Published in IDC '16: Proceedings of the the 15th International Conference on Interaction Design and Children: Manchester, UK, June 21-24, 2016. New York: ACM. pp. 196-205.
http://doi.org/10.1145/2930674.2930693

# Seeking Independent Management of Problem Behavior: A Proof-of-Concept Study with Children and their Teachers

**Camellia Zakaria[1], Richard C. Davis[1], Zachary Walker[2]**

[1]School of Information Systems,
Singapore Management University,
Singapore
**{ncamelliaz.2014, rcdavis}@smu.edu.sg**

[2]Early Childhood & Special Needs Education,
National Institute of Education,
Singapore
**zachary.walker@nie.edu.sg**

## ABSTRACT
Problem behaviors are particularly common in children with neurodevelopmental disorders like Autism and Down syndrome. These behaviors sometimes discourage social inclusion, inhibit learning development, and cause severe injuries, but caregivers are often unable to attend to their children immediately when the behaviors occur. Recent research shows that problem behavior can be automatically detected with wearable devices, but it is still not clear how to reduce caregivers' burdens and facilitate academic, social, and functional development of children with problem behaviors. We conducted a field study at a school with 21 children who exhibit problem behaviors and found that they needed frequent interventions in the form of visual cue cards and verbal reminders. We then developed a proof-of-concept that uses smart watch notifications to help children control their behavior without intervention from caregivers. A preliminary evaluation indicates that notifications modeled after teachers' current intervention strategies can help children control their problem behaviors.

### Author Keywords
Problem behavior; wearable computing; children; Autism Spectrum Disorder; Down syndrome; proof-of-concept

### ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

## INTRODUCTION
Young children with neurodevelopmental disorders like Autism Spectrum Disorders (ASD) and Down syndrome are at risk of developing problem behaviors, such as *body rocking, head banging,* or frequent *screaming* or *crying*. These behaviors typically manifest in children due to stress, anxiety or attention seeking [5]. While these behaviors can be benign and even comforting, they can become injurious or discourage social inclusion and learning development if left unchecked [5,10]. For these reasons, problem behaviors often warrant intervention from caregivers (i.e. teachers, parents, or helpers). However, due to the frequency of these behaviors, it is not always possible for caregivers to give their children the supervision they require.

Children need to develop healthy coping strategies to control their behaviors. Some researchers have developed tools that recognize common stereotypical behaviors using wearable sensors like accelerometers and heart rate monitors [16]. Researchers have used these recognizers to develop automated behavior measurement tools that help parents and caregivers understand and improve their response to problem behaviors [9,16]. In contrast, the goal of our project is to design automated interventions that help children manage problem behaviors without intervention from a caregiver.

We conducted a field study at a school for children with special needs in Southeast Asia. Ten teachers described their daily experience with 21 children who exhibit a variety of problem behaviors. This study clarified when behaviors were harmful and how they were controlled in class. We also learned that problem behaviors often take root because children lack support for developing and maintaining positive behavior outside of school.

Based on our field study results, we built a proof-of-concept for a system that helps children independently manage their

**Figure 1. A child participant who would scream when walking was asked to run errands during our final evaluation. A customized visual-haptic or audio notification was sent to the smart watch when the behavior was observed.**

behaviors. Children wear smart watches paired with smart phones (see Figure 1). Recognition is simulated through wizard-of-oz: when a problem behavior is observed, the teacher sends a customized visual-haptic or auditory notification to the watch reminding the child to stop. We evaluated this prototype in a field experiment and found that three of the four children we observed responded positively to our notifications. Our results show how fully automated systems could reduce the burden on caregivers who manage problem behaviors.

The contributions of this paper are:

1. A field study of ten teachers who work with 21 children with problem behaviors. The study reveals why and how to design automated tools that control such behavior.
2. A proof-of-concept prototype that helps children manage problem behaviors by sending customized notifications to their watch when behavior occurs.
3. An evaluation that compares the effectiveness of two types of notifications (visual-haptic and audio) on four children with problem behaviors.

## RELATED WORK

We now look at existing research related to problem behavior. Our focus here is on the kinds of intervention strategies used by practitioners and systems designed for treating such behavior.

### Assessment and Interventions to Problem Behavior

Problem behaviors are most common among children with neurodevelopmental disorders like ASD and Down syndrome who have limited communication skills or poor social development [5]. Behaviors such as aggression, disruption, self-injury, and stereotypy may hamper a child's learning development and social participation, especially when it becomes part of their behavioral repertoire [10]. Therefore, many problem behaviors are severe enough to warrant intervention.

However, choosing the best type of intervention is challenging, because problem behaviors have many causes. For example, children with ASD are often sensitive to changes in daily activities. Research has shown that some children with ASD perform better in task-training sessions when they are allowed to engage in stereotypical behavior like *hand flapping* and *tongue clicking*, although such behavior could eventually become problematic [21]. On the other hand, a child exhibiting problem behavior may simply be seeking attention or escape from difficult tasks [14]. For these reasons, determining when and how to intervene requires caregivers to make good judgments about the child's behaviors and responses.

Much research has been dedicated to finding appropriate intervention strategies for problem behavior. Traditionally, problem behavior was treated using punishment [8,10]. One basic form of punishment is physical restraint [6]. Another form of punishment is response blocking, where a caregiver blocks a child from receiving the physical sensation of a problem behavior [12]. For example, a caregiver may place their hand between a child's hand and a hard surface to block the sensation of tapping [13]. We found that teachers in our field study commonly use response blocking on children who exhibit self-injurious behaviors like *head banging* and *biting*. Response blocking may seem like a rational choice, especially in preventing self-injurious behavior, but it may lead to an increase in other problem behaviors [13]. Consequently, researchers discourage the use of response blocking or recommend that it be used in combination with alternative stimuli [13].

Recent research has recommended the use of functional behavior assessment (FBA) before interventions [8]. This research led the U.S. Individuals with Disability Education Act (IDEA) to mandate FBA before treating problem behaviors [23], and it has since become a best practice for treatment in behavioral problems [4,8,10]. Methods to conduct FBA generally involve making direct observations and manipulating environmental settings in an attempt to investigate the cause of problem behavior. This helps the caregiver decide on a treatment for the problem behavior [8].

For practitioners using FBA, instruction is the most common intervention strategy [10,14]. Instruction-based intervention provides direct instruction on a targeted behavior [10]. This includes prompting strategies using visual cue cards, self-management skills using recurrent alarms, and telling social stories to children about good behavior [3,10]. A review on interventions for problem behavior found that visual cues reduced aggression and social stories were a common treatment for vocalization [14]. These findings are consistent with those of our field study. Instruction-based intervention was the primary strategy adopted by our teacher participants to help children with problem behaviors in school.

Our work focuses on providing automated instruction-based interventions. We aim to develop a system that delivers these interventions in an appropriate way at an appropriate time, but only if a caregiver determines that instruction should be the primary intervention strategy. FBA is the best strategy caregivers can use to make this determination, and many countries that practice *inclusive education* [17] train special education teachers to use this strategy. Unfortunately, many countries in Asia still struggle with delivering comprehensive teacher training for special needs [17], and none of the teachers in our studies received such training. In any case, our results are applicable whenever instruction is a caregiver's primary intervention strategy.

### Assessment Tools for Problem Behaviors

Increased research into intervention using behavior assessment has led to a growing interest in using computing technologies to assess behavioral problems. This work focuses on automating behavior measurements to provide simple and systematic evaluations for professionals.

### *Detecting Problem Behaviors*

Westeyn et al. spearheaded the development of recognition systems for problem behaviors by using accelerometer sensors to detect seven types of stereotypy [10]. Similarly, Plötz et al. built a system to recognize a range of problem behaviors [19]. The use of simulated data is a drawback for both of these systems, as variation in patterns for each behavior cannot be generalized to all children with similar habits. Albinali et al. bridged this gap by recruiting six children with ASD who exhibited *hand flapping* and *body rocking* behaviors to gather real training data. These participants were observed over a period of 12 months to build a recognition model for each child using the C4.5 classifier [1]. This system was later revised to detect *hand flapping* and *body rocking* in six children using the SVM and Decision Tree classifiers, achieving better results [7].

In other related work, Min et al. mentioned the use of audio sensors to detect *vocalization*, though no results were discussed [15]. Similarly, Kientz and Westeyn considered the use of existing voice recognition technologies to recognize *vocalization* like *screaming* and *giggling* [11,20]. Finally, there are many examples of systems that recognize *walking* and *running* [2,22]. However, we are not aware of any work that seeks to recognize when these activities are problematic.

While research on the recognition of problem behaviors is still ongoing, we believe there is sufficient progress to assume that wearable devices will be able to detect the physical movements and sounds in most behaviors. In our work, we are more concerned with identifying the types of behaviors that need detection, when these behaviors should be managed, and how they should be managed.

### *Assessment Tools*

Progress in recognition of problem behaviors has prompted several researchers to investigate real-time recognition and assessment. Nazneen et al. designed a wrist-mounted accelerometer and heart rate monitor prototype, and developed a visualization interface for problem behaviors. The shared visualization aimed to help caregivers better understand the causes of such behaviors. [16] Several findings from this research are similar to our own. First, both parents and teachers felt a need for a scheduling system to maintain structure in the child's daily life. Both also liked the idea of better coordination between school and home. Finally, the authors stressed the need to customize the color, textures, and types of wearable sensors to fit each child's needs, just as our results show a strong need for customization.

The work presented here supports our effort to build a management tool for problem behaviors. Automatic detection of problem behavior is technically feasible and can be used to monitor children's behavior. However, it is not yet clear that it can be used to help children manage their own behavior.

## FIELD STUDY

We conducted a field study to observe how problem behaviors are currently managed in our home region, Southeast Asia. We also looked for evidence that automatic detection of these behaviors could help children manage their own behavior.

### Method, Participants and Environment

We conducted semi-structured interviews with ten teachers from a school for children with special needs in Singapore. All students at the school have some form of intellectual disability (IQ less than 55) and are between the ages of 7 and 17. All teachers at the school have completed a one-year Special Education diploma and have at least ten months experience working with children with special needs. The teachers we interviewed led or assisted with "Special Behavior" classes for children who exhibit behavioral problems. The curriculum in these classes emphasizes character development more than academics. Teachers further categorized some of these children as *advanced*. *Advanced* children were able to do the following:

- Complete homework and other daily school tasks with less guidance.
- Communicate with teachers through meaningful use of language, even if unable to interact socially with peers.

Each interview began with the teacher filling out a demographics survey and a questionnaire that asked about their students' age range, types of disability, and familiarity with smart devices such as iPad. We then began a semi-structured interview guided by three questions:

1. What are the kinds of behaviors you find problematic in class?
2. What strategies do you use to manage these behaviors for each child? Do behaviors in one student affect the dynamics of the class? If so, how do you manage these reactions?
3. What do you know about the child's wellbeing at home? What are the kinds of concerns expressed during the 'parent-teacher' meeting? What do you observe during your home visits?

At the end of each interview, we explained our design goals to the teacher and asked for their thoughts about how wearable devices could be used to manage problem behaviors.

Interviews took place in a dedicated room at the school and lasted about 30 minutes. Sessions were conducted after normal school hours.

### Results

Our ten teachers identified 21 children who frequently require intervention for behavioral problems, spread across nine different classes. Most children (18) were diagnosed with ASD, one was diagnosed Global Developmental Delay (GDD, a condition with delayed physical and mental development), and two were diagnosed with Down

| | | | | Topograhy of Behaviors | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A | | B | | | C | D | | | | | E |
| Disability | Child | Gender | Advanced? | running | walking (wander) | body rocking | hand flapping | vocalize | body freezing | hand banging | head banging | scratch/pinch | nose picking | biting/licking | throwing |
| ASD | C1 | M | Y | Potentially problematic | | Potentially problematic | | | | | | | | | |
| ASD | C2 | M | Y | | Potentially problematic | Potentially problematic | | | | | | | | | |
| ASD | C3 | M | | | | | Potentially problematic | | | | | | | | |
| ASD | C4 | M | | | | | | | | | Problematic | | | | |
| ASD | *C5 | M | Y | | | | Potentially problematic | | | | | | | | |
| ASD | C6 | M | | | | Potentially problematic | | | | Problematic | | | | | |
| ASD | C7 | M | | | | | Potentially problematic | | | | | | | | |
| ASD | C8 | M | | | | | | Potentially problematic | | Potentially problematic | | | | | |
| ASD | *C9 | M | Y | | | | | Potentially problematic | | | Problematic | | | Problematic | |
| ASD | C10 | M | | | | Potentially problematic | | | | | | | | | |
| ASD | *C11 | M | Y | | | | | | | | | | Problematic | | |
| ASD | C12 | F | | | | | | Potentially problematic | | | | | | | |
| ASD | C13 | F | | | | | | | | | | | | | Problematic |
| ASD | C14 | M | | Potentially problematic | | | | | | | | | | | |
| ASD | C15 | M | | | | Potentially problematic | | Potentially problematic | | | | | | | |
| ASD | C16 | M | | | | | | | | | | | | | Problematic |
| ASD | C17 | F | Y | | | | | | | | | | | Problematic | |
| ASD | C18 | M | | | | | | | | | Problematic | | | | |
| GDD | *C19 | F | Y | | | | | Potentially problematic | | | | | | | |
| DS | C20 | M | | | | | | | Potentially problematic | | | | | | |
| DS | C21 | F | | | | | | | | | | Problematic | | | |

Problematic
Potentially problematic

**Table 1. Problem behaviors reported for 21 children. In the disability column, ASD = Autism Spectrum Disorder, GDD = Global Developmental Delay, and DS = Down syndrome. In the topography of behaviors column, A = elopement, B = stereotypy, C = tantrum, D = self-injurious, and E = property destruction. Children marked with "*" took part in our notification evaluation study. (Note: C9's biting behavior was not reported, but was observed in our evaluation study.)**

syndrome. Teachers classified seven of these children as *advanced*.

### *Types of Problem Behavior*

As shown in Table 1, our teachers described 28 cases of behavioral problems among their students. We clustered similar cases into 12 behavior types shown in the columns of the table. Fifteen children exhibited only one type of behavior, five exhibited two types, and one exhibited three types. The table also shows the topography associated with each behavior: elopement, stereotypy, tantrum, self-injurious behavior (SIB), and property destruction. These topographies of problem behaviors were created to facilitate treatment during FBA [8].

We further classified cases as *problematic* (36%) and *potentially problematic* (64%). All *problematic* cases were self-injurious or property destruction behaviors. *Potentially problematic* behaviors are those that do not cause problems immediately but have the potential to cause problems if left unchecked for more than a few minutes. Most *potentially problematic* behaviors were cases of elopement, tantrum and stereotypy. For example, C2 had a habit of wandering off when the teacher was not looking. He was reported missing multiple times, once lasting for six hours. C1 and C14 liked to break into a run, but this was only problematic when it was possible to run into the street.

### *Managing Problem Behavior at School*

Figure 2 shows the intervention methods that teachers reported using most frequently: picture card, gestures, social stories, verbal reminders, and response blocking. Teachers intervened immediately for all *problematic* cases. A *potentially problematic* behavior that was highly risky (e.g. *running*) also required immediate intervention. However, other *potentially problematic* cases were allowed to continue until they became *problematic*. Teachers intervened only when these cases began to affect the child's learning or their classmates' learning.

All teachers reported that their first intervention would be to provide instruction, usually in the form of verbal reminders or visual cues. The choice of instruction varied widely and often depended on convenience. A teacher explained, "I will use a picture card that shows the 'No' sign every time he bangs his hands on the table. At times, I just cross my hands to gesture a 'No' when it requires my immediate attention and the picture card is not within my reach." Another teacher explained, "It really depends. My teacher assistants use picture cards to get him to stop his behaviors. But I think he responds better at the sight of me. I am the firm one!" Another child (C10) with a *body*

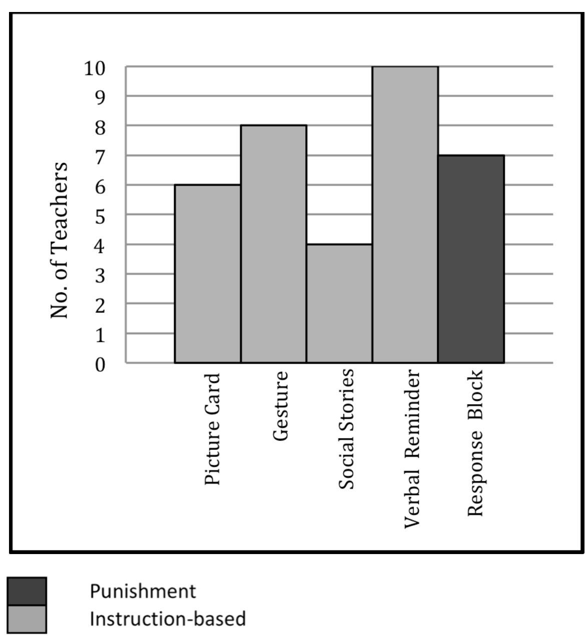



**Figure 2. Intervention strategies used by teachers in our field study to stop problem behaviors in children.**

*rocking* behavior responded only to the sight of a two-legged stool. A teacher explained, “We had to take a picture of a two-legged stool because he hates sitting down on it. He’s conditioned to know that if he continues, he’ll have to sit on it.” Four teachers adopted verbal reasoning with *advanced* children through social stories.

Many teachers pointed out that learning to control problem behavior takes time. For example, one teacher reported of C4, “Compared to last year, my student’s behaviors have significantly been reduced. He used to pull his hair and bang his head frequently. This is his second year now and he does them occasionally.” Children need frequent reminders, as another teacher shared about C9, “My student hums loudly quite often. We must always remind him to be quiet especially when we go for travelling lessons. He listens and keeps quiet for about 15 minutes, before making the noise again.” In a similar report about C21, a teacher said, “Right now it is well-managed because we have one teacher who is always around to remind him. But his parents are still concerned about this behavior at home.” The need to be reminded was more important for younger children (7 to 12 years old) than for older ones (13 to 17 years old) who have received many reminders already. One teacher explained, “The behaviors of the older students are different. They are more settled and know what is expected of them.”

When instruction-based interventions were not successful, teachers resorted to punishment. Seven teachers reported using response blocking, especially in preventing *problematic* behaviors. This includes *throwing* and self-injurious behaviors like *head banging* and *biting*, which together account for 6 of the 10 *problematic* cases reported. Physical restraint was also used to prevent C1 and C14 from *running* when it was dangerous to do so. Finally, as mentioned earlier, C10 was told to balance himself on a two-legged stool if he did not stop rocking back-and-forth in his chair.

Most children reacted well to interventions only if they were rewarded. One teacher said, “We reward them with anything they like: magazine, YouTube video, iPad, sometimes even their favorite food.” Child C20 was a special case who responded to nothing. A teacher explained, “He is a Down syndrome, who frequently freezes himself. When this happens, he would squat and not move for as long as an hour. His parents and I haven’t found anything that he would respond to. We just have to wait until he is ready to move again.”

### *Managing Problem Behavior at Home*

Teachers shared with us their observations from making home visits to these children. For most children (76%), the primary caregiver was a parent. The remaining 24% were primarily cared for by a domestic helper. (Domestic helpers are fairly common in middle-class Southeast Asian families.) Students under a domestic helper’s care often receive less supervision and are not monitored for problem behaviors.

Five parents tried to control their child’s problem behavior at home. One parent had a routine to keep her child occupied. The child’s daily schedule had periods of physical exercise, household chores, schoolwork, and play. Two parents reinforced school training by using the same behavior-control prompts that teachers used. One parent resorted to physical restraint, tying her son’s hands together with a piece of cloth to prevent self-inflicted injuries. One parent used corporal punishment to control a child’s *spitting* and *throwing*.

We asked teachers to recall events that might reveal parents’ attitudes towards their child’s problem behavior. Teachers counted nine parents that were concerned about their child’s behavior but unable to manage it. A common reason for being unable to manage behavior was that parents did not have time to closely monitor their child due to work or household responsibilities. In one case, the primary obstacle was embarrassment. A teacher explained, “The mother has to look after two children, both with Autism. It is tough for her and if she doesn’t give in, the child will scream and neighbors will complain.”

### *Using Wearable Technology*

As previously discussed, while wearable technologies have been proven effective to automatically detect problem behaviors, it is still unclear if they can help to manage such behavior. We asked teachers to describe specific needs that they thought this technology should address.

Six teachers strongly felt that such technology should be used to assist children at home, since they are often alone or minimally supervised. Seven teachers suggested a simple reminder application to alert students of their behaviors. One teacher explained, “Sometimes all they need is a friendly reminder to stop. In fact, they are well trained in school. It’s just a waste that they don’t practice this at home.” Two teachers called for social stories applications to provide learning lessons for *advanced* children, though four teachers believed that games would be more effective.

Two teachers suggested scheduling applications for children at home. This does not directly address the issue of problem behaviors but rather provides a structure to keep children occupied by engaging them in different activities. One teacher asked for an application that facilitates communication with parents. Teachers and parents were used to communicating through the smart phone messaging application WhatsApp[1], but this gives them no easy way to refer to a child’s progress reports. (Note: Nazneen and colleagues explored problems like these, but their solutions are designed for desktop or laptop web browsers rather than smart phones [16].) Language barriers between parents and

[1] https://www.whatsapp.com

teachers can also make textual communication especially difficult.

## Discussion

The objectives of our study were to better understand the difficulties of managing children with problem behaviors and to find out how technology can help. Here we discuss the implications of our findings.

*The need for Independent Living Support.* While one might expect children to receive the best care at home, our results showed that home caregivers often struggle with giving their children the supervision they require. This was often due to high levels of parental stress and time demands. Osborne and colleagues reported the same factors as barriers to providing home-based interventions in their study [18]. The few cases of corporal punishment also suggest that home caregivers may lack the knowledge required to provide proper intervention for children with problem behavior.

To help caregivers who are overburdened with the need to monitor their children, we seek to automate the intervention process and help children manage their behaviors independently. Ideally, the training that children receive in school should be practiced across multiple environments and maintained over time. At the very minimum, a child must continue to practice what is being taught in school while at home.

*The promise of Instruction-based intervention.* Instruction-based intervention was the most common strategy among our teachers to manage problem behaviors at school. Researchers have found instruction-based intervention to be an effective strategy for managing diverse topographies of problem behavior [10,14]. The children in our study often responded well to visual and auditory stimuli by their teachers, but the effectiveness of instruction depends on children learning to listen. We believe, like other researchers [16], that interventions need to be customized to each child and modeled after instructions that children have experienced.

*Sensing Problem Behaviors.* Our findings point to new directions for research into sensing of problem behaviors. As stated earlier, sensing technology can already provide us with the ability to detect a range of everyday activities like *walking* and *running*. Some researchers have also looked at recognizing common stereotypy, particularly *hand flapping, body rocking,* and *vocalizing*. However, the teachers we studied were more concerned about *problematic* cases like self-injurious and property destruction behaviors. Large movements like *hand/head banging*, and *throwing*, will be relatively easy to detect. Self-injurious behaviors like *biting*, *licking*, *scratching* and *nose picking,* which involve small movements, will be harder to detect. As Goodwin and colleagues pointed out, a challenge in detecting these behaviors is accounting for idiosyncrasies in each of them [7].

Detecting *potentially problematic* cases requires more than accurate sensing. The frequency of the behavior and the child's current context influence whether or not the behavior should be controlled. For instance, *running* is easy to detect using accelerometer and heart rate readings. However, a *potentially problematic* run is best detected at certain places and periods of time. A child who is detected to be *running* towards the streets during school hours poses a likelihood of danger to himself. A good approach to detecting a *potentially problematic* run would be to combine motion-sensing technology with a positioning system and a scheduler. Similarly, intervention for *hand flapping* usually occurs when a child becomes disengaged from school activities. Measuring a child's focus of attention through a gaze detection system in conjunction with motion sensing can help determine an appropriate time for intervention.

These insights have informed our vision for an independent behavior management tool that will help children to manage their behaviors without adult supervision. The following section describes our first steps toward realizing this vision.

## EVALUATION OF TWO NOTIFICATION DESIGNS

We envision an independent behavior management tool, as illustrated in Figure 3. By putting a smart watch on a child's wrist, a caregiver will have the ability to monitor the child's behavior at any time. The smart watch features a personalized sensing module to detect specific occurrences of problem behavior in the child, and plays a customized instruction-based notification when it is appropriate to intervene. A message is also sent to the caregiver's smartphone to inform them if the problem behavior persists and their child requires personal intervention.

For our vision to work, the smart watch must be able to both sense problem behavior and catch a child's attention when they exhibit the behavior. Sensing some behaviors will be challenging, as mentioned previously, but we believe it will be achievable over time (perhaps with additional sensors). Therefore, as a first step toward realizing our vision, we built a proof-of-concept prototype

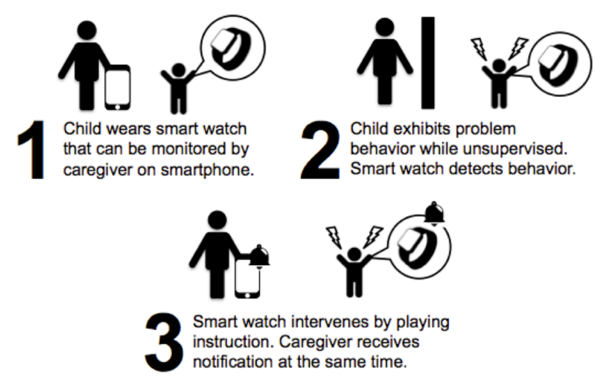



**Figure 3. Our vision of an independent management tool.**

for evaluating different signaling strategies.

Our prototype imitates the instruction-based interventions that are already familiar to children from school: visual cue cards and verbal reminders. These interventions are delivered through visual-haptic or audio notifications on a smart watch. The watch is paired to a smart phone held by a caregiver who simulates automated behavior recognition by pressing a button when intervention is needed. Figure 4 shows the watches and the smart phone interface used in our prototype.

Our notification customization process mimicked the process that would be found in a fully functional system. Both visual and audio notifications were captured with a smart phone and enhanced in ways that could be at least partially automated. Visual notification photos were cropped, brightness and contrast were adjusted, and specular highlights were removed. Audio notification recordings were normalized to give them a constant audio level and then amplified to the highest level possible without clipping.

With this prototype in hand, we conducted a preliminary study to see if our notifications could help children to control their problematic behavior.

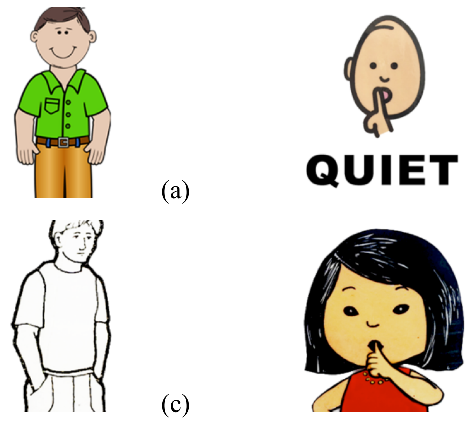
### Method, Participants, and Environment

Our study was a within-subjects comparison of our two notification designs: visual-haptic and audio. We recruited four teacher-child pairs from our field study. Three of the child participants were diagnosed with ASD (C5, C9, and C11), and one was diagnosed with Global Developmental Delay (C19). Each child displayed at least one problematic behavior that required close supervision (see Table 1). We chose only *advanced* children, because teachers believed them to be more likely to respond to notifications, while other children would respond only if given additional rewards.

Teachers customized their notifications before the main study sessions. Visual notifications were photos of the same


(a) (b) (c)

**Figure 4. Watches and caregiver interface in our prototype. (a) Samsung Gear Live used for visual-haptic notifications. (b) ZeWatch2 used for audio notifications. (c) Wizard interface, shown on a Samsung Galaxy SII.**




(a) (b) (c) (d)

**Figure 5. Picture cards chosen by teachers for visual notifications in our experiment. (a) Hands down for C5. (b) Quiet for C9. (c) Hands in Pockets for C11. (d) Quiet for C19.**

cards each teacher used in class to control their child's problem behavior (see Figure 5). Audio notifications were recordings of the teacher's voice speaking the child's name. Some teachers added a few words after the child's name (e.g., "<Name>, hands in pockets!" (C11) or "<Name>, quiet please." (C19)).

All sessions were conducted during normal class sessions and in normal classrooms. Each teacher-child pair had a 30-minute session with one type of notification, followed by a 15-minute break, and finally, a 30-minute session with the other type of notification. The researchers had minimal interactions with child participants in all sessions.

Each session began with the teacher strapping the watch on the child's arm and acclimating the child to the watch by taking a few minutes to point out positive things about it. After this, the teacher would initiate an activity that often resulted in the child exhibiting a problem behavior. For example, C9 screamed when walking, so the teacher asked her to run errands like collecting the class register from the main office. When a behavior was observed, teachers had three ways to respond: do nothing, send a notification to the child's watch (by pressing a button on the smart phone), or personally attend to the child. The smart phone recorded when notifications were sent, and we observed the teacher and the child from a distance. When teachers withdrew momentarily from the child, we probed them on their strategies, priorities, actions, and observations with questions like "why did you return to the child?" or "why didn't you send the alert?" At the end of the study, teachers were asked to fill out a questionnaire that asked about their reactions to the system.

### Results

Table 2 shows the data we collected in this experiment. Two children (C11 and C19) responded exceptionally well to the audio notification. Both responded within five seconds upon hearing the teacher's command through the smart watch and neither exhibited the same behavior within five minutes after intervention. It is worth noting that the effectiveness of an auditory stimulus is likely due to the use of teacher's voices, because teachers are seen as authoritative figures. One teacher explained, "That look on his face is exactly the same as how he would react when I tell him to stop. He really did put his hands in his pockets!"

Audio notifications were less effective for C5 and C9. In C9's case, the problem was the nature of the behavior: his vocalizations were so loud that notifications were inaudible. In C5's case, the problem was related to greater awareness of his surroundings. Upon hearing the notifications, he paused briefly to look for his teacher. When he realized the distance, he ignored the command and continued flapping his hands. He did not stop flapping his hands until the teacher personally intervened. Thus, for C5 the physical presence of his teacher was necessary.

Three of the four children in our study responded poorly to visual-haptic stimuli. Visuals had a positive effect in only one instance: the first notification sent to C19. She felt the vibration from the watch, took one glance at the visual cue, and stopped screaming. Unfortunately, she ignored all subsequent notifications, and the teacher had to intervene. Visuals seemed to have no effect on the other three children. C11 even ignored the notification when his teacher raised the watch close to his eyes while he picked his nose.

| Child (Age in years) | Session | Notification type | Behavior occurrences | Notifications sent | Manual interventions (after notification) | Notification success rate | Avg. time to stop behavior (sec) | Avg. time before next occurrence (min) |
|---|---|---|---|---|---|---|---|---|
| C5 (10) | 2 | Visual | n.a | n.a. | n.a. | n.a. | n.a | n.a |
| | 1 | Audio | 3 | 10 | 2 | 33% | 16 | <1 |
| C9 (8) | 2 | Visual | 4 | 9 | 1 | 75% | 11 | >5 |
| | 1 | Audio | 2 | 9 | 4 | 0% | 9 | <1 |
| C11 (10) | 1 | Visual | 2 | 11 | 2 | 0% | 50 | >5 |
| | 2 | Audio | 1 | 1 | 0 | 100% | 2 | >5 |
| C19 (12) | 1 | Visual | 3 | 14 | 2 | 33% | 18 | <1 |
| | 2 | Audio | 3 | 8 | 0 | 100% | 5 | >5 |

**Table 2. Results of our evaluation of visual-haptic and audio notifications. Each occurrence of problem behavior resulted in one or more notifications.** *Success rate* **shows the fraction of occurrences in which a child stopped without teacher intervention.** *Average time to stop* **counts time from the beginning of an occurrence to the end, whether the child stops on his or her own or the teacher intervenes.**

While visuals had little effect, the vibrations that came with them were surprisingly effective for participant C9. This child did sense watch vibrations but did not associate them with the need to keep quiet until his teacher intervened to direct his eyes to the watch. On subsequent notifications, C9 associated vibrations with the need to keep quiet without looking at the watch at all. The vibrations had a further calming effect on this child that we did not expect: he would frequently raise the watch face to his temple when it vibrated.

The sensation of wearing a watch was unpleasant for two children. C5's discomfort grew from the moment the watch was first strapped on his arm. He showed so much emotional distress at the beginning of the second session that we were unable to continue with the study. C9 also reacted negatively, possibly because he was used to wearing a different watch, but he became more comfortable over time. In the first session, he occasionally hit the watch face on his head, necessitating tighter supervision. C9 was more comfortable with the watch in the second session (after a 15-minute break).

When asked what they liked or disliked about the system, two teachers agreed it was convenient and beneficial, especially for *advanced* children who are able to understand the intent of an audio or visual notification. However, they stressed that such a system would need to recognize a wide variety of problem behaviors. One teacher also expressed a desire for customizable notifications, as she wanted to change the notification during the study and was unable to do so. Finally, two teachers stressed that the watch should be easy and safe to use but difficult to remove.

**Discussion**

These preliminary results indicate that smart watch notifications can help children to manage their problem behavior. Three of our four children responded repeatedly to one type of notification without requiring physical intervention from a caregiver. The one child who responded poorly to both types of notifications was uncomfortable wearing the watch. Notifications could be more successful if there were a way to overcome this discomfort.

Audio notifications appear to be particularly effective in catching a child's attention. These notifications halted two children's problem behavior in only 2-5 seconds. The use of teachers' voices in audio notifications appeared to be a key factor in their success, as children behaved the same way that they behaved in their teacher's presence. However, audio notifications were sometimes unsuccessful, particularly when they could not be heard. Visual-haptic notifications appeared to be less effective, but there were signs that vibration was a stronger factor than the visual stimulus. Vibration was successful in directing one child's eyes to the watch, and another child responded repeatedly to vibrations without looking at the watch.

While these results are encouraging, it is important to note the limitations of this study. First, our prototype simulates behavior recognition, while a final system would need to recognize behavior automatically. Some behaviors, like *hand banging* and *throwing*, are large hand movement that can be easily detected using a smart watch. Others may require additional sensing technologies, such as smart fabric. Some behaviors, such as *biting* and *licking*, may remain challenging to recognize for years to come. Also note that current smart watches are not designed for children. New child-friendly designs or device types may be needed to reduce the possibility of self-injury.

The participants and setting of our study are also limitations. The small sample size makes us unable to apply these results to large populations. Also, all children in this study were described by their teachers as *advanced* students. Other students may need more experience with notifications and more positive reinforcement before they will be able to manage their behavior independently. Our future designs will provide positive reinforcement in the form of rewards like games or fun visuals, sounds, and vibrations. Such rewards will need to be given judiciously, however, to avoid encouraging problem behavior. Finally, this study was conducted over a short period in a classroom setting, and the novelty of the system could be a factor. We aim to conduct future studies over longer periods in children's homes, where the need for independent management is more urgent.

In summary, our findings indicate that a combination of vibrations and a caregiver's voice could be the most effective type of notification for helping children manage their problem behavior. A system that pairs such notifications with appropriate recognition technology could reduce the need for supervision and bring children with problem behavior a step closer to independence.

## CONCLUSION AND FUTURE WORK

We have presented our first steps toward a system that helps children manage problem behaviors, reducing burdens on caregivers and giving children greater independence. We conducted a field study where ten teachers shared their experience of working with children who have neurodevelopmental disorders and problem behaviors and with their parents. The study showed how children with problem behaviors in our region (Southeast Asia) need greater support in developing and maintaining positive behavior, especially at home. The study also shed light on the types of behavior that need management and the strategies that caregivers currently employ when teaching children to manage their behavior.

These results informed the design of our proof-of-concept system that sends audio or visual-haptic notifications to a child's smart watch to help them manage their problem behavior. We then evaluated the effectiveness of these notifications with four children using customized notifications. Our results indicate that a caregiver's voice and vibrations can be particularly effective in smart watch notifications.

In the future, we will conduct larger experiments to investigate the effectiveness of smart watch notifications for more types of problem behavior. For example, the teachers we studied found *running* and *head banging* harder to manage through instruction-based interventions, and this may require us to revise our strategy. Also, we will expand our system to support other sensing techniques and devices besides smart watches to reduce the possibility of self-inflicted injuries. Third, we will expand our studies to evaluate the effectiveness of notifications over longer periods of time and in environments beyond school boundaries. This will require us to augment our system with a child's schedule, as well as location tracking. Finally, we will add the ability to sense problematic behavior automatically when we find mature sensing technologies for an important class of behavior.

## SELECTION AND PARTICIPATION OF CHILDREN

We approached an independent school for students with learning disabilities, and conducted this study in an urban setting in our home region, Southeast Asia. The school helped us to identify four child participants with neurodevelopmental disorders, believed to be most appropriate to participate. Three of these children were male and diagnosed with ASD, and one was diagnosed with Global Developmental Delay. All children displayed a problem behavior that required close supervision and were enrolled in the "Special Behavior" class. As this study involved a 'teacher and child' setup, we obtained signed consent forms both from teachers and the children's parents. Teachers were also able to terminate the study at any time if the child exhibited signs of emotional distress.

## ACKNOWLEDGMENTS

This work was supported by Singapore Management University.

## REFERENCES

1. Fahd Albinali, Matthew S. Goodwin, and Stephen S. Intille. 2009. Recognizing stereotypical motor movements in the laboratory and classroom: a case study with children on the autism spectrum. *Proceedings of the 11th international conference on Ubiquitous computing*, ACM, 71–80.
2. Ling Bao and Stephen S. Intille. 2004. Activity recognition from user-annotated acceleration data. In *Pervasive computing*. Springer, 1–17.
3. Edward G. Carr and others. 1990. Positive Approaches to the Treatment of Severe Behavior Problems in Persons with Developmental Disabilities: A Review and Analysis of Reinforcement and Stimulus-Based Procedures. Monograph No. 4.

4. Mark K. Derby, David P. Wacker, Gary Sasso, Mark Steege, John Northup, Karla Cigrand, and Jennifer Asmus. 1992. Brief functional assessment techniques to evaluate aberrant behavior in an outpatient setting: A summary of 79 cases. *Journal of Applied Behavior Analysis* 25, 3: 713.
5. Abbey S. Eisenhower, Bruce L. Baker, and Jan Blacher. 2005. Preschool children with intellectual disability: syndrome specificity, behaviour problems, and maternal well-being. *Journal of Intellectual Disability Research* 49, 9: 657–671.
6. Judith E. Favell, James F. McGimsey, and Michael L. Jones. 1978. The use of physical restraint in the treatment of self-injury and as positive reinforcement. *Journal of Applied Behavior Analysis* 11, 2: 225–241.
7. Matthew S. Goodwin, Stephen S. Intille, Wayne F. Velicer, and June Groden. 2008. Sensor-enabled detection of stereotypical motor movements in persons with autism spectrum disorder. *Proceedings of the 7th international conference on Interaction design and children*, ACM, 109–112.
8. Gregory P. Hanley, Brian A. Iwata, and Brandon E. McCord. 2003. Functional analysis of problem behavior: A review. *Journal of applied behavior analysis* 36, 2: 147–185.
9. Gillian R. Hayes, Lamar M. Gardere, Gregory D. Abowd, and Khai N. Truong. 2008. CareLog: a selective archiving tool for behavior management in schools. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 685–694.
10. Robert H. Horner, Edward G. Carr, Phillip S. Strain, Anne W. Todd, and Holly K. Reed. 2002. Problem behavior interventions for young children with autism: A research synthesis. *Journal of autism and developmental disorders* 32, 5: 423–446.
11. Julie A. Kientz, Gillian R. Hayes, Tracy L. Westeyn, Thad Starner, and Gregory D. Abowd. 2007. Pervasive computing and autism: Assisting caregivers of children with special needs. *IEEE Pervasive Computing*, 1: 28–35.
12. Dorothea C. Lerman and Brian A. Iwata. 1996. A methodology for distinguishing between extinction and punishment effects associated with response blocking. *Journal of Applied Behavior Analysis* 29, 2: 231–233.
13. Dorothea C. Lerman, Michael E. Kelley, Christina M. Vorndran, and Carole M. Van Camp. 2003. Collateral effects of response blocking during the treatment of stereotypic behavior. *Journal of Applied Behavior Analysis* 36, 1: 119–123.
14. Wendy Machalicek, Mark F. O'Reilly, Natasha Beretvas, Jeff Sigafoos, and Guilio E. Lancioni. 2007. A review of interventions to reduce challenging behavior in school settings for students with autism spectrum disorders. *Research in Autism Spectrum Disorders* 1, 3: 229–246.
15. Cheol-Hong Min, Ahmed H. Tewfik, Youngchun Kim, and Rigel Menard. 2009. Optimal sensor location for body sensor network to detect self-stimulatory behaviors of children with autism spectrum disorder. *Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE*, IEEE, 3489–3492.
16. Fnu Nazneen, Fatima A. Boujarwah, Shone Sadler, Amha Mogus, Gregory D. Abowd, and Rosa I. Arriaga. 2010. Understanding the challenges and opportunities for richer descriptions of stereotypical behaviors of children with asd: a concept exploration and validation. *Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility*, ACM, 67–74.
17. Renato Opertti, Zachary Walker, and Yi Zhang. 2013. Inclusive Education: From Targeting Groups and Schools to Achieving Quality Education as the Core of EFA. *The SAGE Handbook of Special Education: Two Volume Set* 1: 149.
18. Lisa A. Osborne, Louise McHugh, Jo Saunders, and Phil Reed. 2008. Parenting stress reduces the effectiveness of early teaching interventions for autistic spectrum disorders. *Journal of autism and developmental disorders* 38, 6: 1092–1103.
19. Thomas Plötz, Nils Y. Hammerla, Agata Rozga, Andrea Reavis, Nathan Call, and Gregory D. Abowd. 2012. Automatic assessment of problem behavior in individuals with developmental disabilities. *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, ACM, 391–400.
20. Tracy Westeyn, Kristin Vadas, Xuehai Bian, Thad Starner, and Gregory D. Abowd. 2005. Recognizing mimicked autistic self-stimulatory behaviors using hmms. *Wearable Computers, 2005. Proceedings. Ninth IEEE International Symposium on*, IEEE, 164–167.
21. Mark Wolery, Karen Kirk, and David L. Gast. 1985. Stereotypic behavior as a reinforcer: Effects and side effects. *Journal of Autism and Developmental Disorders* 15, 2: 149–161.
22. Jun Yang. 2009. Toward physical activity diary: motion recognition using simple acceleration features with mobile phones. *Proceedings of the 1st international workshop on Interactive multimedia for consumer electronics*, ACM, 1–10.
23. IDEA - Building The Legacy of IDEA 2004. Retrieved January 26, 2016 from http://idea.ed.gov/explore/view/p/,root,dynamic,QaCorner,7,