It's cool that it changes colors, because it draws attention to the fact that time is up")*. Neither child described TangiPlan as intrusive, nor did it bother other family members.

The main obstacle for using TangiPlan was technical problems. In both cases objects temporarily stopped working during the study, due to battery depletion or unstable WiFi connection with the server. This led to disappointment (Child1: *"It was very annoying that sometimes the objects didn't work"*). The stability, durability and battery usage of the objects ought to be improved. Nonetheless, both families expressed a strong wish to use future versions of the prototype.

5. CONCLUSION AND FUTURE WORK

Children with ADHD experience a deficit in organization, time management and planning (OTMP). We presented a tangible assistive technology intended to improve OTMP during morning routines. We based our technology on previously suggested design guidelines, and implemented them in a prototype called TangiPlan. The prototype consists of six tangible objects, each representing a task that needs to be completed during the morning routine, and a tablet application for planning tasks and matching them with objects. We provided initial validation for the prototype through two case studies, resulting in positive responses from children and parents alike. Future work will include technical improvements and modifications to the design, followed by controlled studies for evaluating the effectiveness of TangiPlan.

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