Adopting Pervasive Computing into Play-based Occupational Therapy to Motivate Behavioral Change in 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 activities, pervasive computing technologies can be used to enhance the effectiveness of play-based occupational therapy. We describe three playful activity designs targeting eating, tooth brushing, and water drinking behaviors in young children.

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

I. INTRODUCTION

Developing new behaviors or persuading behavior changes in young children can be challenging tasks even for experienced parents and teachers. The most common form of behavioral persuasion practiced by parents and teachers is through verbal persuasion. However, verbal-only persuasion often has limited effectiveness due to a lack of incentive to motivate children to change their behaviors, especially for children with communication difficulties (such as children with a diagnosis of autism). As a result, pediatric occupational therapists design and put into practice play-based treatment programs, which leverages the desire of children to play to induce their behavioral change.

Pervasive computing opportunities in behavior modifications for young children

Although play-based occupational therapy has been successful in motivating child behavioral changes [1], it also has several limitations. These limitations create opportunities to apply pervasive computing technologies to further enhance its effectiveness. We have identified the following two main limitations. First, children often receive treatments in a specialized clinic during regular appointment hours. However, many child behavioral problems often do not show up during regular appointment hours at treatment clinics, such as poor eating behavior during lunch time at school, poor tooth brushing or sleeping behaviors before and during bedtime at home, etc. Second, since these functional behaviors are not accessible to therapists, it is difficult for therapists to intervene directly at these specific functional activities. As a result, therapists often use an indirect approach of training children in general skills via play activities [2]. However, an indirect approach suffers from the problem that improvements in general skills do not guarantee improved performance in the target functional activities. A more direct approach is to make the target functional activities playful to engage children into active participation, so that children’s functional performance of the target activities can be enhanced directly. We believe that pervasive computing provides an opportunity to extend the reach of occupational therapists from their treatment clinic into the naturalistic living environment of a client, enabling the occupational therapists to (1) utilize digital technology to assist them in implementing an effective behavior intervention program and (2) target the client’s specific functional behavior at the naturalistic place where the behavior occurs and when the treatment is most effective.
II. PLAY-BASED OCCUPATIONAL THERAPY

“Play is a child’s way of learning and an outlet for his innate need of activity” [1]. For a child, any activity can be turned into a playful activity. Children often engage actively and fully in an activity only if that activity includes the critical ingredients of play.

According to the model of human occupation (MOHO) [4], a daily occupation such as eating food, brushing teeth, etc., is the result of the organization of three subsystems of a person: volition, performance capacity, and habituation. To develop children’s functional ability and become a part of their daily routines, they first need to have motivation to participate in the target activity and sufficient physical and mental abilities to meet the need of performing the target activity. In addition, children’s subjective performance experience will further support or inhibit later performance. In other words, the activity children feel competent to do and find satisfying will more likely be performed again at a later time. Through repeated performance, an automatic behavior pattern can be developed and internalized as a habit. Based on MOHO, we have come up with a play-based occupational therapy model (Fig. 1), which adopts pervasive computing technologies for shaping children’s behavior. In this model, the volition subsystem is facilitated by applying theories of playfulness. According to theories of play and playfulness [5], play comprises three primary elements: intrinsic motivation, internal control, and suspension of reality. Intrinsic motivation means that the individual pays more attention to the process than to the product or outcome. It is the activity itself rather than its consequences that attracts the individual to active participation. 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. The three elements of play comprise the foundation of activity design.

After a child is motivated to participate in an activity, successful experience is needed to bring satisfaction and a feeling of competence to a child; therefore, increase the possibility that the child will attempt to repeat the activity again in the future. In addition, it is important to design an activity with just the right level of challenge, which not only can motivate a child with desire to conquer the challenge but also assure that the challenge is within the child’s physical and cognitive performance capacity to have a successful experience. Moreover, the information a child performer receives about his/her performance while learning a new activity is critical for learning [6]. It is often necessary to design external feedbacks on task success and performance to supplement the feedback from a child’s intrinsic sensory mechanisms. Furthermore, providing an appropriate amount of concurrent feedbacks on whether a child is correctly or incorrectly performing an activity can help improving his/her movements or behaviors. In our model, challenges and external feedbacks are mediated to the child through digital game playing embedded into an activity design.

In order to internalize a proper behavior to become a habit, encouraging repeated performance is necessary. According to Acquisitional theory, behavior is a response to an environment [7]. The environment either reinforces behavior or fails to provide positive reinforcement by instead giving no reinforcement at all. Positive reinforcement such as satisfying experience of performing an activity can increase the possibility of repeating that activity at a

![Fig. 1. Our play-based occupational therapy model](image-url)
III. THREE EXAMPLES OF APPLYING PERVASIVE COMPUTING TO PLAY-BASED OCCUPATIONAL THERAPY

For the past two years at National Taiwan University, we have experimented with various projects that integrate pervasive computing into play-based occupational therapy for children. We describe three of these projects, shown in Table 1, which target eating, brushing, and water-drinking behaviors of children.

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Playful Tray: Reducing poor eating behavior

Mealtime behavior is one of the most frequently cited problems 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 mealtime. To address this eating behavior issue, we have designed a Playful Tray as a tool to assist occupational therapists and parents in reducing poor eating behavior in young children.

The Playful Tray is embedded with an interactive game played over a weight-sensitive tray surface shown in Fig. 2 (c) and (d). By detecting weight changes of the amount of food consumed, the tray surface can recognize and track the natural eating actions of children in real time. Child eating actions are then used as inputs to play a racing game. Screenshots for the Racing game are shown in Fig. 2 (a) and (b). When starting a meal, a child selects a favorite cartoon character to compete in the Racing game. Upon detecting each eating action, one of the characters would race one step forward to the right. When the child completes the meal, the game ends and the character that has traveled the furthest distance to the right wins the game.

The Playful Tray racing game design is based on the play-based occupational therapy model described previously. The game design provides internal control, an element of playfulness, to children by given them choices to select a
favorite cartoon character to compete in the race. In addition, the pace of the game is also controlled by children’s eating behavior. The game design gives a freedom from reality, another element of playfulness, to children by not presenting punishment for not eating or eating too slowly. The game design brings intrinsic motivation by randomly selecting a character to race one step forward after each eating action, which children become motivated to continue playing the game until finishing the meal in order to find out the final result of the race. The Racing game is easily within the performance capability of children by using only their natural eating behaviors as game inputs. In addition, the immediate game response through a character’s racing one step forward provides extrinsic feedback to children. Finally, the randomly selected racing character after each eating action satisfies the partial reinforcement principle to encourage repeated performance of child eating actions.

In our pilot user study on four children with mealtime problems [10], we have found that engaging children in a fun digital play activity can be more effective in motivating eating behavioral changes than using only verbal persuasion. Our pilot user study results have shown that using the Playful Tray reduces the child mealtime duration reduction by an average of 33%. In addition, children are more focused on self-feeding with the Playful Tray during mealtime with a 20% reduction of non-feeding behaviors than without using the Playful Tray [10].

![Racing game screenshots](image1.png)

![Weight sensor and sensing surface](image2.png)

**Fig. 2.** The Playful Tray prototype: (a) and (b) are screen shots for the Racing game; and (c) and (d) show the tray prototype with a Palm-top PC and weight sensing surface.

**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 a required routine for young children before bedtime. However, it is by no means an easy task for parents to get their young children into a habit of brushing their teeth properly and thoroughly. Thus, we have designed and implemented the Playful Toothbrush as a tool to engage young children into active participation and learn proper tooth brushing method as recommended by American Dental Association (ADA) [11].
The Playful Toothbrush incorporates an interactive game played with an augmented toothbrush shown in Fig. 3. The system is consisted of the following components: (1) The toothbrush extension, shown in Fig. 3(b), is coded with different LED marker patterns on its four faces to aid our vision-based motion recognition system. (2) A web camera, shown in Fig. 3(a), is positioned above the child head to capture the top-down view of brushing motions. By analyzing the locations and motions of the LED markers from camera images, our system reconstructs the orientation of the brush extension and rotation of the bristle, and further infers the target group of teeth being brushed. (3) A tooth brushing game, shown in Fig 3(c), takes the child’s current physical brushing motions as game inputs to play a game on a LCD display. The game starts with a virtual image of a child’s dirty teeth. The goal is for a child to thoroughly clean these virtual dirty teeth using his/her own physical tooth brushing motions as game inputs. For example, while a child is brushing his/her outer left teeth group, it is mapped to cleaning the virtual outer left teeth group of the mirror image on the LCD screen, with visible spots of plaques falling off. Fig. 3 (d) and (e) show two game screenshots. When the child finishes cleaning all his/her teeth, the virtual teeth will become completely white accompanying with applause sound.

Fig. 3. The Playful Toothbrush prototype: (a) shows a web camera to capture the top-down view of brushing motions; (b) is the toothbrush extension with LED marker patterns; (c) demonstrates a child using our Playful Toothbrush; (d) and (e) are screenshots of the Brushing game.

The Brushing game design adopts the play-based occupational therapy model described previously. Playfulness is elevated by using brushing actions as inputs to play the game, in which the brushing actions (i.e., the where and how decisions) are controlled by the child. The visual feedbacks on the game display, i.e., plaques falling off the teeth when proper brushing action is detected by our system, provides satisfying experiences to children and motivates them to stay engaged in the game until they finish cleaning all teeth. The game visual feedback also enhances learning by tracking and showing which groups of teeth have not been cleaned, which help children thoroughly clean all teeth.
We have conducted a pilot user study involving 13 kindergarten children over one week period. We have observed that all children loved to play the Brushing game very much. For example, after finishing a brushing session, one child said “It’s very enjoyable”. Our pilot user study also compared the teeth cleansing effect between our Brushing game and oral instruction from their teacher and/or parents. The teeth cleansing effect was measured by special plaque disclosing dye that attaches to plaque on teeth and which children swish the dye in their mouth before each brushing session. The ratio of faces of teeth with plaques was counted before and after brushing for each child. Our pilot user study results have shown that using the Brushing game, the plaque decreasing rate is double of that without using the Brushing game (67% vs. 32%). The children’s teeth were cleaner after playing the Brushing game than without it (9% vs. 37% of the faces of teeth with plaques remained in average).

Mug-Tree: Encouraging healthy habit of drinking fluid regularly

Water is essential for survival of all life on earth, including humans. Since water consists of about 60%~70% of our body weight, we need plenty of fresh water replenishment everyday to keep water flowing in the body and stay healthy. However, recent studies [12] have found that most people, from children to elders, do not drink enough water. Such chronic water deficiency may lead to both short and long term health illnesses, including asthma, allergies, and migraine headaches. A better way of keeping body healthy is to develop a habit of drinking water regularly from childhood. Thus, we have created an everyday drinking mug called Mug-Tree, which can remind and motivate children to drink water from the mug regularly when performing sedentary work, such as drawing, reading, and writing on a table, watching TV, etc.

The Mug-Tree is embedded with an interactive game played over a drinking mug shown in Fig. 4. Our system is consisted of the following two components. (1) A mercoid switch sensor, shown in Fig. 4(b), is installed at the mug base to detect and recognize drinking events by the tilt motion of the mug. (2) A digital photo frame receives drinking events transmitted wirelessly from the mug, and then uses the drinking events as inputs to play the watering tree game shown in Fig. 4(c). This game is based on a metaphor in which an act of caring and watering a virtual tree symbolizes a similar act of caring for one’s own body through regular water drinking. When a mug detects that a user does not drink enough water regularly, the virtual tree will gradually turn from beautiful green full of leaves, shown in Fig. 4(d), to withered bare branches, shown in Fig. 4(e).

![Fig. 4. The Mug-Tree prototype: (b) shows the mercoid sensor embedded under the mug; (c) illustrates the structure of the digital picture frame; and (d) and (e) are screen shots of the tree watering game.](image-url)
The Mug-Tree game design follows our play-based occupational therapy model described previously. The Mug-Tree game first enhances playfulness by having children realize that their drinking actions can affect the outcome of the virtual tree. Then, simplicity of the game also ensures that the needed performance to bring successful and satisfying experiences to the game challenge are easily within a child’s ability (i.e., a child simply needs to drink water regularly to succeed in the game). In addition, the design of a slowly withering virtual tree motivates the child to periodically drink from the Mug to prevent the virtual tree from withering away.

IV. DESIGN CONSIDERATIONS

Based on our experiences with Playful Tray, Playful Toothbrush, and Mug-Tree, we have identified the following design issues when embedding pervasive computing technology into play-based occupational therapy.

Enjoyment: motivation to participate in play activity

The digital game must bring sufficient enjoyment and pleasure to children to attract their active participation in the activity for the target behavior. Motivation to perform an activity usually comes from two sources: external rewards and enjoyment of the activity itself. External rewards mean the accompanying benefit of performing an activity. When the rewards seem unattractive to a child, the child will feel a lack of motivation to participate in the activity. On the other hand, if an activity is playful, i.e., with high levels of the three elements of play (intrinsic motivation, internal control and suspension of reality), carrying out the activity itself will be enjoyable and self-reinforced rather than reinforced by external rewards. For example, in the Racing game, children can select a favorite cartoon character and then play the game. This design motivates children to participate in the target activity, and continue eating to try and help their character win. In the Brushing game, the virtual image of a child’s dirty teeth motivates the child to clean them by brushing his/her own teeth thoroughly.

Engagement: simple and easy-to-understand interaction

Since young children have limited physical and cognitive capabilities, the game interaction and device manipulation should be simple for them. For game inputs, our design strategy relies on using the natural behaviors of children as game inputs, in which children are familiar performing them. For example, a child simply has to eat from a bowl, brush a group of teeth, or drink from a mug to play the Racing, the Brushing, or the Watering Tree games.

The game feedbacks should also be intuitive for child easy understanding, i.e., an uncomplicated game metaphor in which a child can effortlessly make the connection between his/her natural behavior inputs and the corresponding digital game response. For examples, the Brushing game provides an intuitive mapping between a child brushing his/her own outer left teeth and the game responding with plaques falling off the virtual outer left teeth. The Mug-Tree game also provides an intuitive analogy that their body is just like a slowly dehydrating tree that requires regular water intake.

Attention: focus on the target activity rather than game playing

Since children need to focus their attention on the target activity, introducing a digital game will inevitably divert some of their attention away from the target activity to game playing. Because the use of the digital game is intended to motivate children to change their target behavior, the digital game design should not draw too much attention away from the main activity and thus lead to the undesirable result of digital playing overtaking or distracting performing target activity. In other words, the game design needs to carefully factor and apportion child mental energy cost between the game playing and the target activity. A good design strategy to meet this design goal is to blend together as much as possible the game playing (e.g., the Brushing game) and the target activity (e.g.,
brushing actions) by using the target activity as game inputs and/or relating the game feedbacks (e.g., virtual plaques falling off) to the outcome of the target activity.

V. DESIGN AND TECHNICAL CHALLENGES

From our experiences integrating pervasive computing and play-based occupation therapy for three child behavior modifications, we have found the following challenges when designing solutions suitable for children:

Unpredictable child behaviors

In order for our behavior modifications to work correctly, it is essential that our systems accurately recognize child behaviors and then provide correct game feedbacks to encourage only desirable child behaviors. However, achieving good activity recognition accuracy is especially challenging in young children for the following two reasons. First, even if we assured the young children fully understood how to execute the activity before the trial, they still exhibited a wide variety of unpredictable behaviors. For example, in the eating activity, we observed that children played with the food with their utensils or pushed the tray with their hands, which caused false positive recognitions. Second, different children performed the same activity differently. For example, in the brushing activity, children held their toothbrushes using either left or right hands. In order to improve the activity recognition accuracy, designers must first observe children’s natural behaviors and interview caregivers to thoroughly collect all possible behaviors before designing and implementing an activity recognition method.

Activity Grading

An important element in our play-based occupational therapy model is the experience of performance, or the fitness between the level of challenge in an activity and a child’s physical and cognitive capabilities. Given variations in intra- and inter-individual abilities in children, different children have different just right challenges. In addition, through learning in the treatment program, each child may gradually improve his/her ability. Thus, it becomes necessary to apply grading in an activity design, i.e., different levels of challenges fitting to each child’s ability. For example, the rules associated with recognizing a correct brushing behavior can be adjusted less strict for young children to ensure that they can more easily succeed with their current performance ability. On the other hand, the rules can be set stricter to make it more challenging for an older child with higher performance ability.

Personalization & customization

A key advantage of using digital technology is that it can be easily personalized and customized according to environmental or human factors such as preferences of children, changing performance of a child, different deployment environments, etc. Consider the example of the tooth brushing activity, the bathroom settings for the tooth brushing activity are different in school and at home, in which their lighting condition may affect optimal camera setup. Children may prefer to use either left or right hands to hold their brushes, which affect the brushing motion model in activity recognition. Different children have different heights that affect camera viewing angle. Child preferences about game characters may differ based on genders. To enable personalization and customization, the system should have features supporting either automated adaptation or manual adjustment.

VI. CONCLUSION AND FUTURE WORK

Our experience in adopting pervasive computing technologies for play-based occupational therapy has shown encouraging results in assisting occupational therapists in shaping young children’s behavior. For our future work, from talking to parents, teachers, and therapists, we have found there are many habitual developmental tasks for young children, from self-care behaviors, such as regular urinating, sleeping, self-dressing, etc., to learning proper
social manners, and these child habitual developmental tasks pose great challenges for parents and kindergarten teachers. This study opens up many potential applications for adopting persuasive techniques in play-based occupational therapy for young children.

REFERENCES


RELATED WORK ON BEHAVIOR MODIFICATION USING PERSURATIVE COMPUTING:

Many researchers have looked into how pervasive technology can manifest into our living environment to motivate behavioral change. Tooth Tunes [1] is a smart toothbrush designed to motivate the practice of tooth brushing in young children. The toothbrush is embedded with small pressure sensors to recognize brushing activity when the toothbrush is pressed against teeth. Upon the sensors being activated, a two-minute piece of music is played to reinforce children in continuing brushing for at least two minutes. Waterbot [2] is a device installed at a bathroom sink to track the amount of water usage in each wash. The system contains flow sensors to detect the amount of water usage. By showing the current water usage in comparison to the average household water usage, the system encourages behavioral change toward water conservation. CarCoach [3] is an educational car system that can utilize sensors in a car to detect good or bad driving habits, such as excessive braking, sudden acceleration, the use of signals when turning, etc. Subsequently, CarCoach aims to provide polite, proactive, and considerate feedback to drivers by factoring into their mental state and current road conditions.

Compared to the related works described above, our works adopt a similar approach of embedding behavioral intervention into living environment. However, the approach proposed also differs from that above. Most significantly, we take a play-based occupational therapy approach that uses pervasive technology to enhance the effect of habit training for young children. Because occupational therapy emphasizes functional behavioral improvements that are often observable and measurable, pervasive technology can be deployed in children’s environments to detect their functional behaviors and provide just-in-time behavior interventions. In our works, we have found that pervasive technology is a good match for occupational therapy.


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