PigScape: An embodied video game for cognitive peer-training of impulse and behavior control in children with ADHD

This paper describes a therapeutic full-body controlled video game for children with attention deficit / hyperactivity disorder (ADHD). The game supports a co-located gameplay with a depth-sensing camera and a large media screen. Children play the game in pairs for improved impulse and behavior control, self-regulation, peer-communication, and emotion regulation. The gaming was implemented as a part of a neuropsychological group intervention for children with confirmed deficits in attention or diagnosed ADHD. We present a final design of the game and associated gaming routines, explain anticipated health benefits of the gaming, outline how the gaming can be used for research and therapeutic purposes, and provide directions for future research.

CCS CONCEPTS •Human-centered computing~Human computer interaction (HCI)~Interaction techniques~Gestural input•Human-centered computing~Interaction design~Interaction design process and methods~User centered design

Additional Keywords and Phrases: Child-computer interaction, Game design, Active gaming, Embodied techniques, Gesture-based interfaces, Kinect, Depth camera, Children, Attention deficit / hyperactivity disorder (ADHD), Impulse control, Inhibition, Cognitive training, Rehabilitation.

1 INTRODUCTION AND BACKGROUND

Many children with attention deficit / hyperactivity disorder (ADHD) have a challenge of high distractibility. Yet, the core ability for maintaining goal-directed behavior (e.g., completion of tasks, performing on-task behavior) is inhibition of inner and outer impulses and stimuli [1, 9]. Lately, computerized gaming has started to be leveraged for ADHD treatment and monitoring. Indeed, gaming that is fun yet educational and skill-building could complement traditional intervention schemes or serve as a stand-alone mean of ADHD rehabilitation and diagnostics [11]. Examples of useful gamified interventions for children with ADHD could focus on the recognition of patterns of problems and managing own thoughts, behaviors, and emotions (e.g., learning how to concentrate on a task, think about consequences of own actions, etc.).

Among various computerized solutions for ADHD such as desktop or mobile/touch-based support for training or therapy [8], virtual classrooms [5], and biofeedback [4, 15], only few applications exist that go beyond the desktop paradigm and allow users to move freely in a space [6, 10]. They utilize embodied technologies for tracking of body/hand gestures and movements, thus, enabling interaction with objects on a large media screen. It has been shown that while playing immersive body-controlled video games, children with ADHD may achieve equal or even superior results as compared with their neurotypical peers [3]. This is a promising result for the development of training applications that engage children with ADHD in mental and physical skill acquisition [13]. Noteworthy, energy expenditure during embodied gaming is comparable to that associated with light to moderate physical activity and can improve physical functions (e.g., motor skills and postural control) of children [2]. Active physicality of such embodied gaming benefits children with ADHD who may not yet be able to control their hyperactivity and impulsivity to that extent as to commit to regular and prolonged sedentary training sessions. Embodied gaming as a mean of learning is suitable especially for those

children who have developed hyperactivity as a compensatory mechanism - these children need to physically move to stay focused on a task [12, 13].

We present an embodied game called PigScape for cognitive impulsivity training and measuring a child's ability to inhibit impulses. This game is a product of working in close collaboration child neuropsychologists, HCI researchers, graphics designers, and specialized school teaching staff. Children (N = 4; two of them had a formal ADHD diagnosis) helped to customize game graphics, adjust difficulty levels, create game narration, and define a gesture vocabulary to control the game. Next, we present the core design of PigScape game, explain its anticipated therapeutical effects, and outline how the gaming can be used for research and therapeutic purposes.

2 PIGSCAPE GAME APPLICATION

The logic of the game is based on a well-known physical go/no-go exercise in which a child stays motionless for a predefined time. The freezing is performed on demand, usually after a short period of active movement (like dancing or running). This exercise, with a purpose of suppressing excessive movement in a state of high arousal, is recommended for children with ADHD for strengthening their impulse control and, therefore, behavioral regulation in the end [1]. Variants of this go/no-go task are used in neuropsychological assessment batteries of attention and executive functions [e.g., 7].

In our design, the game includes physically active periods of play lasting a few minutes and much shorter freezing tasks (Figure 1). The protagonist is a pig escaping from a pigsty. In active periods, the pig runs from left to right while collecting coins and other items on its way in a side-scrolling obstacle course (Figure 2, a). Children perform a jump to control their pig avatars, avoiding obstacles and reaching higher collectibles. Optionally, jumping with both hands up grants the avatar wings, allowing them to jump even higher and to reach further collectibles. At some point, the running pig encounters a human silhouette of a predefined shape. A child's task is then to repeat the posture and remain perfectly still for maybe ten seconds to start with. After a freezing task, an active period carries on followed by another freezing task, and the game continues this way. The freezing tasks get gradually longer, increasing, for instance, from ten seconds to one minute as Figure 1 illustrates. Another factor contributing to the difficulty of play is a freezing posture that can vary during the game to maintain engagement and make the game suitably challenging to play (Figure 2, b and c).

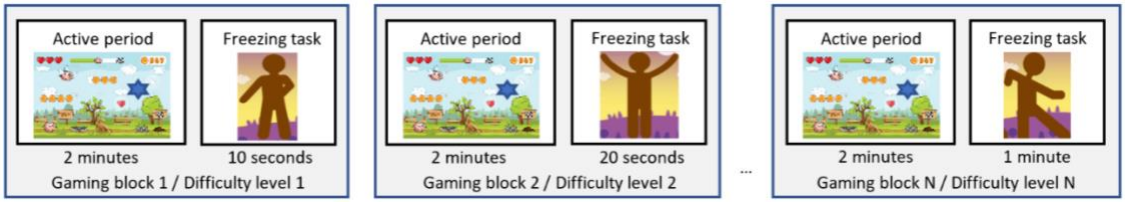

Figure 1: A PigScape game session overview with gaming blocks of consecutive physically active periods and freezing tasks. Game graphics is royalty-free assets with a license allowing redistribution for non-commercial use.

2.1 Design choices for ADHD

Next we outline some of the design choices to support children's motivation and learning with PigScape gaming.

- **Co-located gameplay**. In group games, children with ADHD often interfere with each other and may easily get distracted by the peer's behavior. Our wish was therefore to support a co-located gameplay so that children play the game in pairs. This offers a learning environment in which the children receive support and guidance on improving

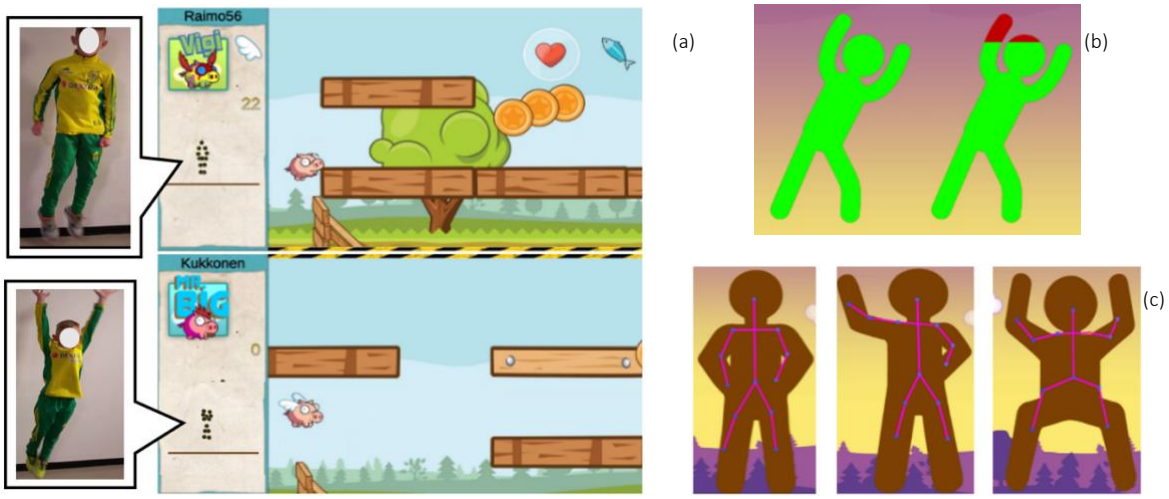

Figure 2: **(a)** Active gaming for two players. Children bodies are visualized as dotted silhouettes. **(b)** Visualization: 100% success of the freezing task (left) and 86% success of the freezing task (right). **(c)** Body postures of different difficulty. Game graphics is royalty-free assets with a license allowing redistribution for non-commercial use.

their peer-communication, self-control, and emotion regulation from the neuropsychologists attending the gameplay. The game can be organized either competitively or collaboratively.

- **Ease-of-use and child satisfaction** directly affect therapeutical efficacy of the gamified training. To achieve high intensity of the training in terms of weekly hours, the gaming needs to be fluent and motivating. Maintaining engagement and motivation are critically important for supporting a child's perception of the gaming as her/his own personal choice (as opposed to a treatment or therapy). Thus, the game always starts from a physically active period that has self-explanatory graphics and logic with many elements of traditional, recreational gameplay. It was our intention that no special knowledge or skills are required from children to engage with the game right from the start.
- **Rewards are displayed, failures ignored.** Due to altered motivational processing (i.e., reward and punishment sensitivity), children with ADHD benefit more from immediate and positive feedback [14]. For freezing tasks, at first, we designed that if a child moves, the game "notices" it and gives an immediate "penalty" (e.g., takes away powers or decreases a score). After piloting the game with children with ADHD we realized that a less strict condition that would not affect the score directly would work better. Therefore, the game counts a success in the freezing task as a percentage from 0 to 100% and visualizes the result to a child, as Figure 2, b illustrates. The game is adjustable, for example, it detects only large movements and disregards small "fidgeting".
- **Re-joining the game** implies that the game continues automatically, even if a child for some reason stops controlling the game, which may happen in case of a technological failure or moments when a child refuses to play. In this case, the pig continues to run an obstacle course without a dramatic decrease in the score or powers. Since children play in pairs, it may be important for them to perform well in front of each other. Failures to demonstrate a good gaming performance to a peer may negatively affect self-esteem of a child, his/her motivation, and, consequently, effectiveness of the training. Therefore, games that allow and motivate players to re-join the gameplay without "reputational losses" are preferable in ADHD rehabilitation.
- **A personal best score of a child** (as compared to the scores of all other children participating in a rehabilitation program) are visualized because it is a strong motivational factor for children with ADHD.

2.2 SYSTEM DESCRIPTION

The game is played with a large projector screen, a depth camera Microsoft Kinect Sensor V2 for Windows, and a powerful laptop (e.g., MSI GT72S Dominator Pro with Windows 10, 2.7GHz Intel Core i7-6820HK, and 16 GB RAM). A recommended distance between the sensor and the players is ~2.5 meters. The game software prototype was created using Unity 2018, while the gesture tracker was implemented using the Kinect for Windows SDK 2.0 C++ wrapper. Twenty body-joint positions obtained by Kinect API were tracked in the freezing tasks. In jump detection, positions of the player's head, shoulders, and hands were processed. The gesture tracker broadcasts the body-joint positions through UDP to the game software, where they are normalized for the screen space.

3 PRELIMINARY RESULTS & DUSCUSSION

The PigScape gaming was implemented as a part of a neuropsychological group intervention, called Rehabilitation of Executive Function and Attention at the Psychology Clinic of the XXX University. The intervention is designed for school-aged (6–12 years) children with problems of executive function and attention. The analysis of 6-weeks-long clinical evaluation and 3-months-long far transfer effects of the PigScape gaming with children with ADHD and attention deficits (N = 10) is still ongoing. There is a preliminary evidence based on the heart rate variability measurements concerning effectiveness of the training in terms of enhanced attentional regulation and response accuracy towards monotonous and go/no-go tasks.

A decrease in number of children taking part in the gaming as a part of their prolonged rehabilitation program is a general indicator of their overall motivation and engagement into the training activities. During the six gaming sessions, none of the children dropped out the gaming that manifests high motivation of the children to continue with PigScape training. As final feedback after the last sixth gaming session, seven children (70%) mentioned that the time of the gaming passed too quickly, they would participate in the training again, and they would recommend the training to their friends. Most children (80%) deemed the game as easy to understand and/or control by body movements.

When asked at the end about the most interesting and positive experiences in PigScape gaming, four children noted that they liked jumping. Noteworthy, while jumping with hands up was an optional feature of the game, children enjoyed it: "*I have got to jump with a pig and score points. Kept hands in the air while jumping (received wings)*" [J1] and "*It was fun to be able to fly*" [P1]. Three children mentioned that it was fun to perform the freezing tasks. One child specifically mentioned that he liked to win: "[It was nice to] see my name going up in the list [of all other players]" [L1]. When asked about negative experiences, four children mentioned that the freezing task was physically demanding: "I broke my neck" [L1]. Four children mentioned game functions related to jumping as a negative experience (mostly related to technical problems).

4 FUTURE WORK AND CONCLUSIONS

The overarching aim of our work would be to develop prescriptive guidelines for ADHD game-like therapies and define appropriate measures to evaluate the training outcomes. We recommend implementing games, like PigScape, primarily as a part of psychosocial group therapy for children with ADHD, for example, children play the game during weekly group meetings of their rehabilitation program. Because children with ADHD have difficulties in completing assignments without direct supervision, it is advisable to start with a fully supervised gaming (where a trained child neuropsychologist facilitates the gameplay, provides assistance and guidance) and gradually teach children self-instructions of staying on a task during independent work. Thus, the gaming can subsequently be translated into online or parental-supervised home therapy programs.

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