Pervasive Computing in Play-based Occupational Therapy for Young Children

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Abstract—Pervasive computing technologies can assist parents and occupational therapists in modifying behaviors in young children. In occupational therapy, an effective mean to motivate child behavior change is by designing playful activities which leverages the desire of children to play to induce their behavioral change. By embedding digital technology into playful activity, pervasive computing technologies can enhance the effectiveness of play-based occupational therapy. This study proposes to play-based activities targeted at eating and tooth brushing behaviors in young children.

Index Terms—Behavior modification, activity recognition, playful interaction, children.

I. INTRODUCTION

Developing new behaviors or persuading behavioral changes in young children can be challenging even for experienced parents and teachers. Behavioral persuasion by parents and teachers is usually verbal. However, the effectiveness of verbal-only persuasion is limited, particularly in children with communication difficulties (such as children diagnosed with autism) because it offers limited incentive to change. Therefore, pediatric occupational therapists often use play-based activities to induce behavioral changes by leveraging the desire of children to play. The term play-based occupational therapy refers to the use of a child occupation, i.e., play, to cultivate general skills and abilities needed to perform daily functional activities [1].

Pervasive computing for behavior modification in young children

Play-based occupational therapy has proven successful in motivating behavioral changes in children [1]. Its limitations can be overcome or minimized by pervasive computing. One limitation is that children often undergo treatment in specialized clinics during regular appointment hours. However, many behaviors, such as eating, tooth brushing or sleeping, cannot be observed during regular appointment hours at treatment clinics. Since therapists cannot directly observe these functional behaviors, direct intervention in these specific functional activities is impossible. Therefore, therapists can only train children in general skills and hope that they automatically apply the skill when it is needed. [2]. However, because activity performance is an interaction among person, activity and context, improving general skills does not ensure improved performance in the target functional activities. A more direct approach would be to make the target functional activities playful to engage children to actively participate so that functional performance of the target activities can be enhanced directly. Pervasive computing provides opportunities to extend the reach of occupational therapists from the treatment clinic to the natural living environment of a client and enables occupational therapists to (1) utilize digital technology to help implement effective behavior intervention programs and (2) target a specific functional behavior at the place where the behavior naturally occurs and at the time when the treatment would be most effective.

This paper is organized as follows. Section 2 describes the rationale for the play-based occupational therapy which employs pervasive computing for child behavior modification. Section 3 then gives two examples (Playful Tray and Playful Toothbrush) for changing child eating and brushing behaviors. Next, Section 4 examines design
considerations for the Playful Tray and Playful Toothbrush, and Section 5 discusses design and technical challenges. Conclusions are finally drawn in Section 6, along with recommendations for future research.

II. 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 of a child can become a playful activity. Children often engage actively and fully in an activity only if that activity includes the key elements of play [4]. Therefore, pediatric occupational therapists (OTs) often exploit the universal desire of children 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. The human is conceptualized as a system comprised of three subsystems: volition, habituation and performance capacity. Volition motivates occupational behavior. Habituation organizes occupational behavior into patterns or routines. Performance capability refers to physical and mental abilities to perform the occupational behavior. To develop functional performance such as eating food or brushing teeth so that they become part of their daily routine, children must have volition or motivation to participate in the target activity as well as adequate physical and mental ability to meet the need of performing the target activity. Additionally, subjective performance experience further supports or inhibits subsequent performance. Restated, the activity children feel competent in doing and find satisfying is more likely to be repeated. Through repeated performance, an automatic behavior pattern is developed and internalized as a habit. In this study, a play-based occupational therapy model based on MOHO (Fig. 1) employs pervasive computing technologies to shape behavior. In this model, the volition subsystem is facilitated by applying theories of playfulness. According to theories of play and playfulness [4], play is comprised of three primary elements: intrinsic motivation, internal control and suspension of reality. Motivation is intrinsic if the individual is more concerned with the process than the product or outcome. The activity itself rather than its consequences attracts the individual to participate actively. Moreover, internal control is defined as individuals being in charge of their actions and at least some aspects of the activity outcome. Suspension of reality refers to the pretend quality of play. All three elements are essential for an effective play-based activity design. To successfully induce active child participation, activities should be designed to maximize intrinsic motivation (minimize extrinsic motivation), internal control (minimize external control) and provide freedom of suspension of reality.

![Fig. 1 The play-based occupational therapy model](image)

After a child is motivated to participate in an activity, a successful experience gives the child feelings of satisfaction and competence, thus increasing the likelihood of the child repeating the behavior in the future. Thus, activities must be designed with the appropriate level of challenge which not only motivates a child to conquer the challenge but also ensures that the challenge is within the physical and cognitive ability of the child. Moreover, the information a child receives about his/her performance while learning a new activity is critical for learning [6]. External feedback on task success or performance can supplement that from intrinsic sensory mechanisms. Therefore, providing an appropriate amount of concurrent feedbacks on whether a child is correctly or incorrectly performing an activity is a constant challenge for occupational therapists. In the proposed model, external feedback and graded challenges are provided to the child through digital game play embedded in an activity design.
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]. Further, how the environment interacts with the behavior of the child, e.g., by providing positive or negative reinforcement, influences skill acquisition. Positive reinforcement such as the satisfying experience of performing an activity can increase the likelihood of later repeating that activity. Further, previous studies [8] have shown that partial reinforcement is most effective for shaping behavior. Partial reinforcement is defined as reinforcement given only when the behavior occurs and with no discernible pattern. To reinforce the desirable behavior, the game design should encourage repetition of the activity or behavior until it becomes internalized as a habit.

III. EXAMPLES OF PERVERSIVE COMPUTING IN PLAY-BASED OCCUPATIONAL THERAPY

During the past two years at National Taiwan University, we experimented with various projects integrating 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. Both projects involved collaboration between pediatric occupational therapists and computer scientists at both the design and evaluation stages.

**Playful Tray: Improving poor eating behavior**

Mealtime behavior is the behavior problem most frequently cited by parents of young children [9]. Despite nutritional concerns, spending excessive time to eat a meal affects the participation of children in daily school and family routines and often contributes to negative parent-child interaction during mealtimes. To address this eating behavior issue, the Playful Tray was designed as a tool to assist occupational therapists and parents in improving eating behavior in young children.

The design attempts to improve eating behavior specifically targeting those children whose long eating behavior was caused by not paying sufficient attention to eating or by frequently talking to other people. Although eating is normally considered a social event, excessive non-eating related activities such as those exhibited by children who eat very slowly can be problematic. Therefore, the playful games were designed to encourage the child to focus on eating without reducing the possibility of social interaction.

Two Playful Tray prototypes, the Racing Game Tray and the Fishing Game Tray, are described here. As Fig. 2 shows, both trays embed an interactive game played over a weight-sensitive tray surface. By detecting weight changes in the amount of food consumed, the tray surface can recognize and track the natural eating actions of children in real time. Eating actions are then used as input to play a game. Fig. 3 shows screenshots for the Racing game and the Fishing game. In the Racing Game Tray (Figs. 3(a) and (b)), a child consumes a meal by first selecting a favorite animal to compete in a race. Upon detecting each eating action, one of the animal moves one step forward to the right. When the child completes the meal, the game ends, and the animal that has traveled the furthest distance to the right wins the game. In the Fishing Game Tray (Figs. 3(c) and (d)), a child selects one of two penguins to compete in a fishing game. 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 in the bucket wins the game. To encourage parental-child interaction, a parent can participate in the game by choosing another animal or penguin to compete with the child.

Several design changes from the previous Racing Game Tray (Figs. 2(a) and (b)) to the current Fishing Game Tray (Figs. 2(c-f)) came about from parental feedback given after their children used the Racing Game Tray. (1) A common complaint was that the 3-centimeter thickness of the Racing Game Tray caused difficulty eating for young children with short arms. The new Fishing Game Tray addresses this issue by using a specialized load cell which is 50% thinner (1.5 centimeters). (2) The Racing Game Tray was also difficult to clean after eating. To address this
issue, the Fishing Game Tray was redesigned with a lightweight, foldable and protective placemat sleeve (Fig. 2(d)) which can be removed from the load sensing module (Fig. 2(f)) for ease of washing and cleaning after meals. (3) A final issue was that children eventually became bored with the game. To address this issue, a smart phone was adopted as a game platform (Figs. 2(c) and (e)) for Internet connectivity, which enables parents to download new games from a website until the desired behavioral changes take place. Since this design utilizes 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 only needs to purchase the Bluetooth weight-sensing unit and the placemat sleeve.

![Fig. 2. The Playful Tray prototypes: (a) the previous tray prototype; (b) a Palm-top PC and weight sensing surface; (c) the redesigned tray prototype; (d) a placemat sleeve protecting the weight sensing unit; (e) a mobile phone running the Penguin Fishing game; and (f) a Bluetooth weight sensing unit that streams weight change events to the mobile phone.](image-url)
Fig. 3. The Playful Tray Games: (a) and (b) are screen shots of the Racing Game used in the previous prototype; (c) and (d) are screen shots for the Fishing Game used in the current prototype.

In a pilot user study, four child-parent pairs played the Racing Game Tray [10]. The four children were 4 to 7 years old; two were diagnosed with Asperger syndrome, one had high function autism and one had no specific diagnosis. All four participating parents complained of excessively long meals (30 minutes to over one hour) after the children reached the age of 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 Racing Game Tray then video-recording the four pairs using the Racing Game Tray within one week. The meals were familiar foods prepared by parents. For more details on the user study procedure, we refer interested readers to [10]. The pilot user study revealed an average 33% reduction in the duration of meals. Children were more focused on eating during mealtime with an average 20% 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 feeding, was increased in one of the child-parent pairs.

Playful Toothbrush: Motivating proper and thorough tooth brushing

Proper brushing is essential for cleaning teeth and gums effectively and for maintaining oral hygiene [11]. For many parents, tooth brushing is an essential routine practice for their young children before bedtime. However, habitual, thorough and correct brushing is difficult to teach. The Playful Toothbrush was thus designed as a tool to engage young children in actively participating in and learning the tooth brushing method recommended by the American Dental Association (ADA) [11].

As Fig. 4 shows, the Playful Toothbrush incorporates an interactive game into a brushing activity. The system consists of the following components: (1) The toothbrush extension, shown in Fig. 4(b), is coded with different LED marker patterns on four surfaces to aid the vision-based motion recognition system. (2) As Fig. 4(a) shows, a web camera is positioned above the head of the child 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. The system further infers the target group of teeth being brushed. Because of the privacy concerns raised by the presence of a camera 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 and store the camera after each brushing session, which typically lasted only 2–3
minutes. (3) The tooth brushing game, as Fig. 4(c) shows, takes the current physical brushing motions as game 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 the physical tooth brushing motions of the child as game input. For example, the brushing of the outer left teeth group is mapped to a virtual mirror image of the outer left teeth group on the LCD screen. As each area is brushed, layers of plaque fall off. Figs. 4(d) and (e) show two game screenshots. When the child finishes cleaning all his/her teeth, the virtual teeth become completely white and an applause sound is heard.

A three-week user study examined use of the system by thirteen children aged 72-82 months. Since the participating kindergarten school requires children to brush their teeth after meals or snacks, tooth brushing is a habitual activity. The Playful Toothbrush system was installed at the restroom sink where the children normally brushed their teeth. The trial user study consisted of the following four phases. In the pretest, children were asked to brush their teeth using their own toothbrushes (i.e., without the Playful Toothbrush) for one day. In the training phase, children used the Playful Toothbrush for 5 days. In post-test and subsequent one-week follow-up, children were again asked to brush their teeth using their own toothbrushes over two- and one-day periods. Video cameras were set up to record brushing sessions. Effectiveness of tooth brushing and the number of brushing strokes were measured. Brushing effectiveness was determined by a plaque disclosing dye. The ratio of tooth surfaces exhibiting plaque before and after brushing was determined 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% (without using the Playful Toothbrush) to 67%, and the average number of brushing strokes increased from 190 strokes to 248. The one-week follow-up results suggested that both teeth cleaning effectiveness and number of brushing strokes were maintained.

Fig. 4. The Playful Toothbrush prototype: (a) a web camera for capturing a top-down view of brushing motion; (b) the toothbrush extension with LED marker patterns; (c) a child using the Playful Toothbrush; (d) and (e) screenshots of the Brushing game.
IV. DESIGN CONSIDERATIONS

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

**Volition**

To leverage the motivation of children to engage in the targeted activity, three elements of playfulness need to be increased for the activity. The element of internal control in the Playful Trays is ensured by using the eating actions of children as inputs in both the racing game and the fishing game. Additionally, the ability to select an animal in the game gives the user a sense of control. Since children play the racing or fishing game during eating (i.e., the game as a part of the eating activity) rather than after eating (i.e., the game as a reward for good eating behavior), the game increases the intrinsic motivation of playfulness. Because in the racing or fishing game there is no consequence when children lose the game, it provides the suspension of reality element required for a sense of playfulness.

A similar approach to designing the Playful Tray was adopted in designing the Playful Toothbrush. The brushing motions of the user are again used as input to play the game, thus increasing the element of internal control in the user. Since children play the brushing game while brushing their teeth (i.e., the game as a part of the brushing activity) rather than after brushing their teeth (i.e., the game as a reward for good brushing behavior), the game reinforces the intrinsic motivation of the children to engage in the playful toothbrush game. Additionally, the brushing game provides positive rewards and visual/audio satisfaction with the proper brushing behaviors by gradually reducing the spots of plaque on the virtual image of teeth. This visual display further reinforces the behavior.

By increasing the three elements of playfulness - internal control, intrinsic motivation and suspension of reality, the digital games successfully induced children to engage in the targeted activities of eating meals and brushing teeth.

**Performance Capacity**

Occupational performance is the outcome of the interaction between person, occupation and environment. Therefore, an activity and environment which provide the appropriate level of challenge is likely to induce the best performance [12]. The goals of the Playful Tray are to reduce poor eating behavior and to improve meal completion time in young children. Since 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 but without distracting them from eating. Therefore, both the Racing and Fishing games were designed to require only consumption of a meal to play the game. Additionally, by providing an immediate response to each eating action (i.e., one of the animals racing one step forward or a penguin hooking a fish), the games allow children to focus their attention on their eating activity.

The Playful Toothbrush design also uses the brushing action of children as game input as a means of teaching proper tooth brushing skills. A brushing technique appropriate for young children and an effective teaching method were identified given the limited perceptual, motor and cognitive abilities of young children. The horizontal scrubbing method was selected because it is the most natural technique and is adopted automatically by young children [13]. Additionally, the criteria of proper brushing action set in the game were adjusted to match the performance ability of the target children so that the game was sufficiently challenging (i.e., not too difficult and not too easy) 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. In order to encourage children to brush all their teeth patiently, the brushing game design provides not only immediate positive visual feedback (i.e., layers of plaque removed from the teeth) after each successful
brushing stroke, but also audio feedback by playing musical notes on the 7-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 (i.e., the child should now brush the indicated area, as Figure 3(c) shows). 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**

Both eating and brushing are routine tasks in everyday life. The goal of the game is to help parents and occupational therapists cultivate proper habits in children during their daily routines. Moreover, the proposed game design should enable children to automatically perform these routine tasks without the game environment. Therefore, repetitive practice of these behaviors is essential. In the game designs of Playful Trays, 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 the child to repeat the proper behavior. In the Playful Toothbrush game design, both the 7-note diatonic tone and the numerical sequence, which are familiar to children, were used to induce children to automatically repeat their behaviors. After a certain period of practice, the behaviors should become internalized and then performed routinely and automatically.

V. DESIGN AND TECHNICAL CHALLENGES

The experience of the authors in integrating pervasive computing and play-based occupational therapy for modifying the above 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 behaviors and then provide correct feedback to encourage only desirable child behaviors. However, achieving acceptable activity recognition accuracy is especially challenging in young children. Even after observing natural behaviors in children and interviewing caregivers to identify numerous possible behaviors before designing and implementing an activity recognition method, unpredictable child behaviors still occur. For example, in the eating activity, false positive recognitions occurred when children played with the food with their utensils 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 value. In the brushing activity, even after ensuring that children fully understood how to execute the activity, they still exhibited a wide 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 right challenge to the children. Therefore, pilot study(s) are vital both for assuring the usability and practicality of the design and for standardizing the experimental procedure.

**Real-time activity recognition**

To achieve an optimal learning effect, the proposed behavior modification systems must recognize child behaviors 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 only weight sensors. However, using computer vision to filter non-eating behaviors requires a high computational load and would have significantly slowed activity recognition, thus reducing the playfulness of the racing game.
Activity grading

An important element in the proposed play-based occupational therapy model is the experience of performance, or the fitness between the level of challenge in an activity and the physical and cognitive capabilities of a child. Given the varying intra- and inter-individual abilities between children, the appropriate level of challenge may differ markedly. Therefore, the rules of a game must be flexible enough to suit different children. Additionally, through learning in the treatment program, each child gradually improves his/her ability. Thus, grading becomes a necessary element in activity design, i.e., different levels of challenges are needed for different levels of ability. For example, the rules associated with recognizing a correct brushing behavior may be less strict for young children to ensure that they succeed given their current performance ability. Conversely, rules may be stricter to challenge an older child with higher performance ability.

Personalization & customization

A key advantage of digital technology is that it is readily personalized and customized according to environmental or human factors such as preferences of children, changing performance of a child, different deployment environments, etc. For example, lighting conditions which can affect optimal camera setup may differ between a school and home environment and require different settings for the tooth brushing activity. Children may prefer to use either the left or right hand to hold their brushes, which may affect activity recognition in the brushing motion model. Varying height of children may affect camera viewing angle. Child preferences regarding game characters may 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, a valid concern is the behaviors may fade away when they are no longer reinforced. For example, a child may hurry to finish brushing to play or sleep. Therefore, it is 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/Toothbrush and the retention of the effects. This issue also raises the related question of whether behavior modification technology should be deployed permanently or temporarily (i.e., long-term installation in an environment or short-term installation with an expectation of quick removal after the desirable behavioral changes take place). 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 destabilizing disability (which may be permanent) vs. a walker for a toddler learning to walk (which is normally temporary).

VI. CONCLUSION AND FUTURE WORK

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