A VIRTUAL REALITY BASED TIME SIMULATOR GAME FOR CHILDREN WITH ADHD

Pongpanote Gongsook,
Eindhoven University of Technology, the Netherlands
p.gongsook@tue.nl

Jun Hu,
Eindhoven University of Technology, the Netherlands
j.hu@tue.nl

Francesco Bellotti,
University of Genoa, Italy
franz@elios.unige.it

Matthias Rauterberg,
Eindhoven University of Technology, the Netherlands
g.w.m.rauterberg@tue.nl

ABSTRACT

This project aims at investigating how effective virtual reality is in manipulating and eventually training time perception for children with learning and/or behavior disorders. Children with attention deficit hyperactivity disorder (ADHD) appear to have problems in time perception and this affects their daily life. Cause of ADHD is still unknown but it is believed that it comes from some impairments in their brain. Connectivity of multiple brain regions is needed for time perception. Small dysfunctions in these brain regions may cause time perceiving problems. However, they can be trained in their early ages. Given its ability to create immersive space-temporal environments, virtual reality could be useful in improving the sequential time perception. In particular, adding the engagement factor, we believe that a virtual reality based game could be a very promising tool for training. This paper presents the theoretical and empirical framework, design, and evaluation of virtual reality based game for training time perception of children with ADHD.

Keyword: Time Perception, Virtual Reality, Game, Attention Deficit Hyperactivity Disorder, Learning Disorders

1. INTRODUCTION

Our research question is "how effective of rehabilitation using virtual reality, or/and other suitable technologies, to manipulate the perception of time in the application area in which children with learning and behavior disorder can explore the concept of time?"

What is the time? One thinker says that time is a flow of the forth dimension [34]. Another thinker says that there is no time exist in reality [31]. In physical time, it is an instrumental prescription, which mapped ordered series of events onto the continuum of real numbers [33]. Between the two events A and B, if the value of $|t_A-t_B|$ is not equal to zero, event A and B occurred at a different time. In psychological time, it is explained as a hypothetical discrete structure of mental activity [33].

Whether that time really exists or not, it has already become part of our daily life. Children with attention deficit hyperactivity disorder (ADHD) have a time problem [15]. This problem affects on how they behave. However, with an effective training, they can lower or get rid of the problem in their early age. We have found that VR is an effective tool in treating children having ADHD. Therefore, we aim at creating a virtual reality based game that can manipulate the perception of time for children with ADHD.

2. THEORETICAL BACKGROUND

2.1 ADHD

Attention Deficit-Hyperactivity Disorder (ADHD) is a behavior condition which is identified by the DSM-IV [9]. Its symptoms must be present before the age of seven, persist for at least six months, and severe enough to impact daily functioning across several settings, for example at home, school, and social interaction. Epidemiological studies have indicated that in 18 European countries ADHD occurs in around 10-20 percent of people who having mental health problems [17].

There are three subtypes of ADHD, the first subtype is the hyperactive (ADHD-PH); children diagnosed with this type are usually overactive and having impulsiveness. Besides, they are demonstrating excessive motor fidgets, excessive talking, and a tendency to interrupt people. The second subtype is the inattentive (ADHD-PI); children diagnosed with this subtype are marked by having difficulties with attention skills such as selected and sustained attention. Moreover, they are difficult in organizing tasks, activities, and increase incidence of learning disability. The third subtype is the combined subtype (ADHD-C), which exhibit mixed behaviors between inattentive and hyperactive [26]. The criteria of children with ADHD derived from [2] are shown in table 1. One suggestion for parents is that it is recommended for your child to undergo ADHD assessment if your child having eight or more criteria, because rehabilitation as well as training could be done while they are in the early developmental stages [3].

Table 1. Criteria for Attention-Deficit Hyperactivity Disorder

A. A disturbance of at least six months during which at least eight of the following are present: (1) often fidgets with hands or feet or squirms in seat (in adolescents, may be

limited to subjective feelings of restlessness)
(2) has difficulty remaining seated when required to do so
(3) is easily distracted by extraneous stimuli
(4) has difficulty awaiting turn in games or group situations
(5) often blurts out answers to questions before they have been completed
(6) has difficulty following through on instructions from others (not due to oppositional behavior or failure of comprehension), e.g., fails to finish chores
(7) has difficulty sustaining attention in tasks or play activities
(8) often shifts from one uncompleted activity to another
(9) has difficulty playing quietly
(10) often talks excessively
(11) often interrupts or intrudes on others, e.g., butts into other children's games
(12) often does not seem to listen to what is being said to him or her
(13) often loses things necessary for tasks or activities at school or at home (e.g., toys, pencils, books, assignments)
(14) often engages in physically dangerous activities without considering possible consequences (not for the purpose of thrillseeking), e.g., runs into street without looking
B. Onset before the age of seven.
C. Does not meet the criteria for a Pervasive Developmental Disorder.

2.2 ADHD's brain

We believe that the root cause of ADHD comes from their brain impairments. The prefrontal and dorsolateral prefrontal cortex, basal ganglia, and cerebellum are major regions found to be impaired in ADHD [30]. Children with ADHD have significantly smaller cerebral and cerebellar volumes, particularly the right cerebellum and they have significantly lower levels of activation in the basal ganglia [15], [32].

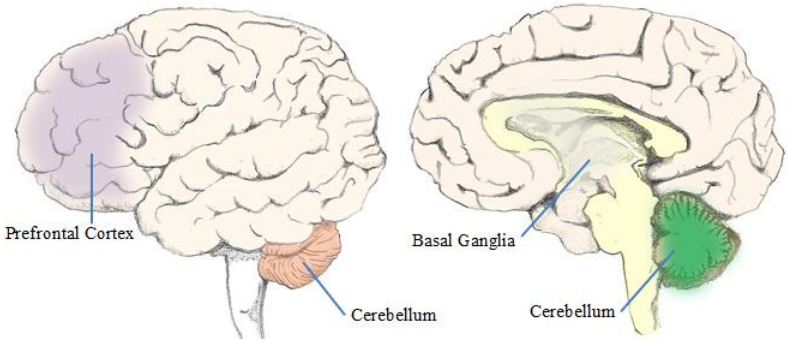

Figure 1. Illustration of human's brain

The cerebellum is traditionally labeled as a motor controller, but it involved in the perception of time since the motor control must be integrated with precise time information in order to predicting the spatial location of the target object and concurrently activating groups of muscle thus perform actions properly [14]. Casini and Ivry [8] found that cerebellar patients have a more specific problem related to timing. Smith et. al. [30] found that the cerebellum's vermis region, which associated with perceptual timing skills, has been shown to be reduced in size in children with ADHD. Their caudate nucleus volumes were firstly abnormal in childhood, but eventually become normal as they grow older. Moreover, they have significantly reductions in the right prefrontal gray matter, and the left occipital gray and white matter compared to controls [30], [32]. In addition, there is a steady decrease blood

flow in the cerebellar midline in highly hyperactive children with ADHD, which subsequently increased after taking methylphenidate (MPH) [32].

The basal ganglia are composed of the corpus striatum, substantia nigra, and subthalamic nuclei. The basal ganglia are typically associated with the control of posture and movement, and they also mediate in temporal information processing. They seem to be a key point for accurate time estimation, and not limit for movement timing. Harrington, Haaland et al. [13] investigated the role of the basal ganglia and found that the basal ganglia and its thalamocortical pathways are connected with timing operations. Meck [21] found rats which lesion of substantia nigra and corpus striatum suffered from time interval discrimination disability but could be treating using dopamine. Toplack [32] found that lesions of the ventral putamen can increase the percentage to be diagnosed as ADHD with inattentive-subtype. Moreover, metabolically increased in the corpus striatum is found in hyperactive children with ADHD. Hurks and Hendriksen [15] revealed that a symptom of inattention is significantly correlated with time reproduction in a long time interval, whereas hyperactivity/impulsivity is correlated with verbal time estimation and retrospective time estimation, but without time reproduction. In addition, there are significantly lower levels of activation in the basal ganglia in participants with ADHD compared to normal controls.

Prefrontal cortex particularly in the right hemisphere is associated with timely processing. The right inferior prefrontal cortex and anterior cingulate have shown to be activated in functional magnetic resonance imaging (fMRI) studies while estimating time [30]. Rubia et, al. [28] investigated brain activities of seven children with ADHD compared with nine controls equivalent in sex, age, and IQ with fMRI. All the participants were performed a stop task which requires an inhibition of planned motor response, and motor timing task which respond to the sensory cue. Results revealed that hyperactive ADHDs showed less power of response in the right mesial prefrontal cortex while they were performing both tasks. Moreover, during the stop task, they are lower power of response in the right inferior prefrontal cortex and left caudate. Prefrontal cortex seems to connect with a functional development in attention as the brain continues to mature [35]. Therefore, it could be concluded that the symptom of ADHD is associated with subnormal activation of the prefrontal cortex.

2.3 Time

Time is something uneasy to describe. Wallis [34] proposed that time is a fourth dimension of our mind where human divided present into two symmetrical spurts, of which one falls back toward the past, whereas the other springs toward the future. Wallis called future as a ‘perception’ which is merely an illusion that memory follows. Perhaps time is just an illusion, Tolle [31] suggested that everything happens in the present moment called ‘the Now’. Undoubtedly, that past and future don’t have a reality on their own. They are merely mental concepts created within our mind. The past is the thinking of memories while future is the projection ahead, but everything can really happen only in the present moment. Therefore, no time really exists in reality.

No matter what time is an illusion or nonexistence in reality, it is already involved with our life. Roughly categorize, there are four different time-scales in humans:

microseconds, milliseconds, seconds, and circadian rhythms [7]. The fastest scale of interval processing is a time that sound takes to travel from one ear to the other. The interval processing in milliseconds to seconds scale are motion detection, speech recognition, and music perception. The final time-scale is the interval time we are appetite, and sleep-wake cycles.

Regarding to time perception reviewed by Langereis [18], humans could have two distinct perceptual time models: time with no central clock, or time with an internal clock. For the time with no central clock, Thomas and Brown [6] developed and tested a mathematical model which explained that attention is related to time. Attention is weighted between time related task and non-time related task. If attention is weighted towards time related task, the time seems passing very slowly. On the other hand, if attention is weighted into the non-time related task, the time seems passing very fast or time flies. In terms of time with an internal clock, Meck [21] proposed a mathematical model which tries to explain human temporal processing. In this model, human possess a timing mechanism called pacemaker or oscillatory process. It produces pulses that are gaited by a switch before enter into an accumulator. The accumulator will pass pulses in a linear fashion into a comparator in which they will be compared to a sample of the expected time of some relevant event acquired from a long term memory. A response is made, if the values are close enough according to a specific decision rule applied by a comparator. If a result gained from the response is positive, the values will then be transferred to store in the memory for later reference.

Although we cannot directly perceive time with our senses, it can be perceived by reasoning about one's surrounding events thus predict, anticipate, and respond to events as past or present that happen within one's local environment [24], [40]. From the age of three, children start developing their sensitivity to duration [11]. In order to perceive time, collaboration between multiple brain regions is needed, these are include but not limit to the cerebellum, basal ganglia, and prefrontal cortex. Children with ADHD have brain impairment in those regions, and this could be the reason why they have difficulties in processing, reading, and telling time [15]. Even though there are quizzes and tests on the internet that aim to improve children's time reading [38], most of them are designed for normal children. Given its ability to create immersive credible space-temporal environments, the goal of our research is to improve the state of the art by creating a virtual reality game aimed at simulating time comprehension for children with ADHD.

2.4 Virtual reality based game

Virtual reality (VR) is a medium that supports high level of presence, such as the feeling of being in a world that exists outside the self. Given the virtual environments' high believability and simulation potential, knowledge obtained in VR can be transferred to apply in a real world environment [25].

VR has been used as an assessment tool as well as a tool for rehabilitation. VR provides better controllable perceptual environment for reliable attention assessment, it provides more consistent stimulus presentation, and it provides more precise when scoring [22]. Highly controllable distracts events under simulated real-world condition in VR makes it a reliable tool to test that children are having ADHD or not, because ADHD children were more affected by distractions in VR thus significantly

did worse performances than those without ADHD [1] [4]. Virtual Reality Medical Center in San Diego puts VR in medical practice for treating ADHD [42]. Lee et. al. [19] found that VR is effective in treating children having ADHD. Their improvement of attention is achieved through VR. People who have mild to moderate mental retardation improved their time perception after treated with VR [23].

Implement VR as a game should enable availability of a very useful and innovative tool for training. VR simulations allow children with certain impairments to experience ad-hoc generated situations and scenarios that have a strong didactic value and could be difficultly set up in the real world [27]. Fairley suggested that patients would feel more amused when they are rehabilitated using games that utilize VR [12]. Game is a system in which players engage in a compelling interaction, defined by rules and goals, that results in a quantifiable outcome [29]. It attracts children's attention. It can define specific goals, rules, and stories. It provides children with challenging tasks. It is something fun and engaging, which motivates children to continue playing. With a feeling of immersion from VR and through proper game mechanics, children are expected to be immersed in the virtual world and absorb the flowing of knowledge with ease.

3. GAME DESIGN

No existing effort in training time perception using a Game in Virtual Reality Environments (GVR) has been found yet. Therefore, we aim at GVR to train and improve time perception of children with ADHD. Gaming is chosen because it is attractive and can provide immediate and formative feedback to players [5]. This single player GVR aims at improving the working memory of children with ADHD, which found out as one of their core cognitive deficits [10]. Improving the working memory might reduce some of their symptoms and associated behavior problems [16].

The children will explore the game in full 3D space (although they are mostly touching the ground because of the Y-axis pulling from game's gravity). It includes mini games, that are embedded in the missions, for specific memory tests for time estimation. The game trains the children's time perception using in-game visual environment such as shadow of trees or the appearance of the sky at different times of the day. For instance, from time to time in-game objects' shadows will change correlated with a direction and light intensity of one light-source in the game acting as the game's sun. This way children may learn and be able to differentiate between day and night. The game uses game-world time while teaching and uses real-world time while testing [36]. The display device used in our first iteration is a standard monitor with a standard input device. Before GVR is used as a psychological assessment tool for acquisition and time comprehension, it must be evaluated by psychologists for its suitability to use with early-age children, get an approval from medical board as well as from parents of the children.

3.1 Storyline

The main story line used in GVR should be linear so we can ensure that all the children experience the same branch of decisions. The story in the game is as followed order: (1) Once upon a time there is one detective rabbit named "Moby" who lives peacefully in an animal village. (2) One day something strange occur. Every night one carrot in the village's garden continues to disappear. No one knows

who steal it. Villagers tried to catch the thief but he is very cunning, and always avoid being caught by the folks. (3) Moby goes to see an Elder Turtle and ask for his suggestion. The Elder Turtle advice him to build a hideout to hide inside and waiting to catch the thief. However, Moby must collect three things. (4) The first thing, he must have planks of wood from an uncle bear who lives as a lumberjack in the forest. (5) The second thing, he must have nails from a crow's nest which built on a very high tree. (6) The last thing, he must have a hammer from a cow who lives in a barn. (7) After Moby collects all things, he goes to the carrot garden and starts building a hideout. Then he goes inside to wait for the thief. (8) In the dark, there is a sound outside *Quake* *Quake*. (9) Moby suddenly jumps out of the hideout and he successfully catches the thief. It is a mole who steals carrot. The mole asks not to send him to jail, he promises to return all carrot he stole. Moby frees the mole, and receive all carrots back. (10) After that the villagers celebrate heroic acts of Moby. The End.

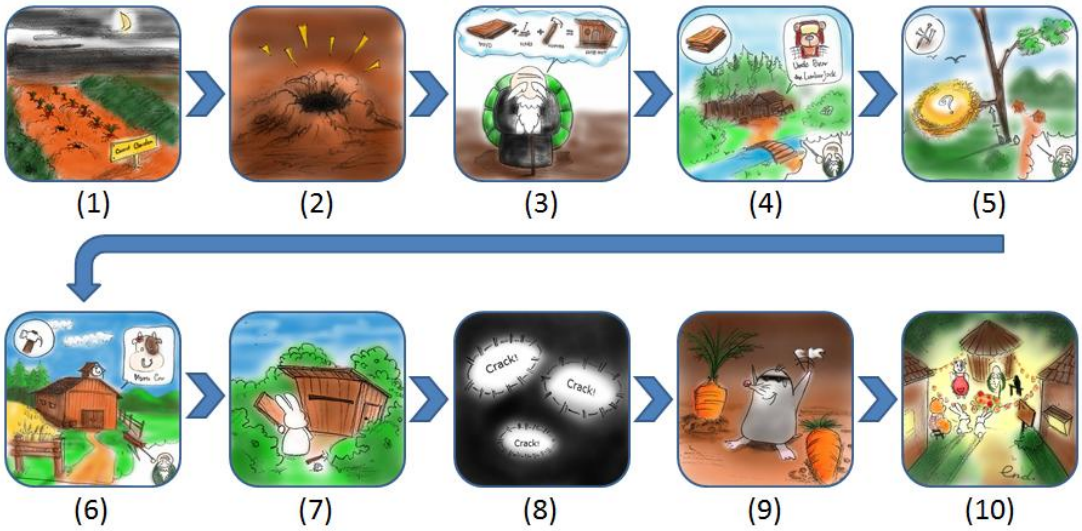

Figure 2. Game's storyboard

3.2 Time perception teaches in the story

Children will be gradually learning about time while they are playing and trying to complete quests (mini games). Time elements in the game are 1) to estimate a time for a moving object 2) to estimate a time spent in order to complete an activity and 3) to wait and be patient.

In the quest that Moby must go to the forest (step 4 in figure 2). He asks for planks of wood from the uncle bear. The bear tells him that there is one apple tree that grow above the river. The fruit is very delicious but there is no way to reach the apple tree. The only way to get apples is to wait for them to drop from the tree into the river and pick them up from the river. In order to pick an apple, children must be waiting and estimate the time that the apple is within the range to pick up. They may trained to wait and be patient, and may learn about moving object's time estimation.

In the quest that Moby goes to ask for nails from a crow (step 5 in figure 2). The bird tells him that Moby can have all nails but they are stored in his nest. Furthermore Moby must go up and get the nails from the nest himself. Unfortunately, the tree is so high that Moby cannot climb. He must find another way to reach the crow's nest. Then he found a balloon which can carry him up. The only one concern is not filling

the air into the balloon too much or else it will blow. Children may be tested to estimate an average time to fill the air into a balloon.

In the quest that Moby goes to borrow a hammer (step 6 in figure 2). The cow requests Moby to match up analog and digital clock faces in a correct time. Moby will get one score each time he made a correct match up. If the score reaches at some point, the cow will lend him a hammer. Children may learn and at the same time tested to read a clock.

4. IMPLEMENTATION

Combination of tools is used to implement the game. The game environment is implemented using Unity[tm] game engine version 3.5.5 from Unity Technologies [41]. This tool comes with an integrated development environment (IDE) called MonoDevelop. It supports various programming languages such as C#, JavaScript, and a dialect of Python named Boo, besides it is free of charge. Buildings in the game are modelled using Blender[tm] version 2.64 from Blender Foundation [37]. It is an open source software which programmed using Python programming language. The benefit of using Blender with Unity is the complete model file can be directly import to use in Unity. Image mapping in the game is edited using the GNU Image Manipulation Program (GIMP) version 2.8 from the GIMP developers team [39]. Sounds in the game are downloaded from free downloadable sound effect sites.

Figure 3. Looks and feels inside the game

Sample screenshot is shown as figure 3. The first part that we implemented in the game is its terrain. We defined size of the terrain, raise hills and valleys. Then we painted grass and pathway using textures—set of images. All buildings are modelled in Blender. They are UV mapped with textures, and customized their animations before being imported into Unity. Trees and foliages are placed in the latest. Interactive objects in the game are created in Blender, which latterly be embedded with custom scripts written using C# in MonoDevelop. The game is programmed to record the position of a player, elapse time, and scores as a log file for later analysis.

5. DISCUSSION

Our game has been evaluated and got feedbacks from professional experts in the fields of clinical child-neuropsychology, entertainment computing, human-computer interaction, game industry, and user-system interaction, with the following comments:

Although the story in our game is fun and interesting, it is rather complex for children age between 5-8 years old. However, it may be suitable for children age between 8-12 years old. We agreed to simplify the story to be simple enough for children in the age of five to understand. The backstory should be selected from a group of activities that children should be familiar with, such as to prepare a birthday party. Children must be able to know what to do after hearing only one or a few briefing provided by the game's opening scene or textual introduction.

Considering about how playfulness and attractiveness of the game, we would like to test our next iteration game as a pilot study. This approach can provide us feedbacks thus answer to such question. The feedbacks observed from child's behaviors will be useful for our next iteration because they can tell us about features in the game which is 'In' and which is 'Out'.

Graphic in the game is satisfiable. By this graphical output, the feeling of presence could be happening while playing the game. Standard display provides limited immersion to a player, whereas display in CAVE likes environment is limited the applicability of the game down to only in a laboratory setting. Therefore, we would like to study further about display the game on a curved screen. Furthermore, the standard input device could be replaced by a two-button joystick.

We would like to use a bio-feedback to collect a physiological data. A tool to measure the electrical activity of the brain such as a non-invasive electroencephalogram (EEG) where brain signals are obtained from electrodes attached to the scalp surface could be used. Moreover, an eye tracking system is another tool we could use to measure what kids looking while playing the game. It could answer us, do the children look at the certain object that we expect them to pay their attention or not? However, we would like to study about how intruded of these tools on the body space of children.

Children with ADHD are likely to be attached to competitiveness, so we plan to add some clues for them to achieve game's goals. Audio clue is another thing that we can add into the game. In the fastest time scale, Sound localization is a duration that sound takes to travel from one ear to the other. Moreover, the loudness of a sound can tell children how far the source is.

We plan to integrate Mnemonic strategy in the next iteration of this project. It is a strategy of which encoding the information in a way other than directed remembering [20]. For example, instead of using textual display, days in a week can be displayed as order of number from 1 to 7. Rhythmic sounds for timing synchronization such as Tic-Tac sounds should also be included in our next iteration. Counting ticks can be used as a timing clue. If we play one tick every second, children may count that, and they may aware of how long the time passes with a cumulative number the ticks counted.

6. CONCLUSION

Our goal is to investigate how effective time simulation in virtual reality is for children with learning disorders. Children with ADHD have time perception problems. Their brain impairments could be the cause of the problem. However, the severity degrees of their symptoms can be lowered in their early ages. In this paper, the first iteration of GVR has been designed, implemented, and evaluated by experts.

7. ACKNOWLEDMENT

This work was supported in part by the Erasmus Mundus Joint Doctorate in Interactive and Cognitive Environments (ICE), which is funded by the EACEA Agency of the European Commission under EMJD ICE FPA n 2010-0012. We are also very grateful for the collaboration with Dr. Jos Hendriksen from Kempenhaeghe centre for neurological learning disabilities.

8. REFERENCES

[1] R. Adams, P. Finn, E. Moes, K. Flannery, and A. “Skip” Rizzo, “Distractibility in attention/deficit/hyperactivity disorder (ADHD): The virtual reality classroom,” *Child Neuropsychol*, vol. 15, no. 2, pp. 120–135, 2009.

[2] R. Barkley, *Attention-deficit hyperactivity disorder: A handbook for diagnosis and treatment*, 3rd ed. New York: Guilford Press, 2006.

[3] R. A. Barkley, S. Koplowitz, T. Anderson, and M. B. McMurray, “Sense of time in children with ADHD: effects of duration, distraction, and stimulant medication,” *J Int Neuropsychol Soc*, vol. 3, no. 4, pp. 359–369, 1997.

[4] S. Bioulac, S. Lallemand, A. Rizzo, P. Philip, C. Fabrigoule, and M. P. Bouvard, “Impact of time on task on ADHD patient’™s performances in a virtual classroom,” *Eur J Paediatr Neurol*, no. 0, pp. 1–8, Jan. 2012.

[5] S. S. Bioulac, L. Arfi, and M. P. Bouvard, “Attention deficit/hyperactivity disorder and video games: A comparative study of hyperactive and control children,” *Eur Psychiatry*, vol. 23, no. 2, pp. 134–141, 2008.

[6] R. A. Block, *Cognitive Models of Psychological Time*. LAWRENCE ERLBAUM ASSOCIATES, 1990, p. 283 pp.

[7] D. Buonomano, “The biology of time across different scales,” *Nat Chem Biol*, vol. 3, no. 10, pp. 594–597, 2007.

[8] L. Casini and R. B. Ivry, “Effects of divided attention on temporal processing in patients with lesions of the cerebellum or frontal lobe,” *Neuropsychology*, vol. 13, no. 1, pp. 10–21, 1999.

[9] DSM-IV-R, *Statistical Manual of Mental Disorders, Text Revision (DSM IV--R)*. Arlington,VA, 2000.

[10] M. J. Dehn, *Working Memory and Academic Learning Assessment and Intervention*. Wiley, 2008.

[11] S. Droit-Volet, “Alerting attention and time perception in children,” *J Exp Child Psychol*, vol. 85, no. 4, pp. 372–384, Aug. 2003.

[12] M. Fairley, “Fun and Games: Virtual Reality Turns the Work of Rehab into Play,” 2010. [Online]. Available: http://www.oandp.com/articles/2010-05_01.asp. [Accessed: 10-Jun-2012].

[13] D. L. Harrington, K. Y. Haaland, and N. Hermanowicz, “Temporal processing in the basal ganglia,” *Neuropsychology*, vol. 12, no. 1, pp. 3–12, 1998.

[14] E. Hazeltine, L. L. Helmuth, and R. B. Ivry, “Neural mechanisms of timing,” *Trends Cogn Sci*, vol. 1, no. 5, pp. 163–169, 1997.

[15] P. P. Hurks and J. G. Hendriksen, “Retrospective and prospective time deficits in childhood ADHD: The effects of task modality, duration, and symptom dimensions,” *Child Neuropsychol*, vol. 17, no. 1, pp. 34–50, 2011.

[16] T. Klingberg, H. Forssberg, and H. Westerberg, “Training of working memory in children with ADHD.,” *J Clin Exp Neuropsychol*, vol. 24, no. 6, pp. 781–91, Oct. 2002.

[17] S. J. J. Kooij, S. Bejerot, A. Blackwell, H. Caci, M. Casas-Brugué, P. J. Carpentier, D. Edvinsson, J. Fayyad, K. Foeken, M. Fitzgerald, V. Gaillac, Y. Ginsberg, C. Henry, J. Krause, M. B. Lensing, I. Manor, H. Niederhofer, C. Nunes-Filipe, M. D. Ohlmeier, P. Oswald, S. Pallanti, A. Pehlivanidis, J. a Ramos-Quiroga, M. Rastam, D. Ryffel-Rawak, S. Stes, and P. Asherson, “European consensus statement on diagnosis and treatment of adult ADHD: The European Network Adult ADHD.,” *BMC Psychiatry*, vol. 10, no. 1, p. 67, Jan. 2010.

[18] G. Langereis, J. Hu, P. Gongsook, and M. Rauterberg, “Perceptual and Computational Time Models in Game Design for Time Orientation in Learning Disabilities,” in *E-Learning and Games for Training, Education, Health and Sports*, vol. 7516, Heidelberg: Springer Berlin, 2012, pp. 183–188.

[19] J. Lee, B. Cho, J. Ku, J. Kim, J. H. Lee, I. Y. Kim, and S. I. Kim, “A study on the system for treatment of ADHD using virtual reality,” in *Conference Proceedings - IEEE Engineering in Medicine and Biology Society*, 2001, vol. 4, pp. 3754–3757.

[20] M. A. Mastropieri, “Enhancing School Success with Mnemonic Strategies,” *Interv Sch Clin*, vol. 33, no. 4, pp. 201–208, 1998.

[21] W. H. Meck, “Neuropharmacology of timing and time perception,” *Brain Res Cogn Brain Res*, vol. 3, no. 3, p. 233, 1996.

[22] T. Parsons and T. Bowerly, “A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods,” *Neuropsychology*, vol. 13, no. 4, pp. 363–81, Jul. 2007.

[23] D. Passig, “Improving the Sequential Time Perception of Teenagers with Mild to Moderate Mental Retardation with 3D Immersive Virtual Reality (IVR),” *J Edu Comput Res*, vol. 40, no. 3, p. 18, 2009.

[24] R. Le Poidevin, “The Experience and Perception of Time,” *The Stanford Encyclopedia of Philosophy*, 2011. [Online]. Available: http://plato.stanford.edu/archives/fall2011/entries/time-experience/. [Accessed: 20-Jun-2012].

[25] G. Riva, F. Mantovani, and A. Gaggioli, “Presence and rehabilitation: toward second-generation virtual reality applications in neuropsychology,” *J Neuroeng Rehabil*, vol. 1, no. 1, p. 9, 2004.

[26] A. Rizzo and J. Buckwalter, “The virtual classroom: a virtual reality environment for the assessment and rehabilitation of attention deficits,” *Cyberpsychol Behav*, vol. 3, no. 3, pp. 483–499, Jun. 2000.

[27] F. D. Rose, E. A. Attree, B. M. Brooks, and T. K. Andrews, “Learning and memory in virtual environments: a role in neurorehabilitation? Questions (and occasional answers) from the University of East London,” *Presence*, vol. 10, no. 4, pp. 345–358, 2001.

[28] K. Rubia, S. Overmeyer, E. Taylor, M. Brammer, S. C. Williams, A. Simmons, and E. T. Bullmore, “Hypofrontality in attention deficit hyperactivity disorder

during higher-order motor control: a study with functional MRI," *Am J Psychiatry*, vol. 156, no. 6, pp. 891–896, 1999.
[29] K. Salen and E. Zimmerman, *Rules of play□: game design fundamentals*. Cambridge: MIT Press, 2003.
[30] A. Smith, E. Taylor, J. W. Rogers, S. Newman, and K. Rubia, "Evidence for a pure time perception deficit in children with ADHD," *J Child Psychol Psychiatry*, vol. 43, no. 4, pp. 529–542, 2002.
[31] E. Tolle, *The power of now: A guide to spiritual enlightenment*. New World Library, 2004.
[32] M. E. Toplak, C. Dockstader, and R. Tannock, "Temporal information processing in ADHD: Findings to date and new methods," *J Neurosci Methods*, vol. 151, no. 1, pp. 15–29, 2006.
[33] J. Wackermann, "Inner and outer horizons of time experience.," *Span J Psychol*, vol. 10, no. 1, pp. 20–32, May 2007.
[34] R. Wallis, "Time--Fourth Dimension of the Mind," *Ann N Y Acad Sci*, vol. 138, no. 2, pp. 784–784, Feb. 1967.
[35] R. Wassenberg, J. G. Hendriksen, P. P. Hurks, F. J. Feron, E. H. Keulers, J. S. Vles, and J. Jolles, "Development of inattention, impulsivity, and processing speed as measured by the d2 Test: results of a large cross-sectional study in children aged 7-13," *Child Neuropsychol*, vol. 14, no. 3, pp. 195–210, 2008.
[36] J. Zagal, "Temporal frames: a unifying framework for the analysis of game temporality," *DiGRA*, pp. 1–8, 2007.
[37] "Blender 3D Modeling tool," *Blender Foundation*, 2012. [Online]. Available: http://www.blender.org/.
[38] "Learn to Tell Time Games & Websites for Kids," *LearningReviews.com*, 2012. [Online]. Available: http://www.learningreviews.com/Telling-Time-Websites-Games-for-Kids.html. [Accessed: 28-Jun-2012].
[39] "The GNU Image Manipulation Program (GIMP)," *GIMP team*, 2012. [Online]. Available: http://www.gimp.org/.
[40] "Time Perception," *Encyclopedia Britannica Online*, 2012. [Online]. Available: http://www.britannica.com/EBchecked/topic/596177/time-perception. [Accessed: 20-Jun-2012].
[41] "Unity3D Game Engine v3.5," *Unity Technologies*, 2012. [Online]. Available: http://unity3d.com/.
[42] "Vrphobia," *The Virtual Reality Medical Center (VRMC)*, 2011. [Online]. Available: http://www.vrphobia.com.