Pervasive Computing in Play-Based Occupational Therapy for Children

Embedding digital technology into playful activity can make play-based occupational therapy more effective. This study proposes two play-based activities to improve children's eating and tooth-brushing behavior.

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Developing new behavior or encouraging behavioral changes in children can be challenging even for experienced parents and teachers. Such persuasion is usually verbal, but verbal-only persuasion isn't always effective, particularly in children with communication difficulties, because it offers limited incentive to change. So, pediatric occupational therapists often use play-based activities to induce behavioral changes by leveraging children's desire to play. The term play-based occupational therapy refers to the use of a child occupation—that is, play—to cultivate the general skills and abilities needed to perform daily functional activities.[1]

Play-based occupational therapy has proven successful in motivating behavioral changes in children,[1] but it does have limitations. One drawback is that children often undergo treatment in specialized clinics during regular appointment hours. However, behavior such as eating, brushing teeth, or sleeping can't be observed during this time. If therapists can't directly observe these functional behaviors, they can't intervene. Therefore, therapists can only train children in general skills and hope that they apply the skill when it's needed.[2] However, because activity performance is an interaction between a person, activity, and context, improving general skills doesn't ensure improved performance in the target activities. A more direct approach involves making the target activities fun to engage children to actively participate, which directly enhances their performance.

Pervasive computing can provide opportunities to extend occupational therapists' reach from the treatment clinic to the client's natural living environment. It also enables occupational therapists to use digital technology to implement effective behavior intervention programs and target specific functional behaviors where it naturally occurs and when it would prove most effective.

Play-Based Occupational Therapy

"Play is a child's way of learning and an outlet for his innate need of activity."[3] Almost any activity can become a playful one for children. They're most likely to fully engage in activities that include the key elements of play.[4] Therefore, pediatric occupational therapists (OTs) often exploit children's universal desire to play as a means of cultivating the general skills and abilities needed for functional activities.

According to the model of human occupation (MOHO),[5] occupation is essential for human self-organization. Humans are conceptu-

Strategies	Volition		Performance		Habit
	Increase playfulness by elevating the degrees of (1) Intrinsic motivation (2) Internal control (3) Suspension of reality	→	Just the right level of challenge and concurrent feedback to assure successful experience	→	Encourage repeated performance to internalize the behavior

Figure 1. The play-based occupational therapy model. This model offers strategies for behavioral shaping.
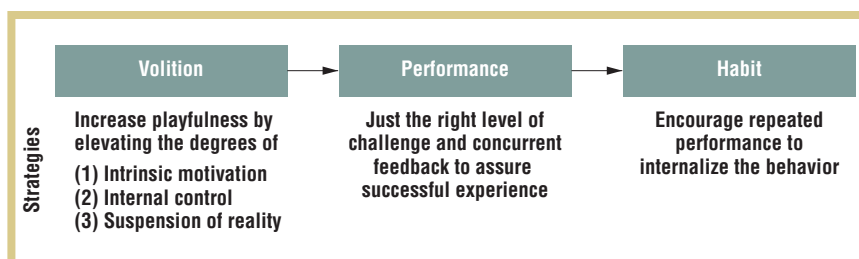
alized as a system composed of three subsystems:

- *volition* motivates occupational behavior,
- *habituation* organizes occupational behavior into patterns or routines, and
- *performance capability* refers to physical and mental abilities needed to perform the occupational behavior.

For children to develop functional performance, such as eating food or brushing teeth, so that it becomes part of their daily routine, they must have the volition and performance capability to perform the target activity. Additionally, subjective experience further supports or inhibits subsequent performance. Restated, children are more likely to repeat an activity they feel competent in doing and find satisfying. Through repeated performance, children develop an automatic behavior pattern and internalize it as a habit.

In this study, our play-based occupational therapy model based on MOHO (see Figure 1) employs pervasive computing technologies to shape behavior. The volition subsystem is facilitated by applying theories of playfulness. According to researchers,[4] play comprises three primary elements: intrinsic motivation, internal control, and suspension of reality. Motivation is intrinsic if the individual cares more about the process than the product or outcome. The activity itself rather than its consequences attracts the individual to participate actively. Moreover, we define internal control as individuals being in charge of their actions and at least some aspects of the outcome. Suspension of reality refers to the pretend quality of play. All three elements are essential for an effective play-based activity design.

Activities designed with the appropriate level of challenge not only motivate children to conquer challenges but also ensure that those challenges are within their physical and cognitive abilities. Moreover, the information children receive about their performance while learning a new activity is critical for learning.[6] External feedback on task success or performance can supplement the results through intrinsic sensory mechanisms. Therefore, providing an appropriate amount of concurrent feedback on whether children are correctly performing an activity is a constant challenge for occupational therapists. Our model provides external feedback and graded challenges through digital game play embedded in an activity design.

As noted earlier, encouraging repeated performance is necessary to internalize a behavior so that it becomes habitual. According to the acquisitional view, child behavior is a response to an environment.[7] How the environment provides positive or negative reinforcement influences skill acquisition. Positive reinforcement such as satisfaction in performing an activity increases the likelihood children will repeat the activity. Previous studies have shown that partial reinforcement, which has no discernible pattern and is given only when the behavior occurs, is most effective for shaping behavior.[8]

Pervasive Computing in Play-Based Occupational Therapy

We experimented with various projects that integrated pervasive computing with play-based occupational therapy for children. Two such projects were the Playful Tray and the Playful Toothbrush, which target eating and brushing behaviors in children.

Playful Tray: Improving Poor Eating Behavior

Mealtime behavior is the problem parents most frequently cite.[9] Despite nutritional concerns, spending excessive time to eat a meal affects the child's routine and often contributes to negative parent-child interaction during mealtime. To address this issue, we designed the Playful Tray to assist occupational therapists and parents in improving children's eating behavior.

The design attempts to improve behavior in children who take too long to eat because they don't pay attention to eating or get distracted talking to others. Although eating is normally considered a social event, excessive noneating-related activities can be problematic. Therefore, we designed playful games to encourage children to focus on eating without reducing social interaction.

We designed two Playful Tray prototypes: the Racing Game tray and the Fishing Game tray. As Figure 2 shows, both trays embed an interactive game over a weight-sensitive tray surface. By detecting weight changes in the amount of food consumed, the tray surface can recognize and track a child's natural eating actions in real time. Eating actions are then used as input to play a game. Figure 2 shows screenshots for the Racing Game and the Fishing Game. In the Racing Game tray (Figure 2a and 2b), a child consumes a meal by first selecting a favorite animal to compete in a race.
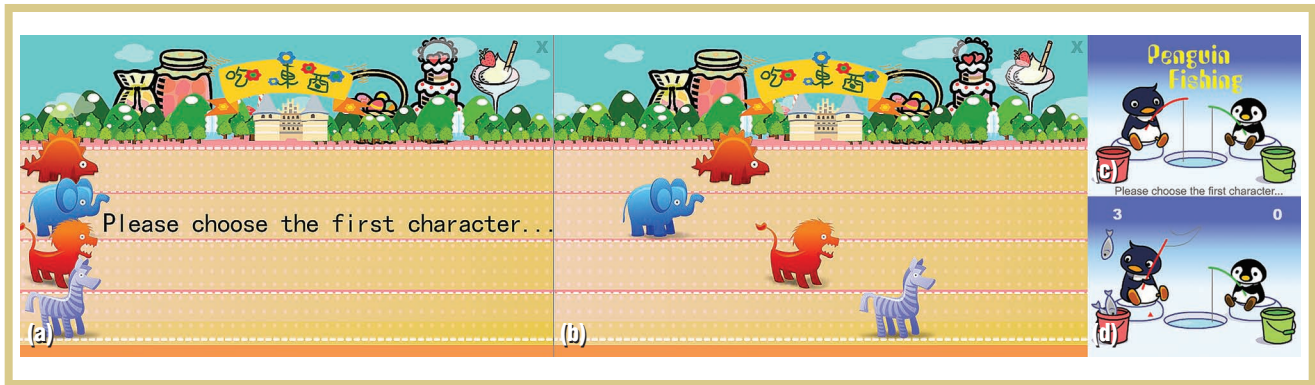
Figure 2. The Playful Tray games designed to improve children's eating behavior: (a–b) screen shots of the Racing Game; (c–d) screen shots for the Fishing Game.

Upon detecting each eating action, a random animal moves one step forward to the right. When the child completes the meal, the game ends, and the animal that's traveled the furthest wins. In the Fishing Game tray (Figure 2c and 2d), a child selects one of two penguins to compete in a fishing tournament. Upon each eating action, one of the penguins hooks a fish and drops it into a bucket. When the child completes the meal, the game ends, and the penguin with the most fish wins. To encourage parent-child interaction, a parent can participate in the game by choosing another animal or the other penguin to compete with the child in the same game. To discourage a child from taking small bites, the bites must accumulate above a certain weight threshold to trigger a game response.

We made several design changes from the previous Racing Game tray (see Figure 3a and 3b) to the current Fishing Game tray (Figure 3c–3f) on the basis of feedback from parents whose children had used the Racing Game tray in the pilot study.[10] A common complaint was that the 3 cm thickness of the Racing Game tray made it difficult for children with short arms to eat. The new Fishing Game tray addresses this issue by using a specialized load cell that is 50 percent thinner (1.5 cm). The Racing Game tray was also noted to be difficult to clean. To address this issue, we redesigned the Fishing Game tray with

a lightweight, foldable, and protective placemat sleeve (Figure 3d), which parents can remove from the load sensing module (Figure 3e) for washing and cleaning after meals. Finally, parents reported that children eventually became bored with the game. To address this issue, we adopted a smart phone as a game platform (Figure 3f) for Internet connectivity, which lets parents download new games until the desired behavioral changes take place. Because this design uses the smart phone hardware and software as the game runtime environment, the weight-sensing module becomes a Bluetooth accessory that wirelessly reports weight-change readings to the game running on the phone. This design also achieves an important cost advantage. A parent who already owns a smart phone needs only to purchase the Bluetooth weight-sensing unit and the placemat sleeve.

In a pilot user study, four child-parent pairs used the Racing Game tray.[10] The four children were between 4 and 7 years old; two were diagnosed with Asperger syndrome, one had high-functioning autism, and one had no specific diagnosis. All four participating parents complained of excessively long meals (30 minutes to more than an hour) after the children began self-feeding. Upon obtaining informed consent from the parents, the user study involved video-recording the eating activities of four parent-child pairs without the Rac-

ing Game tray, and then video-recording the four pairs using the Racing Game tray. Over a one-week period, we observed two meals per pair (one with and one without the Playful Tray). Three pairs were observed at our clinic, while one pair was observed at their home. The meals were familiar foods prepared by parents. For more details on the user study procedure, see our previously published work.[10] The pilot user study revealed an average 33 percent reduction in the duration of meals. Children were more focused on eating during mealtime with an average 20 percent reduction in non-feeding behaviors when using the Playful Tray. Finally, social behavior frequency, defined as behavior directed toward the parent but not directly related to eating, was increased in one of the child-parent pairs.

Playful Toothbrush: Motivating Proper, Thorough Brushing

Proper brushing is essential for cleaning teeth and gums effectively. For many parents, brushing is an essential routine for their children before bedtime. However, habitual, thorough, and correct brushing is difficult to teach. Thus, we designed the Playful Toothbrush as a tool to engage children in brushing their teeth according to American Dental Association guidelines (www.ada.org/public/games/animation/index.asp).

As Figure 4 shows, the Playful Tooth-

Figure 3. The design of the Playful Tray prototypes: (a) the previous tray prototype; (b) a Palm-top PC and weight sensing surface; (c–d) a placemat sleeve protecting the weight sensing unit; (e) a Bluetooth weight sensing unit that streams weight change events to the mobile phone; and (f) a mobile phone running the Fishing Game.

brush incorporates an interactive game into a brushing activity. The system consists of the following components:

- The toothbrush extension is coded with different LED marker patterns on four surfaces to aid the vision-based motion recognition system (Figure 4a).
- A Web camera is positioned above the child's head to capture the locations and motions of the LED markers for the system to reconstruct the orientation of the brush extension and rotation of the bristles (see Figure 4b). The system further infers the target group of teeth being brushed. Because of privacy concerns raised by a camera's presence in a bathroom, the camera had a suction hook for easy attachment to and detachment from the bathroom mirror, enabling a parent to quickly remove the camera af-

ter each brushing session, which typically lasted two to three minutes.

- The toothbrushing game (Figure 4c) takes physical brushing motions as input, which appears on an LCD display. The game starts with a virtual image of uncleaned teeth. The objective is to thoroughly clean the virtual teeth using physical tooth brushing motions. For example, brushing the outer left tooth group is mapped to a virtual mirror image of the outer left tooth group on the LCD screen. As each area is brushed, layers of plaque fall off. Figure 4d and 4e show game screenshots. When the child finishes cleaning all his or her teeth, the virtual teeth become completely white and an applause sound plays.

A 10-day user study, which took place over three weeks, examined system use with 13 children between the

ages of 6 and 7 years old. Because the kindergarten school in our study requires children to brush their teeth after meals or snacks, toothbrushing is a habitual activity. We installed the Playful Toothbrush system at the restroom sink where the children normally brushed their teeth. The trial consisted of the following phases:

- *Pretest.* We asked children to brush their teeth using their own toothbrushes for two days.
- *Training phase.* Children used the Playful Toothbrush for five days.
- *Post-test and subsequent one-week follow-up.* We again asked children to brush their teeth using their own toothbrushes, over one- and two-day periods.

We set up video cameras to record brushing sessions, and we measured
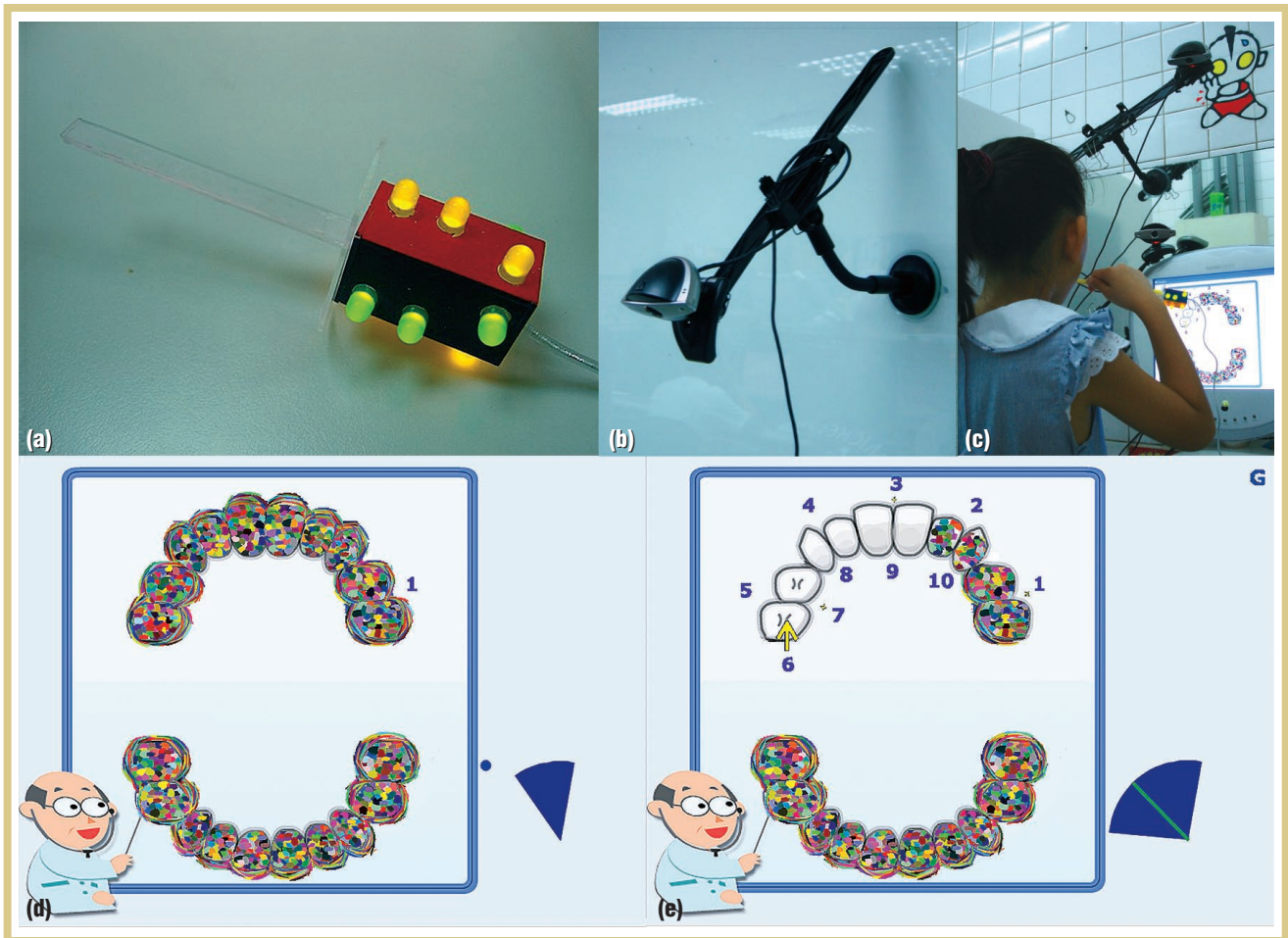
Figure 4. The components and the brushing game of the Playful Toothbrush prototype. (a) The toothbrush extension with LED marker patterns; (b) a Web camera for capturing a top-down view of brushing motion; (c) a child using the Playful Toothbrush; (d–e) screenshots of the brushing game.

both the effectiveness and number of brushing strokes. We used a plaque-disclosing dye to determine brushing effectiveness. We determined the ratio of tooth surfaces exhibiting plaque before and after brushing for each child. The comparative results indicated that after using the Playful Toothbrush, the average percentage of cleaning effect (computed by subtracting the before-plaque indices from the after-plaque indices) doubled from 32 percent (without using the Playful Toothbrush) to 67 percent, and the average number of brushing strokes increased from 190 strokes to 248. The one-week follow-up results suggested that the children maintained both teeth cleaning effec-

tiveness and the number of brushing strokes.

Design Considerations

Our experience in using the Playful Tray and Playful Toothbrush revealed the following design issues when embedding pervasive computing in play-based occupational therapy.

Volition

To leverage the children's motivation to engage in the targeted activity, we need to increase three elements of playfulness for the activity. We ensure internal control in the Playful Trays by using the child's eating actions as inputs in both the racing and fishing games.

Additionally, the child's opportunity to select an animal in the game gives a sense of control. Because children play the racing or fishing game while eating (that is, as part of the eating activity) rather than after eating (that is, as a reward for good behavior), the game increases the intrinsic motivation of playfulness. Because the racing or fishing games have no consequences when children lose the game, it provides the suspension of reality required for a sense of playfulness.

We adopted a similar approach in designing the Playful Toothbrush. The children's brushing motions are again used as input to the game, thus increasing the element of internal control for chil-

dren. Because children play the brushing game while brushing their teeth (that is, as part of the brushing activity) rather than after brushing their teeth (that is, as a reward for good behavior), the game reinforces the child's intrinsic motivation to engage in the game. Additionally, the brushing game provides positive rewards and visual/audio satisfaction with proper brushing behaviors by gradually reducing spots of plaque on the virtual image of teeth. This visual display further reinforces proper behaviors.

So, by increasing the three elements of playfulness, the digital games successfully induced children to engage in the targeted activities.

Performance Capacity

Occupational performance is the outcome of the interaction between person, occupation, and environment. Therefore, an activity and environment that provide an appropriate challenge are likely to induce the best performance.[11] The Playful Tray aims to reduce poor eating behavior and improve meal completion time in children. Because both of these goals are related to motivation and attention rather than motor skills, the game design must be playful enough to actively engage children without distracting them from eating. Therefore, we designed both the Racing and Fishing games to require only consumption of a meal to play the game. Additionally, by providing an immediate response to each eating action (that is, an animal racing one step forward or a penguin hooking a fish), the games allow children to focus their attention on their eating.

The Playful Toothbrush design also uses brushing actions of children as game input as a means of teaching proper brushing skills. We identified a brushing technique appropriate for young children and an effective teaching method given the children's limited perceptual, motor, and cognitive abilities. We selected the horizontal scrubbing method because it's the most natural technique and children automatically adopt it.[12] Additionally, we adjusted

the criteria of proper brushing action to match the target children's performance ability so the game was sufficiently challenging for children to have a successful and enjoyable experience.

In comparison, instilling proper and

thorough brushing behavior is more complex and difficult than reducing slow eating behavior. To encourage children to brush all their teeth patiently, the brushing game design provides not only immediate positive visual feedback after each successful brushing stroke (that is, layers of plaque removed from the teeth) but also audio feedback by playing musical notes on the seven-note diatonic tone (Do-Re-Mi-Fa-So-La-Ti). This feedback gives children a sense of control over the progress of their performance. Additionally, the brushing game enforces a brushing sequence for the child to follow by indicating the current target area of teeth with a number (that is, the child should now brush the indicated area; see Figure 4e). Brushing other areas of teeth produces no game response or reward. Enforcing this brushing order guides children to systematically brush all areas of their teeth.

Habituation

To enable children to automatically perform routine tasks without the game environment, repetitive practice is essential. In the Playful Tray game designs, the sequence of the animals racing one step or the penguin hooking a fish after each eating action is randomly chosen. This positive yet unpredictable reinforcement of proper behavior is effective for encouraging children to repeat proper behavior. In the Playful Toothbrush game design, both the seven-note diatonic tone and the numerical se-

quence, which are familiar to children, were used to induce children to automatically repeat their behaviors. After a certain period of practice, their behaviors become internalized and are then performed routinely and automatically.

By increasing the three elements of playfulness, the digital games successfully induced children to engage in the targeted activities.

Table 1 summarizes the relationships of the design dimensions, goals, implementation, and effectiveness of the Playful Tray and Playful Toothbrush.

Design and Technical Challenges

Our experience in integrating pervasive computing and play-based occupational therapy for modifying the two child behaviors revealed the following general challenges when designing solutions suitable for children.

Unpredictable Child Behaviors

An effective behavior modification system must accurately recognize child behavior and then provide correct feedback to encourage only desirable behavior. However, achieving acceptable activity recognition accuracy is especially challenging in children. Even after observing natural behavior in children and interviewing caregivers to identify possible behavior before designing and implementing an activity recognition method, unpredictable child behavior still occurs. For example, in the eating activity, false positive recognitions occurred when children played with the food or pushed the tray with their hands. To address this issue, eating actions are recognized by calculating the absolute weight decrease rather than using relative weight decrease over time. In the brushing activity, even after ensuring that children fully understood how to execute the activity, they still exhibited a wide

TABLE 1
The relationship of the design dimensions, goals, implementation,
and effectiveness of embedding pervasive computing technology in play-based occupational therapy.

Design dimensions	Goals	Implementation	Effect
Volition	Increase a child's motivation to participate in the targeted activity.	Make a target activity more playful by using the key movement of the targeted activity as game input.	The child becomes motivated to actively perform the targeted activity.
Performance capacity	Ensure that a child will have a successful and enjoyable experience.	Set the appropriate level of difficulty in the game to match the child's physical and cognitive capabilities while inducing proper performance in the targeted activity.	The enjoyable experience of playing a game reinforces the child's willing participation in the targeted activity.
Habituation	Cultivate proper habits in a child's daily routine.	Apply reinforcement to reward desirable performance and increase the chance of repeating the proper behavior so that it can be internalized.	The child will show the proper behavior automatically without using the playful game design.

range of unpredictable behaviors. For example, some children became anxious and performed erratically when their actions were ineffective. To resolve this problem, we adjusted the criteria of a proper brushing behavior to provide just the right challenge. Therefore, pilot studies are vital both for assuring the design's usability and practicality and for standardizing the experimental procedure.

Real-time Activity Recognition

To achieve an optimal learning effect, the proposed behavior modification systems must recognize child behavior to provide real-time feedback. However, increased activity-recognition accuracy requires more computation, which can affect real-time performance. Therefore, designers must carefully balance recognition accuracy and speed. For example, when designing the Playful Tray, we first considered combining computer vision to filter weight-reading noises, which offers better accuracy than weight sensors alone. However, using computer vision to filter noneating behavior requires a high computational load and would have significantly slowed activity recognition, thus reducing the racing game's playfulness.

Activity Grading

An important element in the proposed play-based occupational therapy model is the experience of performance, or the fitness between the activity's challenge level and the child's physical and cognitive capabilities. Given the varying intra- and inter-individual abilities among children, the appropriate challenge level could differ markedly. Therefore, the game's rules must be flexible enough to suit different children. Additionally, through learning in the treatment program, each child's ability gradually improves. Thus, grading becomes a necessary element in activity design—that is, different ability levels require different challenge levels. For example, the rules associated with recognizing a correct brushing behavior might be less strict for young children to ensure that they succeed. Conversely with older children, rules might be more strict to challenge them with higher performance ability.

Personalization and Customization

A key advantage of digital technology is that it's readily personalized and customized according to environmental or human factors such as the child's preferences, evolving performance levels, different deployment environments, and so forth. For example, lighting conditions, which can affect optimal camera setup, might differ between a school and home environment and require different settings for the brushing activity. Children might prefer to use either the left or right hand to hold their toothbrushes, which could affect activity recognition in the brushing motion model. Children's varying height could affect the camera viewing angle. Child preferences regarding game characters could exhibit gender differences. To enable personalization and customization, the system should have features supporting automated adaptation or manual adjustment.

Regression and Retention of Modified Behaviors

According to the play-based occupational therapy model, children using the proposed playful designs can acquire better brushing skills and eating habits in a short time. However, we were concerned that these behaviors might fade away when they were no longer reinforced. For example, a child might hurry to finish brushing to play or sleep. Therefore, we suggested that parents let their children use the Playful Toothbrush at home to assure proper brushing until children are old enough to assume responsibility for their own dental care. Further research is needed to determine the long-term effects of the Playful Tray and Playful Toothbrush. This issue raises the question of whether behavior modification technology should be deployed permanently or temporarily. We believe that deployment length is

both application- and user-dependent. An analogy is the use of a walker for an elderly person suffering from a permanent destabilizing disability versus a walker for a toddler learning to walk.

This study of pervasive computing technologies for play-based occupational therapy yielded promising results. A future study could examine the long-term, in situ effects of the proposed systems on behavioral change. Additionally, feedback from parents, teachers, and therapists reveals many other habitual developmental tasks in which this technology could prove useful, from self-care behavior (such as regular urinating, sleeping, and dressing) to learning proper social manners. These developmental tasks pose great challenges for parents as well as teachers. This study opens up many potential applications for using play-based occupational therapy to achieve behavioral change in children. P

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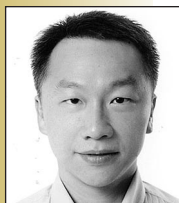
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