Interactive Diagnostic Game for Time Perception:

Timo's Adventure Game

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PROEFONTWERP

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de rector magnificus prof.dr.ir. F.P.T. Baaijens, voor een commissie aangewezen door het College voor Promoties, in het openbaar te verdedigen op donderdag 28 januari 2016 om 14:00 uur

door

Pongpanote Gongsook

geboren te Nakhon Phanom, Thailand

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Pongpanote Gongsook, October 2015

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List of Acronyms

ADHD	Attention-Deficit/Hyperactivity Disorder
ADHD-C	ADHD Combined type
ADHD-PH	ADHD Predominantly Hyperactive
ADHD-PI	ADHD Predominantly Inattentive
APA	American Psychiatric Association
ASD	Autism Spectrum Disorder
CBCL	The Child Behavior Checklist
CPT	Conner's Continuous Performance Test
C-TRF	Caregiver-Teacher Report Form
DCD	Developmental Coordination Disorder
DI	Design and implementation requirement
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition
fMRI	functional Magnetic Resonance Imaging
GUI	Graphic User Interface
HUD	Head-Up Display
METC	the medical ethical test committee
RDI	Research through Design and Implementation
TRF	Teacher's Report Form
TTS	Text-to-Speeches
UI	User Interface
WISC-IV	Wechsler Intelligence Scale for Children–Fourth Edition

Structure of this thesis

This thesis consists of four parts.

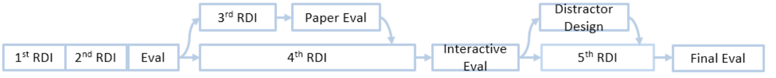
Part I Timo's Adventure, describing Timo's Adventure computer game, the preliminary reasons for creating this game, its storyline, and how to use Timo's Adventure.

Part II Theoretical foundations, describing the state of the art behind the design and implementation of Timo's Adventure computer game. With collaborative work between TU/e and Kempenhaeghe, the psychological aspects were mostly provided by Kempenhaeghe and most of my works were dedicated to the technological and design aspects.

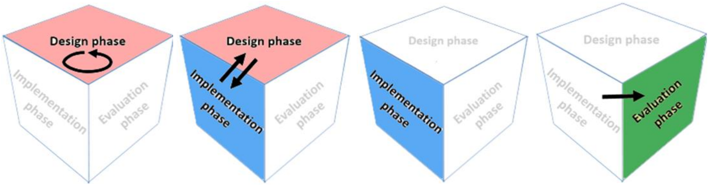
Part III Designs and Implementations, this part consists of nine chapters for the approaches I followed in the design and development of the project. Chapter 3 describes the overview of my iterative development stages. Chapter 4, 5, 7, 9, and 12 describe the incremental details in each iterative development stage. Each iterative development chapter also has design and implementation requirements inside. These requirements gradually increased as the work progressed through a number of iterations in the design cycle. Chapter 8 and 10 describe the evaluation of the game, while it was still in development. Chapter 11 is dedicated solely for the reason why we implemented distractors inside the game. Chapter 13 describes the game architecture design. Chapter 14 is dedicated solely for the data logging mechanism. Chapter 15 describes the evaluation and statistical result of the game.

Part IV Reflection, in this part I reflect on the scientific contribution from the work described in this thesis.

Symbolical schemes used in this thesis

- 

The figure above indicates the present stage, and how it relates to the whole work in the timeline. The first stage was 1st RDI, and the last stage was the final evaluation. The arrows from left to right represents the flow of time. There are five stages of research through design and development, and many times two stages were done concurrently. The reader can find this schema at the beginning of each chapter starting from chapter 4.

- 

This project followed a method of applied research through design and implementation in the incremental steps with micro iteration cycles. Symbols above represent the presented development stages in the applied research through design and implementation.

Throughout this thesis, the reader can find the symbols above, showing in the introduction section of each chapter how the applied research through design and implementation was intertwined.

- Whenever a shade colored block is used, this denotes some extra explanations such as the game story.

PART I Timo's Adventure

Chapter 1. A brief introduction to Timo's Adventure

1.1. Introduction

Timo's Adventure was developed as a collaboration project between Eindhoven University of Technology, The University of Genoa, and Kempenhaeghe Center for neurological learning disabilities. This multi-disciplinary collaboration benefitted Timo's Adventure in that it brought together perspectives from technology, (serious) game design, industrial design, and child-neurological learning disabilities, as well as resources and connections.

Timo's Adventure is an interactive computer game designed to assess different attention processes and contribute to the diagnosis of Attention-deficit/hyperactivity disorder (ADHD) by targeting time related aspects (see Figure 1). Time perception problems have been found in children with ADHD. However to our knowledge, currently no computer games have been designed to diagnose ADHD by targeting time perception. Use of a computer gaming environment offers the possibility to objectively measure behavior in a safe and ecologically valid environment and also offers the possibility to enhance user engagement and motivation with fantasy elements and a storyline. In short, Timo's Adventure game is best used to complement other psychological assessment/methods.

1.2. Timo's Adventure in a nutshell

Figure 1 Timo's Adventure title screen

Timo's Adventure has vivid graphics in a cartoony style for children aged between four to seven years old. It has six mini games that children can play, and has the following story to make it even more appealing to the child. The story is about a child helping a galactic traveller named 'Timo'[1].

Timo is a robot who likes to travel across the galaxies with his rocket. His rocket is unlike any rocket on earth. Its fuel is stars, which can be rewarded as a result of someone doing a good thing. He does not travel alone because his friends usually accompany him. He loves his friends so much even though his friends are pretty naughty and cause him trouble.

One day his friends forgot to refuel the rocket before they went adventuring, so the rocket fuel tank is nearly empty in the middle of the trip. Timo lands his rocket on earth, and must refuel the rocket or else he and his friends cannot travel back home. Timo knows that there is a kind child near his landing site. So he hurries to the child's house before dawn to ask for help.

The child wakes up and then sees a robot. The robot introduces himself. He traveled from his home world here by his rocket, but now he needs the child help because his rocket has run out of fuel. The child agrees to help him. Therefore, Timo suggests that the child must get dressed first.

Figure 2 Screenshot of making sandwiches mini game

After the child succeeds dressing, he accompanies Timo to a kitchen (see Figure 2). They need to prepare something to eat while going outside. Here the child would make five sandwiches for himself, Timo and his friends. And because each one prefers different ingredients for a sandwich, no sandwich would be made with the same ingredients.

[1] 'Timo', 'Timo's Adventure' and its game story were co-designed by Eindhoven University of Technology and Kempenhaeghe, center for neurological learning disabilities.

The appearances of Timo and his friends were the work of PDEng student Christian Sallustro (Sallustro, 2013)

The child and Timo walk across a valley, and reach a river. Timo's rocket landed on the other side of the shore. However, the wooden bridge is broken so they must find another means of transportation to cross the river. Luckily, there is a balloon machine near the river. Timo has an idea that they could inflate balloons and then fly over the river. He tests his idea with one of his friends, and it works. Therefore, the child is encouraged to try inflating a balloon for the group.

Figure 3 Screenshot of monkey mini game

After successfully crossing the river, Timo and the child are confronted with a monkey who is blocking the pathway (see Figure 3). It eats bananas and leaves a lot of its peels on the pathway. The child might try to clear the banana peels; however the monkey will add more banana peels if it sees the child doing that. The child has to carefully observe the monkey and clear the banana peels only when it looks away.

The adventure becomes more fantasy when they pass the monkey and reach a magic land. There are stars popping up from the ground at this special place. The child should catch stars as fast as he can before they disappear in the air. These will be Timo's souvenirs. They leave the magic land and head towards Timo's rocket.

Finally they reach the rocket. Timo's friends can refuel the rocket now, and then it can fly again. Timo and the child have to wait until the rocket is ready. Now the child can choose to wait until it completely refuels, in which case Timo brings the child home with his rocket (big reward), or not to wait in which case Timo brings the child home by his teleportation device (small reward). Either choice, Timo brings the child home. He thanks the child for helping him, and then goes back to his home-world.

1.3. Using Timo's Adventure

Timo's Adventure can be run on any modern personal computer or laptop (see Figure 4). The system should have a 2.5 GHz processor speed or equivalent. Timo's Adventure is a computer game displayed in a 3D environment. It needs high graphic processing power therefore we do not recommend running Timo's Adventure on a computers using integrated graphics chipsets, but instead running it on a discrete video card. The video card should support Pixel Shader 2.0 and the computer should have the latest version of DirectX installed. Timo's Adventure is best displayed on a standard wide-screen monitor capable of displaying in a 16:9 aspect ratio. The optimal resolution to run Timo's Adventure is 1600x900 pixels. Timo's Adventure is a Microsoft Windows application; although it can run on Windows XP, we recommend to run Timo's Adventure on Windows 7 or Windows 8 operating system for better touch interaction. Timo's Adventure supports both mouse and touch screen input. Instructions in Timo's Adventure are verbal, therefore a sound card is needed. Timo's Adventure needs at least 310 MB of hard drive space with 1 MB of additional space for logged data.

Timo's Adventure is a single-player game so no network or internet connection is required. Timo's Adventure is easy to distribute, it does not require to be installed onto the hard drive. It can operate even from a USB flash drive. We recommend to copy it into a folder that allows full read-write accessibility for optimum performance. The logged data is saved in the sub folder with '_Data' of the executable file of Timo's Adventure. Psychologists could open and read the logged data with a text editor. However, we recommend to use the semi-automated data-mining application provided with Timo's Adventure for ease of data processing.

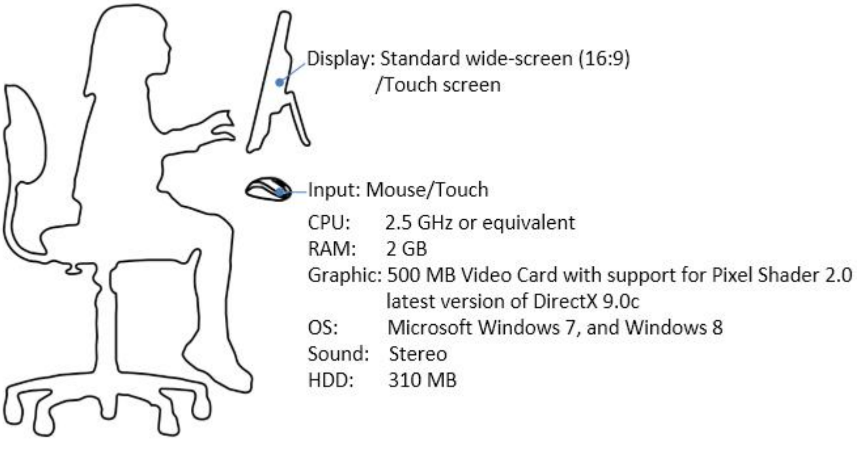


Figure 4 System requirements

PART II Theoretical foundations

Chapter 2. State of the art

2.1. Introduction

Three disciplines have been connected in this thesis namely “Computer game design”, “Attention-Deficit/Hyperactivity Disorder (ADHD)”, and “Time”. Time is a conceptual understanding, by means of which human beings sense and observe changes within the surrounding environment. We gradually understand this concept as we grow up, children often learn about time from their parents. Children with mental disabilities such as ADHD have timing deficits. We created a computer game intended to diagnose the symptoms of ADHD by targeting time perception and associated information processing problems. This chapter will guide you through the state of the art of those aforementioned disciplines.

2.2. The mystery of time

Time is a conceptual understanding of the ever changing environment. The more we understand the concept of time, the more we see what makes us a unique creature; a time bounded creature that calls itself human. Sleep-wake cycles, daily routines, schooling system, workforce ages, retirement, and ultimately death are all associated with time. Time is something difficult to define. Wallis (1967) stated that time is a fourth dimension of our mind where humans divide the present into two symmetrical spurts, of which one moves backwards to the past, whereas the other moves towards the future.

Perhaps time is just an illusion, Tolle (2004) suggested that everything happens in the present moment called ‘the Now’. Undoubtedly, past and future do not have a reality of their own. They are merely mental concepts created within our mind. The past is thinking of memories, while the future is projection ahead. Since everything can really happen only in the present moment; therefore, no time really exists in reality.

Roughly categorized, there are four different time-scales in humans: microseconds, milliseconds, seconds, and circadian rhythms (Buonomano, 2007; Mauk & Buonomano, 2004). The fastest scale of interval processing is the time that an auditory stimulus takes to travel from one ear to the other. In humans sound takes approximately 600 μs to travel between the left ear and the right ear. Animal seems surpassing human in a very short temporal discrimination, barn owls could detect differences of sound by approximately 10 μs. The interval processing in milliseconds to seconds scale are motion detection, speech recognition, and music perception. The final time-scale is the interval time associated with appetite and sleep-wake cycles.

The sun and the earth rotation act as the master clock that our brain can perceive of changing events. Day and night are common phenomena that every sun-exposed living being experiences. This changing of events provides us the natural synchronization of our sleep-wake cycle. Without this we will be desynchronized from other humans (Oppenheim, 2006). Nature controls the length of day, in which earthlings share and inference this length in our daily activities, but once the natural length of day ended we use an artificial-lighting system to lengthen daylight.

Perhaps all walks of life possess time individually. Therefore, we can still live even without a master clock such as the sun. By his experiment in 1962, Siffre concluded that we possess a bio-mechanism controlling our behavior (stated in Fraisse, 1973). He left from normal living and locked himself in a place that has no time guidance at all. He went down an underground cave and lived there alone for several months. Eventually it was reported that his sleep wake cycle was around 24.5 hours to 25 hours per cycle, which differed from 24 hours a cycle of the earth's dwellers. This gradually caused his time to dilate and desynchronize from the time above the ground but was able to resynchronize after he came back.

It is believed that humans do have an endogenous timing mechanism called the biological clock, which runs independently from any exogenous timing mechanisms (Block, 1990). Regarding time perception, a review by Langereis and colleagues (Langereis, Hu, Gongsook, & Rauterberg, 2012), states that humans could have two distinct perceptual time models: time with an internal clock (the Scalar Timing Theory) and time with no central clock (the Attention Timing model).

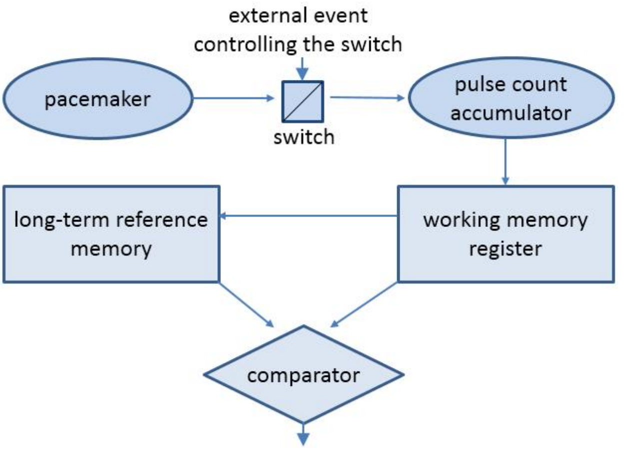


Figure 5 The internal clock model (Adapted from Church (1984), as cited in Wackermann & Ehm, 2006).

Several researchers have performed research on the Scalar Timing Theory (Gibbon, Church, & Meck, 1984; Meck, 1984, 1996), or the 'internal clock model' (Gibbon et al., 1984). The idea behind this theory is that a psychological clock exists in the human brain. The model consists of a pacemaker, which pulses at a constant frequency and passes the pulses to an accumulator that counts and stores them in working memory. In the working memory, the pulses are compared with pulses fetched from long-term memory in the so-called comparator, resulting in a behavioral response (see Figure 5).

The Attention Timing model was proposed by Thomas and Brown (1974). This mathematical model explains that attention is divided between two processing tasks, a temporal processor and a non-temporal processor. They proposed that if attention is weighted towards the temporal processor, the time seems to pass very slowly. On the other hand, if attention is weighted towards the non-temporal processor, the time seems to pass very fast or time flies. Fraisse stated that *"the more one pays attention to time, the longer it seems, with the extreme being expectancy which is nothing but expectancy of a desired or feared event. Reciprocally, duration seems short when the task is difficult and/or interesting"* (Fraisse, 1984). This model conformed with Feuerstein's finding that stress led to increases in subjective to objective time ratio and time following a period of stress was reported to pass quickly (Feuerstein, 2003).

One of the examples was that if attention has been paid to time, the perception of time could be slowed down. David Eagleman explores that time can really slowdown in a near death situation (Stetson, Fiesta, & Eagleman, 2007). He made a time watch that consists of a blinking red light emitting diode (LED) and set the blinking to a rate that was faster than a normal human could read. He attached the watch to one arm of the participant, and let the participant fell down from a crane to experience a near death situation. If time would not slow down, the participant should not be able to read the time from the watch. But it turned out that the participant was able to read some number shown on the watch while falling down. Eagleman claimed that time could really be slowed down per individual. The reason that caused time to slowdown could be the result of attention paid and some chemical surges, such as adrenaline, within the brain of the participant in the fearful situation. As a result, time appeared to slow down and the participant was able to make more decisions than normal for the sake of raising its chances of survival.

2.3. Time perception

We have no perception organ to directly perceive time; we do not even perceive *time* as the way we use our sensory organs, but changes or events *in* time (Le Poidevin, 2011). Our best guess is we perceive time through a well-developed interconnectivity between multiple brain regions (see Figure 6), including the cerebellum, basal ganglia, and prefrontal cortex (Gibbon, Malapani, Dale, & Gallistel, 1997; Hazeltine, Helmuth, & Ivry, 1997; Wassenberg et al., 2008). Research suggests that the prefrontal, striatal, and cerebellar regions are associated with time perception and motor timing (Smith, Taylor, Rogers, Newman, & Rubia, 2002). The cerebellum is traditionally labeled as a motor controller, but the perception of time is involved because motor commands must be integrated with precise time information in order to properly perform actions. Time is used for predicting the spatial location of the target object and concurrently activating groups of muscle (Hazeltine et al., 1997). Individuals with cerebellum dysfunction may lose accurate movement timing for an event-based temporal, but not an interval-based temporal (Toplak, Dockstader, & Tannock, 2006). Conformed that the patients with impairments in cerebellar have a more specific problem related to timing (Casini & Ivry, 1999).

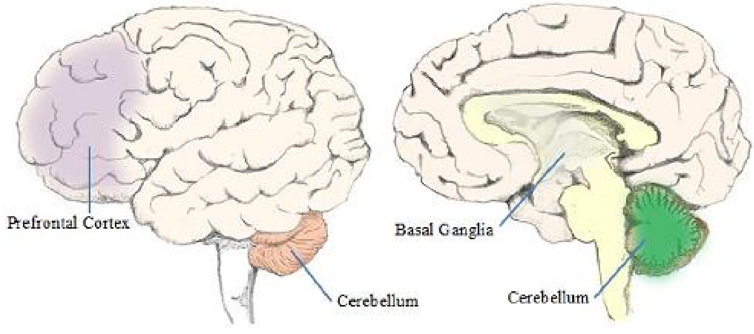


Figure 6 Illustration of human brain regions of the cerebellum, basal ganglia, and prefrontal cortex. With their well-developed interconnectivity, time can be perceivable (Gongsook, Hu, Bellotti, & Rauterberg, 2012).

The basal ganglia, prefrontal cortex, and posterior parietal cortex are suggested to be involved in interval timing (Hurks & Hendriksen, 2010). In addition, Harrington and colleagues investigated the role of the basal ganglia and found that the basal ganglia and its thalamocortical connection to timing operations (Harrington, Haaland, & Hermanowicz, 1998). The basal ganglia are typically associated with the control of posture and movement but they also mediate temporal information processing. Moreover, they seem a key point for accurate time estimation, not restriction for a movement (Toplak et al., 2006). In an animal, Meck (1996) found that rats with a lesion in the basal ganglia showed time interval discrimination disabilities, while treatment with a dopamine agonist normalized timing accuracy.

The prefrontal cortex, particularly the right hemisphere, is associated with time processing. Humans develop time discrimination at the age of three, our accuracy with this ability increases when we grow up (Droit-Volet, 2003). An experiment conducted with patients who have lateral prefrontal cortex lesions revealed that they were impaired on long interval duration discrimination, between 300 to 600 milliseconds (Toplak et al., 2006). It could be suggested that the prefrontal cortex mediated temporal information processing for long time durations, but not on short intervals. Furthermore, it seems connected with a development in attentional functions as the brain continues to mature (Wassenberg et al., 2008).

2.4. Learning Disorders and time perception problems

Time perception may be assumed to be impaired in children with learning disabilities. Only a few studies have been done on this topic. Here are some examples of developmental disorders where a timing problem was reported.

1. Children with Developmental Coordination Disorder (DCD; American Psychiatric Association, 2000) have a slow rate of information processing, resulting in a clumsy movement control (Wilson & McKenzie, 1998). They have impairment in visual information processing which would be expected to lead to problems in motor coordination.
2. Children with autism spectrum disorder (ASD) have deficits in complex functions such as perception, attention, memory, and social interactions, and also show deficits in duration judgment (Szelag, Kowalska, Galkowski, & Pöppel, 2004; Wallace & Happé, 2008).
3. Children with dyslexia have time orientation deficits. It has been shown that dyslexic children perform significantly worse than normal children in the tasks where they have to reproduce a rhythmic tapping sequence (Stambak, 1951).
4. Lack of concentration and timing problem become evident in children with ADHD (Houghton, Durkin, Ang, Taylor, & Brandtman, 2011; Noreika, Falter, & Rubia, 2013; Toplak & Tannock, 2005; Yang et al., 2007; Zakay & Block, 2004). For example, the road-crossing behaviors of adolescents with and without ADHD were found to have lower marginal safety in ADHD due to their impaired time estimation (Clancy, Rucklidge, & Owen, 2006). Children with ADHD may have difficulties in processing, reading and telling time (R. Barkley, Koplowitz, Anderson, & Mcmurray, 1997; Hurks & Hendriksen, 2010) and a diminished functioning of reaction time and information processing speed (Leth-Steensen, Elbaz, & Douglas, 2000).

The problem that the children with these disorders have in common is a neurobiological origin of the learning problems, which also involves the well-developed interconnectivity covering multiple parts of the brain. As attention processes and deficits were the primary focus of our collaboration with Kempenhaeghe Center of neurological learning disabilities (Hendriksen, Peijnenborgh, Aldenkamp, & Vles, 2015), we selected ADHD as our target example for our study.

2.5. Attention-Deficit/Hyperactivity Disorder

Attention-Deficit/Hyperactivity Disorder (ADHD) is a behavior condition identified by the Diagnostic and Statistical Manual of Mental Disorders, Fourth

Edition (DSM-IV) (American Psychiatric Association, 1994). ADHD is among the most common childhood neurobehavioral disorders, and symptoms frequently remain even when the child becomes an adolescent and an adult (Biederman, Mick, & Faraone, 2000). Epidemiological studies have indicated that three to five percent of the general population of the United States is affected by this disorder (Rizzo & Buckwalter, 2000), and eight to 12 percent of children worldwide (Faraone, Sergeant, Gillberg, & Biederman, 2003). Studies have shown that the prevalence of ADHD can range from 2.2 to 17.8 percent (Skounti, Philalithis, & Galanakis, 2007), and around 20 percent of parents of children with ADHD have symptoms of ADHD themselves (Kooij et al., 2010).

According to the DSM-IV (APA, 1994) ADHD symptoms must be present before the age of seven, persist for at least six months, must be poorly adapting and inconsistent with the person's developmental level, and severe enough to impact daily functioning across several environment settings (Goldman, Genel, Bezman, & Slanetz, 1998). In neuropsychological studies, children and adults with ADHD reveal subtle but clear impairments in several complex functional systems such as selective attention, memory, reaction time and information processing speed, motor speed and visuomotor ability, inhibitory control, and working memory (Gualtieri & Johnson, 2005). There are three subtypes of ADHD (Rizzo & Buckwalter, 2000):

1. ADHD Predominantly Hyperactive (ADHD-PH), children diagnosed with ADHD-PH are usually overactive, have impulsiveness, and demonstrate excessive moving and excessive talking.
2. ADHD Predominantly Inattentive (ADHD-PI), children diagnosed with ADHD-PI have difficulties with attention skills such as selective attention, and sustained attention. Moreover, they have difficulty organizing tasks, activities, and show increased incidence of learning disabilities but without the hyperactive behavior.
3. ADHD Combined type (ADHD-C), children who are diagnosed with ADHD-C exhibit mixed behaviors between inattentive and hyperactive.

2.5.1. How to diagnose ADHD

ADHD is a clinical diagnosis. This means that there is no objective method for making this diagnosis (Gualtieri & Johnson 2005). The DSM-

IV describes 18 behavioral symptoms that constitute the ADHD syndrome (APA, 2000). Gualtieri and Johnson (2005) suggested that health professionals (psychiatrists, psychologists, pediatricians) may diagnose ADHD using a combination of various approaches including:

1. A medical examination for physical and neurological status.
2. A neurocognitive assessment of intellectual abilities, like the Wechsler Intelligence Scale for Children–Fourth Edition (WISC-IV) (Wechsler, 2003) and specific cognitive functions such as memory, executive functions, language capacities and attention processes by using paper and pencil tasks or computerized tasks.
3. Parents and teacher scores in the Disruptive Behavior Rating Scale (DBRS) (Barkley & Murphy, 1998).
4. The Child Behavior Checklist (CBCL), that parents can fill out to describe their children's emotional and behavioral problems (Achenbach & Ruffle, 2000).
5. Direct observation of the behavior of the child by health professionals.
6. School reports using the Teacher's Report Form (TRF) (Edelbrock & Achenbach, 1984), the Caregiver-Teacher Report Form (C-TRF) (Achenbach & Ruffle, 2000), or other adjunctive evaluations and questionnaires to help pinpoint specific behaviors.

In addition to those aforementioned approaches, health professionals can use a computer program for assessment of attention processes such as:

1. The Conner's Continuous Performance Test (CPT), which is a test of vigilance or sustained attention, or the Tests of Variables of Attention (TOVA) (Gualtieri & Johnson, 2005).
2. Some Computerized Neurocognitive Batteries (CNB), including the MicroCOG (Elwood, 2001), CogTest (www.cogtest.com), and CNS Vital Signs (Gualtieri & Johnson, 2006), that have been used to evaluate patients with ADHD.

ADHD and learning disabilities are rarely detected until children are four to seven years of age, when they are exposed to reading and other tasks in school (Glascoe, 2000), and there are clusters of symptoms such as inattention, hyperactivity, and impulsiveness which make the diagnosis process more difficult.

To distinguish between normal children and children with ADHD, psychologists need a measurement to assess attention-processes and the ability to inhibit a response. They commonly use CPT as a measurement. This laboratory-based measurement requires participants to maintain vigilance and react to a specific stimulus within a set of continuously presented distractors. This test is designed to assess arousal, activation, and effort of the participant in boring and repetitive task to sustain their attention, that a person with ADHD symptoms should find difficulty to confront (Parsons, Bowerly, Buckwalter, & Rizzo, 2007; Rizzo & Buckwalter, 2000). The test may show a succession of letters while a participant must make a response when the letter 'X' appears right after the letter 'A'. However, the ability of CPT to make predictions on an individual's diagnosis of ADHD is limited. For example, the test is administered in a quiet room, with few distractions or noise, all of which differ from the general classroom conditions that children with ADHD usually operate in. Therefore this test can lead to misdiagnosis such as indicating ADHD children as normal or vice versa (Adams, Finn, Moes, Flannery, & Rizzo, 2009).

Another measurement is the Conner's Comprehensive Behavior Rating Scale (Conners, 2008). This is used to measure the DSM-IV criteria required for an ADHD diagnosis by means of a rating form to be filled in by the teacher or parents of the participant. However, it may also have limited predictive validity and may lack sensitivity to low base rates, which may lead to underestimation because of the bias of the rater (Parsons, Bowerly, et al., 2007).

2.5.2. Time perception deficits in ADHD

Research conducted by Hurks and Hendriksen (2010) revealed that ADHD-PI is significantly correlated with time reproduction in a long time interval, whereas ADHD-PH is correlated with verbal time estimation and retrospective time estimation, but without time reproduction. In addition, brain activities investigated with functional Magnetic Resonance Imaging (fMRI) of seven children with ADHD compared with nine controls (equivalent in sex, age, and IQ) revealed that children with ADHD-PH showed less power of response in the right mesial prefrontal cortex while they were performing both tasks (Rubia et al., 1999). Moreover, there are less activities and responses in the right inferior prefrontal cortex and left caudate. Therefore, it could be concluded that ADHD is associated with subnormal activation of the prefrontal systems.

As already mentioned in the previous section time perception is a brain based process. Abnormalities in brain regions could lead to timing problems. The prefrontal and dorsolateral prefrontal cortex, basal ganglia, and cerebellum are major regions found to be involved in ADHD. Moreover, the right inferior prefrontal cortex and anterior cingulate has shown to be activated in fMRI studies while estimating time. In addition, the basal ganglia are key regions with abnormal morphology in ADHD children, and shown to be involved in time perception and dysfunction during cognitive testing (Smith et al., 2002).

Children with ADHD have significantly smaller cerebral and cerebellum volumes, particularly right cerebellar and the cerebellum's vermis region, which are associated with perceptual timing skills (Smith et al., 2002). They also have significant reductions in right prefrontal gray matter, and left occipital's gray and white matter (Smith et al., 2002; Toplak et al., 2006). A metabolic increase in the striatum, and a steady decrease blood flow in the cerebellar midline (vermis) has been found in highly hyperactive children with ADHD, which subsequently increased after taking methylphenidate (MPH) (Toplak et al., 2006). In addition, lesions of the ventral putamen are increased, in the basal ganglia of children with ADHD-Predominantly Inattentive.

Time perception problems were found to be globally affected in children with ADHD. They have been found to perform worse in tasks related to temporal processing abilities such as time production, time reproduction, and motor timing, which could be interpreted as core executive dysfunctions (Yang et al., 2007). Children with ADHD performed poorly on time reproduction task in which impulsiveness and attention processes were heavily involved (Smith et al., 2002).

It was suggested that these children may have a perceptual deficit in time discrimination, which may only be detectable in brief durations of several hundred milliseconds. A temporal perception deficit in the range of milliseconds in ADHD may impact upon other functions such as perceptual language skills and motor timing. These results conformed to those of Barkley et al. (1997) who found that children without symptoms of ADHD had more accuracy on a time reproduction task and were less often affected by a distraction.

A time-related measurement is connected to temporal processing skills, which include time perception and motor timing. Example of measurements for time perception are verbal time estimation, temporal production, time reproduction, and time discrimination. An example of measurements for motor timing is the control of physical movements, which responds after perceiving a stimulus by sensory organs, such as a click with a mouse or touching with a finger (physical movements) when a warned signal appears (sighting). Temporal processing skills may play an important role in observing deficits in children with ADHD, especially their impulsiveness. In time production and reproduction tasks, impulsiveness appears to lead to an underestimation of time intervals. Moreover, several problems of impulsiveness, such as problems with waiting behavior could result of deficits in time estimation or an altered sense of time (Smith et al., 2002).

2.5.3. Assessment of time related aspects in ADHD

As discussed in the previous section children with ADHD may have time perception problems. Until now time perception was not systematically assessed in diagnosing ADHD. In collaboration research with the department of neurological learning disabilities of Kempenhaeghe, we started a project to explore further the possibility to assess time related functioning in children in preschool age (4-8 years) as a basis to support the diagnosis of ADHD. The following time related aspects are considered important in assessing time.

1. Executive functions.
2. Working memory.
3. Time estimation.
4. Response inhibition.
5. Reaction time.
6. Waiting behavior.

1. Executive functions

Executive functions are brain based skills that we use in order to perform tasks. There are three core executive functions: inhibition (or inhibitory control), working memory, and cognitive flexibility (or set shifting) (Barkley, 1997; Gau & Chiang, 2013; Whitney, Arnett, Driver, & Budd, 2001). Through the use of a metaphor, Dr. Brown (Brown, 2006, p.37) gives us a helpful visual image by comparing the executive functions to the conductor's role in an orchestra. The conductor organizes various instruments to begin playing singularly or in combination, integrates the music by bringing in and fading certain actions, and controls the pace and intensity of the music. Barkley and Murphy reported that 89-98 percent of children with ADHD have deficits in executive skills (Barkley & Murphy, 2011). Executive functions are a good predictor of a child's academic performance (Bull & Scerif, 2001), and poor timing skill is related to poor executive functions (Brown, 2006). Therefore, the executive function may indeed be one of the variables that we can use for diagnosis.

2. Working memory

Working memory is a sub system of the executive functions. This system temporarily stores and manages the information required to carry out complex cognitive tasks such as learning, reasoning, and comprehension. Working memory is involved in the initiation, selection, and termination of information-processing functions such as encoding, storing, and retrieving the information. The working memory capacity in children with ADHD is believed to be lower than in normal children (Droit-Volet, Meck, & Penney, 2007; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Toplak & Tannock, 2005). Working memory is a core cognitive deficit in ADHD children (Dehn, 2008). Children with ADHD are often reported to have deficiencies in perceiving temporal durations, because this perception is dependent on working memory (Barkley et al., 1997; Hurks & Hendriksen, 2010). One can think of working memory, which uses and is sometimes used interchangeably with Short-term memory (STM), and Long-term memory (LTM) as a random access memory of a computer and a hard drive respectively— computer peripherals that superficially imitate what humans are capable of. In this metaphor, a computer will hold the really necessary information that is used for processing in its random access memory. In case that the information is not enough, or it needs other information which has been recorded before, the computer will search and acquire the needed information from the hard drive. The STM of humans stores and maintains relevant information in the owner's mind in order to complete the action or plan. It allows each individual to override an automatic response and shift strategies towards a solution which solves the problem; whereas, LTM holds a longer period of information perceived from the past experiences (Caine & Caine, 2006).

It has been reported that working memory skills are a better predictor of academic achievement than intelligence quotient (IQ) scores (Alloway & Alloway, 2010). This may explain why children with ADHD, although they have comparably normal IQs, may still struggle with learning in school.

One often used test of working memory is memory span— the number of items that a person can hold onto and recall (Bailey, Dunlosky, & Kane, 2008). In a typical test of memory span, an examiner reads a list of random numbers aloud at about the rate of one number per second. At the end of a sequence, the person being tested is asked to recall the items in order. The average memory span for normal adults is seven items.

3. Time estimation

Children with ADHD often have temporal distortion problems (West et al., 2000). Although it has been reported by Bauermeister and colleagues (2005) that children with ADHD do not differ in time estimation tasks compared with the controls. The findings suggest that children with ADHD are associated with a specific impairment in the capacity to reproduce rather than estimate time durations, which may be related to the children's deficits in inhibition. Children with ADHD significantly overestimate shorter time interval (between a half to two seconds), and underestimate the longer time interval (between three to six seconds) comparable to the age-matched control group in time reproduction tasks. Zakay stated that larger errors in children's time estimations correspond with the increasing duration of the time interval that the children had to estimate (Zakay, 1992). However, these distortion problems diminish when they grow up. Furthermore, distraction during the presentation of a time interval has been found to decrease the accuracy of children's time reproductions (Zakay, 1992).

4. Response inhibition

Response inhibition is another sub system of executive functions, coined by Barkley (1997). The other terms are executive inhibition (Nigg, 2001), response suppression, or response cancellation (Macleod, Dodd, Sheard, Wilson, & Bibi, 2003). Barkley (1997) suggested that one core deficit in children with ADHD is a deficit involving response inhibition, which refers to three interrelated processes:

1) Inhibition of the initial pre-potent response to an event.
2) Stopping of an ongoing response, which thereby permits a delay in the decision to respond.
3) The protection of this period of delay, and the self-directed responses that occur within it, from disruption by competing events and responses.

Response inhibition is linked with executive functions skills since executive functions need a good response inhibition control for its effectiveness. In academic activity response inhibition difficulty may result in the following behaviors: blurting out answers before one's turn, making careless mistakes in schoolwork, difficulty following school and home rules, start doing a task while just partly listening to the instructions.

Response inhibition could be explained by using a stop-signal paradigm. The stop-signal paradigm proposed by Logan (1984) used a metaphor of a "horse race" between two sets of processes, one that generates a response to the primary stimuli and one that withholds that response. A stimuli-response process will be generated by default. If the stimuli-response process finishes before the withhold-response process, the response is executed, otherwise the response is inhibited. Therefore, the child should stop executing a response as soon as the child found that the No-Go signal occurs during the moment that the child is going to execute such response.

Go/No-Go signals is a psychological test involving the trial-and-error learning of two sets of stimuli (Helenius, Laasonen, Hokkanen, Paetau, & Niemivirta, 2011; van der Meere, Shalev, Borger, & Wiersema, 2009). The first one is a 'Go' signal or reward-approach responses; reacting during this 'Go' signal will receive a positive outcome. The second one is a 'No-Go' signal or punishment-avoidance responses, reacting during this signal will have a negative outcome (Trueblood, Endres, Busemeyer, & Finn, 2011). Trueblood also purposed a simple stochastic model for analyzing response time data in the Go/No-Go Discrimination task, but the aforementioned model had been studied with adults. In short, this is about when to respond and when to wait.

5. Reaction time

Reaction time is the elapsed times between the sensing of stimuli through sensory organs and a subsequent observable behavioral response. Responses can vary from physical movements, an eye movement, or voice reaction. Our interest arose because slower and more variable reaction times have been found to be a characteristic of ADHD (Gooch, Snowling, & Hulme, 2012; Karalunas, Huang-Pollock, & Nigg, 2013). Reaction time has been used as a diagnostic variable (Rovetta, Cuce, Platania, & Solenghi, 2001). Therefore, we believe that it can be applied to ADHD as well.

Our test of reaction time was not a simple reaction time, but more of a warned reaction time. There is a visual signal shown at the designated position where the stimulus will appear on the screen. Reaction time is shortened when the response signal is preceded by a warning signal (Sinclair & Hammond, 2008).

6. Waiting behavior

The study of delayed gratification of Stanford University in 1970s, also known as the Stanford marshmallow experiment, by Walter Mischel, Ebbe B. Ebbesen, and Antonette Raskoff Zeiss (Mischel, Ebbesen, & Zeiss, 1972), is about offering two choices to a child, one marshmallow given immediately after instruction, and one extra marshmallow if the child waits without eating the presented marshmallow for a short period of time. This study showed that the ability to wait before obtaining a reward is developed in children, and is an important variable for future development.

Impulsive behavior is operationalized as occurring when someone response to an immediate reward, and this reward is relatively smaller than another one that would be obtained if the response would be delayed (Grey, Healy, Leader, & Hayes, 2009). The ability to strategically allocate attention during the waiting period could be the key to become successful in waiting for the delayed reward (Mischel, Shoda, & Rodriguez, 1989).

We would like to explore this topic further using a computer game. Based on the hypothesis that attention deficits are related to an ineffectiveness of delaying reinforcement (Brockel & Cory-slechta, 1998), and delayed gratification affects and influences the highly rewards valued for delay decisions in children with ADHD (Marx, Pieper, Berger, Hässler, & Herpertz, 2011).

2.6. Distractor

A distractor is a single or multimodal stimulus which could distract and make the children shift their attention for a period of time. Adam (2009) found that ADHD children were more affected by distractions than those without ADHD. Therefore, including distractors in the game could explore how effective the distractor is in children with and without ADHD.

Regarding the "clinical" model of attentional processes by Sohlberg and Mateer (as cited in Rizzo & Buckwalter, 2000), attention can be classified into five levels as follows:

1) Focused attention— this is the basic ability to respond to specific external stimuli.
2) Sustained attention— usually referred to as "vigilance, or concentration" this is the ability to continuously maintain one behavioral response to an activity. Ability to involve oneself in

academic activities as well as recreational activities might be limited in a person who has impairments in this area.

3) Selective attention— this is also often referred to as “freedom from distractibility.” While there are surrounding distractors or additional activities, this ability maintains behavioral or cognitive attention, filters out irrelevant information around us, and focuses on the things that demand our attention. Because it is impossible to give attention to every stimulus in the present environment, we use selective attention to select which stimuli are worth spending our attention on as events occur. The presence of distractors might cause children who are deficient in this area to be unable to focus on their current activities.

4) Alternating attention— this refers to the ability that allows one to shift the focus of attention between tasks. Using cooking as an example, a person can prepare two or more recipes for a meal by prioritizing the sequences of tasks.

5) Divided attention— also commonly referred to as multi-tasking. The ability to attend and respond to multiple tasks simultaneously is a common experience in everyday life. While multi-tasking, a person performs two different tasks with a really rapidly alternating attention to both of them as if they were performing at the same time.

Researchers have shown a significant effect of distractors with the children with ADHD. Bioulac and colleagues displayed lots of distraction while using VR to distinguish the performances of children with and without ADHD. Results shown that the children with ADHD had lower performance, and they require loads of working memory to sustain performances over time (Bioulac et al., 2012). Our psychological expert suggested that the distractors in the game should be played in a designated time interval, and we could use an eye tracker to observe whether the child pays attention to the distractor or not.

2.7. Computer game

Video games and computer games are different but used interchangeably. A ‘Video game’ is a game that is produced for a consumer gaming system i.e. the Xbox, GameCube and Playstation, but a ‘Computer game’ is a game that is produced for PC (Kirriemuir & McFarlane, 2003). According to Esposito, “A video game is a *game* which we *play* thanks to an *audiovisual apparatus* and which can be based on a *story*” (Esposito, 2005). Pong, the ball-and-paddle video game that simulates table tennis or 'Ping Pong', is considered to be the earliest commercial video game. It was launched in 1972 by Atari. It became the first successful commercial video game, which many families had in their home. The reason that made it succeed could be explained by Huizinga (1944), who stated that humans are playful animals. Play is something we love to do. Games (digitally) afford playful interactions that we cannot have in the real world or in everyday life. They offer the opportunity to freely play with things, where we do not have to worry about the consequences after playing. Play is something humans need in order to get out of their boring everyday life.

Playing games takes time and demands attention from the player. Games are able to motivate players by incorporating fantasy, challenge and curiosity (Malone, 1981). Sometimes humans play a computer game to relieve their bad feelings and lower their tension after a hard day's work. In addition, the positive feeling received from game play could be something that is craved repeatedly, and hence leads to addiction (Salen & Zimmerman, 2003).

2.7.1. Game genre

Game genres are primarily used and coined by game journalists, and are not the result of a systematic study (Järvinen, 2002). Genres of games are the 'names' of categories where each game in the same genre shares similar characteristics. Without seeing the real game in action, game designers can get an idea of what kind of computer game one can expect by just its genre.

Computer games can be classified into many genres and some of them are full of violence, which makes them inappropriate for children to play—or are not allowed to by their parents. These kinds of computer games are mostly of the genre of (first-person) shooter games. For example, *'Halo'*, *'Killzone'*, and *'Call of duty'* etc. However, said games have a very high chance to make the player feel excited, create high blood pressure, and release adrenaline from the adrenal cortex as if he or she does extreme sports (Segal, 1991; Walsh, 2001).

There is also another category of games called 'casual games' that players can play for a short periods of time per day. Mostly the graphics of these games are not as highly detailed as the core game genres such as mentioned above, and most of them are in 2D instead of 3D. Games in this category are sometimes variants of time management games which require a player to plan and organize things in the best possible way, using the time as effectively as possible. Sometimes the games in this category are just games with very simple goals or without a complex game story.

Some of the games are designed solely or specifically for specific exterior purposes these games are called ‘serious games’— a game designed for specific purposes beyond entertainment (Bellotti, Berta, & De Gloria, 2010). Being entertaining is of course important for the game to keep players engaged in the game play. However, in serious games the designer of the game focuses more on the serious part such as knowledge transfer and that the game must be close to the real situation as much as possible. This could kill the entertainment of the game and possibly makes it fail its game-like qualities (Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013; van der Spek, Sidorenkova, Porskamp, & Rauterberg, 2014). In order to prevent that potential pitfall, participatory design can be used to make the game appeal to the player and keep the player engaged.

2.7.2. Benefits of a computer game

As already mentioned in the section about how to diagnose ADHD, absolute methods for ADHD diagnosis do not exist as ADHD is a clinical diagnosis. Psychologists use DSM-IV guidelines for ADHD diagnosis, combined with other tools including traditional psychological methods such as paper-based assessment, parental check lists, or computerized tests. In the pen and paper tests or computerized attention tasks. Children are confronted with a cognitive task they have to perform; children do not perceive those tasks as fun activities.

Rich characteristics of computer games are that they can attract the children's attention and could stimulate intrinsic motivation for children to play because of challenge, control, and fantasy of the games and curiosity of the children (Habgood & Ainsworth, 2011; Salen & Zimmerman, 2003). Therefore, using computer games as a psychological assessment could give psychologists additional diagnostic information because the children may think that they were playing the game rather than doing the assessment. Parents, teachers, and clinicians reported that, despites having poor attention span, children with ADHD often show sustained concentration, show engagement, and behave less impulsively when playing computer games (Barkley, 2006). Moreover, computer games offer players with intense and often relentless action, immediate rewards, challenges, and appealing stories, which seems to be something children with ADHD eagerly desire, and they hardly get from the everyday life outside the digital world.

There is a theory called 'reward deficiency theory' that tries to link game addiction to ADHD (Bioulac, Arfi, & Bouvard, 2008). It explains that a person who is less satisfied with a 'natural reward' tends to look out for an 'unnatural reward' such as an addictive substance that stimulates the reward pathway in the brain. Han and colleagues (2009) suggested that video game play might be a means of self-medication in children with ADHD, because it requires visual working memory, and this stimulates their brain to release more dopamine. Computer games could look like a double-edged sword in this circumstance, because it can have both a favorable effect such as it draws children's attention and strengthens the engagement of game play, but also an unfavorable effect such as video game addiction. However, we believe that our game will not cause video game addiction, because our game will be played only one time by each participant while being closely monitored by a psychologist.

The computer game is best used to complement, not to replace, other psychological assessment/methods. We aim at giving them the feeling that they are playing instead of being tested. Another advantage that computer games could have over pencil-and-paper based assessment is they do not induce a type of the Hawthorne effect (McCarney et al., 2007). Hawthorne effect is a situation where kids behave differently when they know they are being studied. Using a computer game could eliminate such an effect, and improve the ecological and external validity of a diagnosis.

Using an interactive computer game has other important advantages. It ensures that every presentation of the test material is identical (except for minor differences in the case that some children will get more distractors than others because they spent more time clearing the game, the test machine differs in processing speed, monitor size, dedicated 3D rendering module, and video resolution adjustment). Presentations generated by computers should therefore virtually eliminate examiner effects and increase reliability. Computer games eliminate scoring errors and test results are available as soon as the test is completed.

2.7.3. Computer game and the children with ADHD

A large body of literature already exists about using computerized programs developed for children with ADHD (Chacko et al., 2014; Melby-Lervåg & Hulme, 2012; Rapport, Orban, Kofler, & Friedman, 2013; Shipstead, Redick, & Engle, 2012). Furthermore, these programs may also incorporate a game-like mechanism to enhance user engagement and motivation.

Until now several games have been developed and used in research on ADHD. A game based on the popular television series Spongebob, which studied the effect of motivation on children with ADHD and ASD (Geurts, Luman, & van Meel, 2008), showed that motivation helps both groups achieve better performance but was not solely related to cognitive control abilities. •'*Interactive metronome*' is another example of a game-like intervention (Shaffer et al., 2001). This is a neuro-motor therapy using and auditory and visual platform that engages the patient and provides immediate feedback at the millisecond level to promote synchronized timing in the brain. To achieve a higher score, the patient must use motor movements intertwined with cognitive processing, attention, and decision making to tap a handheld-device with precise time as rhythmic stimulus. •'*IntegNeuro*' ("New breakthrough in diagnosis of ADHD," 2010), an objective assessment of cognitive strengths and weaknesses, developed by Brain Resource and the University of Sydney, claims that it could pinpoint young people with ADHD through the tests, which detects variations in sustained attention, impulsivity, inhibition, intrusions and response variability. •'*Groundskeeper*' (Srivastava, Heller, Srivastava, Roots, & Schumann, 2012; Montini, 2013) is a cognitive game targeting on the exercise skills that are affected by ADHD. The University of Minnesota and CogCubed, who developed the game, stated that it has accurately predicted ADHD cases between 75-78 percent. •'*Braingame Brian*' (Oord, Ponsioen, Geurts, Brink, & Prins, 2012; Prins et al., 2013) is a computerize training of three executive functions: visuospatial working memory, inhibition, and cognition flexibility. Those aforementioned executive functions were embedded in the game-like world, where a child may select to train either parts or all of them.

Some computer games are integrated with biofeedback but are focused on a training tool. Examples are •'*Play Attention*' (Freer, n.d.), and •'*S.M.A.R.T. BrainGames*' (Greco, n.d.). These games are designed to let children control the action on the screen with their brain waves. Kaduson and Finnerty (1995) utilized computer games to compare the effects of self-control training, using cognitive-behavioral game play and biofeedback game play among children with ADHD and controls. Hypotheses that self-control training by biofeedback reduces a child's perception of its self-control problems had been supported, but did not generalize to parental report of self-control or behavioral measures. There also a game that use brain computer interface (BCI) technology as a controller. A game that measures and translates a user's attention level to control a virtual hand's movement in the game's world (Jiang, Guan, Zhang, Wang, & Jiang, 2011).

Off-the-shelf games running on the Nintendo's home-video game console called 'Wii' were also used for the rehabilitation of children with ADHD (Chuang, Lee, & Chen, 2010). The authors chose nine games, such as 'shooting range', 'find Mii', 'table tennis', 'laser hockey' and 'charge!' from Wii play, and 'tennis', 'baseball' and 'boxing' from Wii sports. All of the aforementioned games were focused on selective attention, sustained attention, and visual-motor coordination.

2.7.4. Time, children, and computer game

We tried searching for computer games on time for children on the internet. Search queries using 'Time', 'Children', and 'Game' in Google resulted in numerous hits, which when focusing on the majority, we have mathematics games about telling the time. Improving the time concepts of children in game design can already be found in many commercial or free products.

For example, •'*Bedtime Bandit*' is a time constraint game, where a child may try to select the correct analog clock that matches with the time located in the bottom left corner of the screen, before any of them reach the floor. Every incorrect answer leads to a penalty speeding up the falling clock, and reduces the time for the child to make the next selection. •*'Cat and mouse Time'* shows an analog clock in the center, and clock reading text on the left and right of the screen. Within 60 seconds, a child can choose either 'mouse' or 'cat' as the one telling the right time. There is a penalty for making a wrong answer. •*'Clockworks'* is a game from BBC Schools. Children may help Max and Molly fix the tower clocks by telling the time. There are three levels of difficulty involving analog and digital clocks, as well as calculating lapsed time. •*'Clockwise'* from BBC Education. There are three levels for different age groups. Level 1 is for five to seven years old, to learn how to read the hours. Level 2 for six to eight years old, learning about half past-, quarter to-, and quarter past-. Level 3 for seven to nine years old, learning about five minute intervals past an hour. •*'Difference between two times'* from Bgfl.com. This game utilizes a timeline and digital clock to display time, and the child has to calculate time differences between the first time and second time. •*'Hickory Dickory Clock'* from ictgames.com set a goal for the child to select the correct analog clock, which shows its face matching with a time in words located at the bottom of the screen. •*'Nash's Adventures 5-7 years'* is a single linear story game for early age children showing a schedule for children from waking-up, going to school on sports day, and going back home. The tasks are close to the daily routine of a child, such as the clock showing 8 o'clock to wake up, then prioritizing on what to do first, second, and last between 'brush teeth', 'eat breakfast', and 'go to bus stop'. •*'Flip time'* from NASA.org, this cards matching memory game provides a clock time converting between digital and analog format. Children will start from basic eight cards, click on a card then the child may find the second card that matches the time show on the first one.

Figure 7 Screenshots of time games for children
(1) Bedtime bandit (2) Cat and mouse Time (3) Clockworks (4) Clockwise
(5) Difference between two times (6) Nash's Adventures 5-7 years

Langereis and colleagues (Langereis et al., 2012) investigated these games and discovered that most of these games were aimed at teaching normal children a straightforward clock concept, without referring to or being based on clear and solid learning and time perception theories. Furthermore, hardly any of them were designed for children with learning disabilities.

2.7.5. Computer game as a diagnostic tool

Computer games can be developed for the diagnosis of symptoms of ADHD. Pascual (Pascual, Zapirain, & Zorrilla, 2012) stated that games and technological adaptations of traditional psychological tests could lead to empower and enhance concentration and motivation in children and teenagers with ADHD symptoms. Moreover, it is extremely useful in the detection and diagnosis of ADHD at early stages of children with systematic diagnosis tools based on tests and questionnaires. We believe that the performances of children with ADHD who play such games should be different from those of the controls and there is still the unexplored area of using computer games in ADHD diagnosis.

Some of the literature reported that children with ADHD performed worse than the controls while playing a computer game. Clancy and colleagues (2006) reported that participants with ADHD act more dangerously and experience twice as many collisions as controls in an immersive virtual reality simulation of a busy road crossing game. Kerns and Price (Kerns & Price, 2001; Kerns, 2000) tested children about prospective memory with the game-like program named 'CyberCruiser', they did not find the difference of prospective memory between children with ADHD and controls, but found that children with ADHD showed a significantly higher number of times that their car ran out of gas than the control group; possibly due to more forgetfulness.

Some of the researchers found that children with ADHD performed better in psychological assessments with computer games than they previously did on the tradition pencil-and-paper format. Shaw (Shaw, Grayson, & Lewis, 2005) reported that children with ADHD ages six to 13 years old performed more poorly when compared to a control group on a conventional CPT-II, but performed as well as a control group when the same test was administered as a video game. Bioulac and colleagues (2014) found similar results. Lawrence (2002) found that six to 12 years old boys with ADHD performed worse than a normally developing control group when playing a cognitively demanding adventure video game, but performed the same on a motor-skill targeting game, which did not involve high working memory or distractor loads.

Some literature reported no significant effect of ADHD while playing a computer game. Saldana and Neuringer's (1998) found no significantly difference in the test of response variability between groups of children with and without ADHD using a simply video game, which involved pressing one of two buttons when an animated snake crossed a designated area on the screen.

It could be concluded that a computer game has a high potential to be used in ADHD diagnosis. Selection of contents and focus of particular deficits are needed because ADHD is associated with deficits in some but not all aspects of cognitive functions. To our knowledge, none of the computer games have been designed from the bottom up for the diagnosis of ADHD while targeting problems associated with time perception.

The purpose of our diagnostic game is to collect quantitative data and behavioral data without children knowing about it; so called stealth assessment (Shute, 2011). We expect to collect the diagnostically relevant data of children who played the game. We believe that we could be deeper analyzed the qualitative data for the answer, whether their behavior affect their performance or not

In order to achieve that objective, we applied semi-automatic interactions logging in our game, as opposed to questionnaires during game play because these would be disruptive and could break the feeling of immersion of the player (Serrano-Laguna, Torrente, Moreno-Ger, & Manjón, 2012). By operating in the background while a player is playing the game, it will periodically write the events that occur inside the game as well as the time (timestamps) when it happened, into text files.

The logging mechanism logged the start time of each mini game, and events that happen during game play, pertaining to game achievements and game objectives, and the end time of each mini game. We can calculate the time a player used for certain interactions by the differences of their time stamp. This is a tool that is different from traditional psychological tests because it engages children and makes them believe that this is merely a game and not a test.

2.8. Conclusion

Time is a conceptual understanding that humans sense from the changing environment. We believe that humans could possess two distinct perceptual time models: time with an internal clock (the Scalar Timing Theory) and time with no central clock (the Attention Timing model). We can perceive time and use the term ‘time perception’ although we do not have any perception organ to directly perceive time. This is because we do not perceive *time* as the way we use our sensory organs, but changes or events *in* time. The ability of time perception should happen with our brain’s activities that require a well-developed interconnectivity between multiple brain regions named the cerebellum, basal ganglia, and prefrontal cortex.

Time perception may be assumed to be impaired in children with learning disabilities, including children with ADHD. This disorder is among the most common childhood neurobehavioral disorders, and symptoms frequently remain even when the child becomes an adolescent and an adult. ADHD is a clinical diagnosis, which means that there is no objective method for making this diagnosis. The DSM-IV describes 18 behavioral symptoms that constitute the ADHD syndrome. Health professionals may diagnose ADHD using a combination of various approaches. The time perception problem is globally affected in children with ADHD, and deficits have been found in children with ADHD on tasks of time production, time reproduction and motor timing, implicating a deficit in temporal processing abilities. Until now time perception was not systematically assessed in making the diagnosis ADHD.

There were many computerized programs developed for children with ADHD, and they may also incorporate a game-like mechanism to enhance user engagement and motivation. Game design and approaches were seen as a natural tool to make existing intervention and assessments more appealing to young patients and ADHD.

A computer game has several advantages over the traditional paper and pencil tests of attention processes. It enhances motivation, material is presented in an identical way, scoring errors and Hawthorne effects are prevented (McCarney et al., 2007). There is extensive literature on using computer games with children with ADHD. However, at the start of the research most of the literature was about video game addiction, therapy, and treatment of ADHD using computer games and to our knowledge, none of the computer games have been designed for the diagnosis of ADHD by primarily targeting problems associated with time perception.

Considering the information on ADHD and the scarcity of computer games used to support ADHD diagnosis, we started to develop a video game as a serious diagnostic tool for children. We focused on time perception as a core mechanism in assessing attention processes. In collaboration with the psychologists at Kempenhaeghe, the game was designed to work on: executive functions, working memory, time estimation, response inhibition, reaction time and waiting time behavior (see section 2.5). Therefore, the purpose of this study is to design a system that enables psychologists to collect enough data from a serious game to help them in diagnosing the ADHD. Moreover the aim is to create a user-friendly, non-test like assessment that gives to children the feeling they are playing instead of being tested.

2.9. Research question

In this study, we aim to develop a game based diagnostic instrument to be used with children at preschool age to systematically assess time related functioning. The time related aspects as discussed in section 2.5.3 are all operationalized in a game environment. Six mini games were developed to assess different time aspects, and were incorporated in a storyline which attracts the attention of the children. The question pertaining to this process was:

"How to design a game as a diagnosis supporting tool to collect data on time related aspects for children with ADHD?"

PART III Designs and Implementations

Chapter 3. Research through Designs and Implementations

3.1. Introduction

Research through design (Zimmerman, Forlizzi, & Evenson, 2007; Zimmerman, Stolterman, & Forlizzi, 2010) is an iterative approach. It is in itself a scientific process of trying something new, applying existing techniques, seeing what works and what does not, reflecting on intermediate outcomes as learning, giving design considerations and what could be improved, and implementing these in the next iteration.

We applied research through design and iterated extensively in the design and development. Therefore we refer to our approach as Research through Design and Implementations (RDI).

3.2. Iterative development stages

The iterative development stages of the diagnostic tool were roughly divided as Design, Implementation, and Evaluation, adapted from the iterative software cyclic model and the spiral model (Boehm, 1988; Rauterberg, Strohm, & Kirsch, 1995; Rauterberg, 1992).

We also applied the concept of Agile methodology (Larman & Basili, 2003). This incremental software development process could be applied to the development of the game. When combined with the participatory design and user-centered design process, the result of those aforementioned methods were practical in use, which will be described in another section of this thesis.

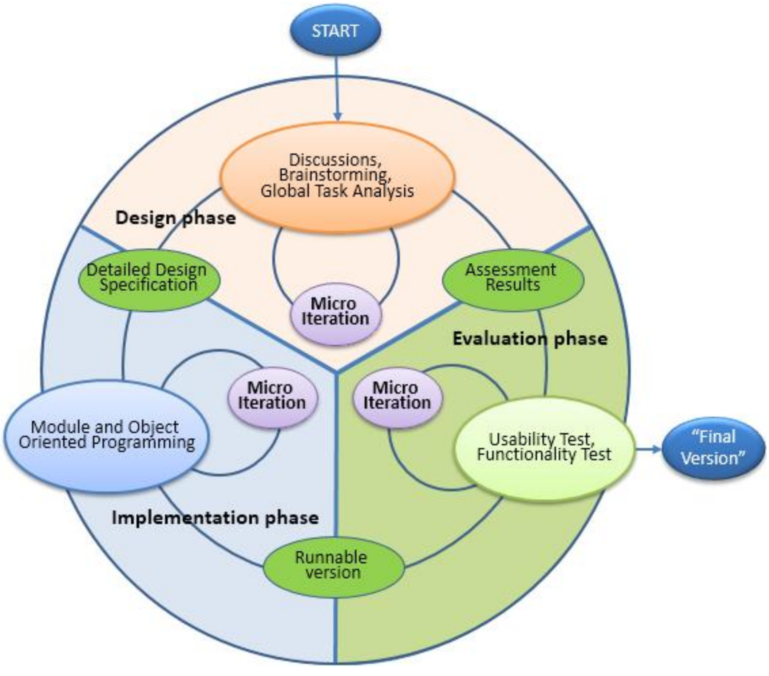


Figure 8 Illustration of the iterative development stages adapted from Rauterberg, (1992). It dictates three phase of development: design, implementation, and evaluation.

3.2.1. Design phase

Gathering data from existing commercial games in the games market, searching for common game elements on online games sites, and looking for the type of games that children would like to play, it became apparent that loosely following these attempts would not be an adequate approach.

Therefore, we applied the participatory design model (PD) and a user-centered design approach (UCD) during the design phase to get deeper insights and direct ideas (Rauterberg, 2003; Read, Gregory, Macfarlane, Mcmanus, & Gray, 2002). Participatory design is an approach to design that involves stakeholders in the design process to help ensure that the final result meets their needs and requirements.

Users were invited to design together with us in the design process. Due to the fact that our game was designed as an additional tool for diagnosis, it would not be used without supervision from a psychologist. Therefore, the users of this case were both psychologists and children. Psychologists participated more towards the functionalities of the game and its visual graphics. Children were also invited to our design process and participated, giving us ideas for the game. This approach was similar to how custom made soft toy companies such as 'Child's Own Studio', 'Draw Your Toy', and 'Make with Grace' design their soft toys; based on the children's own drawings (Adey, 2014; "Draw Your Toy," 2012; Tsao, 2007). We gave the outlines of visual elements in the game to children and encouraged them to express their thoughts by drawing what a character would look like. This design method provided us with a source of ideas for designing characters for the game, which in turn increased the likelihood that the characters we designed would be accepted by children.

Key activities in this phase

- Design the architecture and structure of program to serve the functionality of requirements or user needs. This was the main task of the design. There was more than one technique that could help in the design process. For example, we used participatory design and user centered design.

- The designer must dissect the needs and requirements of users into smaller or sub-requirements. The strategy used here was a top-down approach, because there were no usable components to combine into a game yet. Visualization of a possible end-design based on the user's requirements should be made in the design process. More importantly, it should be at least practicable or based on the technical aspects, which could be implemented towards the final product.

- Make a project plan and feasibility study in order to achieve the goal in the set time frame. This was important in our design because it could tell us how practical the realization of the design would be concerning the technological aspects in relation to time. If there was less chance to finish the implementation in time, then alternative designs should be commenced. The overlap with the implementation could happen because of a lack in human resources. Therefore, a person could have more than one role in a small team.

3.2.2. Implementation phase

The implementation phase focused on the implementation techniques of the game. This was the longest phase of the development life cycle. Creating a game using a game engine gave more freedom in implementation than using a preset online authoring tool. For example, a virtual online-world called 'Second-life' gives some authoring tools for a teacher/ researcher to create his or her own content, but there were some disadvantages such as 1) the content would be hosted on a server and accessed via a network 2) diagnostic testing data is privacy sensitive and indeed Kempenhaeghe operates with medical ethical procedures that prevent us from distributing content outside Kempenhaeghe and 3) the authoring tools provided by Second-life were not enough to cover all of Kempenhaeghe requirement. In addition, we selected Unity 3D because it is free, suitable for a small group of developers, and provided a wide range of platforms to export to, so we could expand our game in the future.

Unity3D has been selected for our game engine because of its growing popularity and because it can be programmed with our implementer's most familiar programming language. The game was initially written in C# in MonoDevelop— Unity's native integrated development environment (IDE), but later migrated to Microsoft Visual Studio 2012 Professional, using the UnityVS plugin for Unity. Furthermore, this phase included modeling 3D models to be used in the game, creating 2D textured images, sound engineering, creating in-game cinematics, programming gameplay, and programming a mechanism for the post processing of data.

Key activities in this phase

- Prioritizing the urgency of functionalities. There were two strategies, which could be used in prioritization, 1) the easiest to implement comes first and 2) the most critical functionality comes first.
- Rapid implementation for a usable prototype. The game would not need to be complete in this development increment; rather, it was a usable prototype that was able to visualize the concept and ideas to team

members. This meant that two or more functionalities were implemented concurrently and combined together as a whole.

3.2.3. Evaluation phase

In the evaluation phase, we brought the game design into discussion and got feedback from psychologists and experts in game design. There was a user test with a paper prototype technique, and an interactive prototype—an unfinished product that's usable to some extent, usually built for testing purposes before further design and development. Following the evaluation, improvements were made.

Key activities in this phase

- Checking the accuracy of program functionalities regarding the design. Testing the requirements to make sure that the game actually fulfills the needs addressed and gathered during the design phase.
- Communicating feedback to the implementer if there was something incorrect, notifying the team and bringing the incorrect functionalities to the table in the design phase; this meant that we needed to interrupt the implementation or put it on hold for some functionalities.

3.3. Micro iterations

Parnas and Clements (Parnas & Clements, 1986) mention that although a software developer has an idealized software design process, in practice this could be far from reality. They also mention that the software design process is always an idealization because of some of these examples:

1. People who need the software are skillful, however they do not know exactly what they want, and cannot articulate to us all that they know.

2. Even if we know the requirements, there are many facts that we need to know to design the software. These details would become clearer as we make progress in the implementation.

3. Even if we know all the details, we cannot fully comprehend all details and design a correct system.

4. Even if we master all the details needed to design the correct system, the project can be subject to changes because of external reasons.

5. Human errors cannot be avoided.

6. We are often burdened by ideas, design, or implementation approaches which formed before we have enough information or experience.

There were iterations at a sub-level within each phase, adapted from the 'iterative-cyclic software process model' (Rauterberg, 1992)— we called 'micro iterations'. The purpose of these micro iterations was not solely a small iterative version of its parent phase, but focusing more on a collaborative process of synchronizing and scheduling. It means we did not design and jump to implementation and evaluation as the full circle before starting the next iteration, but reiterated several times in the design phase. Until we met the agreed point then we could move on to the next phase. These micro iterations help optimize on time and human resources, make a concept clear, enable dynamic changes, and catch possible unwanted defects before they are passed on to the later development phase.

The idea of micro iteration here was that the software development process can be iterated or sprinted (in Agile) several times before passing through to the next process. The software specification or user requirements could be changed during the iteration and this makes the micro iteration useful. Because it empowers teams to re-plan the former design to fit the needs of users, and optimize its value throughout development. This process could in turn lower the unwanted scenarios that teams have to redesign the software right after the software has finished implementation.

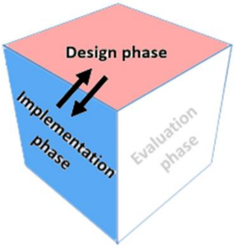
In the design phase, children were not the only users of the game; the participatory design model was also applied to psychologists who would use our game as a diagnostic tool. The participation included gathering requirements, implementing them, communicating and presenting them to the team members, getting feedbacks from team members and reconciling in open discussions. We modified the design accordingly. The aforementioned tasks were iterated until all team members agreed to some extents, before starting on the next phase.

In the implementation phase, a playable prototype of the game was presented after rapid prototyping. The team was aware that the prototype was not the final version, so micro iterations in this phase were not to find programming defects, but rather to visualize the game concepts, formulate the ideas, and to discuss solutions in case that any problem arose. Moreover, additional game elements from users were welcome.

In the evaluation phase, we tested that game met user requirements, and many times we found that we needed to make new improvements. For example, we added more game visual elements, smoothed the scene change, and improved the textures of game objects. Of course, this would bring us back to the design phase and implementation phase. But considering the completeness and usefulness of the game this was necessary. Micro iterations were documented for later reference in case of inconsistency and misunderstanding.

Chapter 4. First RDI of the game

4.1. Introduction



In a serious game development process, even more so than in entertainment game development, a developer team consists of members from diverse backgrounds; for example artists, technical experts, business developers. In this case, the team members from Kempenhaeghe were renowned experts in psychology, but had little knowledge on computer game design and development. On the other hand, members of Eindhoven University of Technology and The University of Genoa had little knowledge on child-neurological learning disabilities. This invariably led to problems in communication due to incompatible technical and medical terms. Therefore, extensive meetings were needed in order to share ideas, create connections, and narrow the gap between different knowledge backgrounds. All received information and ideas were summarized and brought back to do a feasibility study, and further made into work plans.

4.2. Initial requirements from the clinicians

Dr. Jos Hendriksen and Janneke Peijnenborgh, psychologists at Kempenhaeghe, perceived some advantages of a computer game because it attracts attention and motivates the children to play and to finish the test. Furthermore, the computer game could give important and continuous feedback on the child's performance.

The goal of the computer game has been set that it was a tool which can be used in the clinical patient care: in less than half an hour, the clinician has gained information on six important outcome measurements and thus has an idea of the level of functioning of the child such as executive functioning, response to distractors, levels of attention skills, and time related functions. The goal was not to have a tool that could be used exclusively to tell whether a child has ADHD or not—we will always need the information from parents/school, and involvement of a neurologist/psychiatrist, but the game would help the clinician to gain information in the diagnosing process. Furthermore, this game would be designed for young children, and almost all other neuropsychological tests were for older children. Therefore, psychologists wanted to be early in the process of diagnosing, in which the child could be helped as quickly as possible.

4.3. Activities distribution

Regarding the diversity of team members, the value proposition for the team members was discussed, leading to the distribution of activities regarding team member's background and expertise (see Figure 9).

Members of both parties collaborated in the design of the game. Members from Kempenhaeghe helped formulating functionalities and requirements of the game, while Eindhoven University of Technology and The University of Genoa provided technical information and a prospective degree of feasibility to fulfill those requirements. The implementation of the game was solely dedicated to the member of Eindhoven University of Technology. The evaluation of the game was a joint work by both parties, where Kempenhaeghe performed the experiments and Eindhoven University of Technology supplied automated processing of patient data gathered under the supervision of Kempenhaeghe.

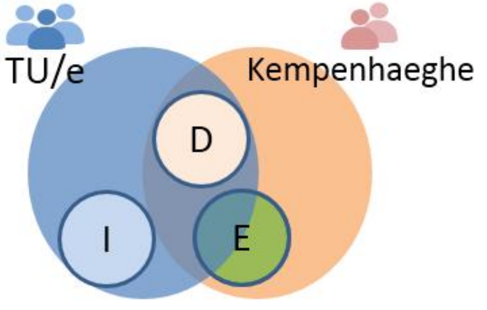


Figure 9 Activities distribution
I = Implementation phase; D = Design phase; E= Evaluation phase.
TU/e = Eindhoven University of Technology

4.4. Design and implementation requirement (DI)

Design and implementation requirement (DI) is the requirement derived from the fragments of requirements. They emerged during the iterative development processes. These requirements were similar to the term 'product backlog' in the Agile methodology. We labeled these requirements with 'DI' followed by a number to denote the order of time when they emerged, e.g. DI01, and to make them easier to trace within this thesis. Two design and implementation requirements were constructed.

4.4.1. DI01 We must use non-intrusive technologies

We wanted to avoid putting something within the body space of children. We did not want an extremely intrusive apparatus such as putting an electrode onto the scalp of a child if we wanted to collect brain activity data. In general, using technology that needs to attach to the body of a child would be avoided.

4.4.2. DI02 The game must be able to test more than one time aspect

Psychologists from Kempenhaeghe wanted to find the answer whether timing aspects can be used as a predictor in the diagnostic process. This thesis has six time aspects formulated in six mini games. The time aspects were selected regarding to the 'time in the questionnaires'.

4.5. Game story

Some of the commercial games were created with a very abstract story or nearly to the point where little to no story exists, such as Tetris and Ataxx. However, story is an essential part of creating a game in this project.

The developmental stage of childhood must be considered in order to design a story for the game. Children in different ages have different preferences. The preferences of children in different ages can be described by four patterns (Miller, 2008).

1) When the children are in toddler, preschool, or kindergarten age, they play with an object and enjoy practicing. They love to do it repeatedly until they master and/or are satisfied with their skill.
2) During 5-to-8 years old, they are fascinated with symbols such as letters and numbers. They are absorbed with fantasy pastimes such as games that they can have a chance to try different roles and they are not afraid to explore in the game world.
3) Between 8-to-12 years old, they love reasoning skills and play according to rules, order, or something predictable. The things they play with should have some causal reasoning behind them.
4) When they are teenagers, they are more concerned with concepts and hypotheses, and they enjoy constructing models.

The target age group of children in this thesis was 4-7 years old, the reason for choosing this age range complies with what Kalff (Kalff et al., 2002) stated that 1) there is a limited amount of research conducted with children 4-7 years old, and 2) The symptoms that can be diagnosed as belonging to ADHD are not obviously shown but will gradually emerge when the child grows up.

Extensive visits to *de Bibliotheek Eindhoven* (the Library of Eindhoven), and reading cartoon books for children within the target age group provided ideas for the game story. There is a small zoo inside Kempenhaeghe, which we visited and we initially created a game story based on animals in this zoo. The story must have a character to convey and run the story. According to Vincent, president of the Montreal-based software company, Kutoka Interactive, *"Games really end up being about character, If people do not identify with the character, they will not play it"* (Miller, 2008, p. 90). If the game does not have a character, it is the player itself who fills in as the missing main character (Miller, 2008, p. 92). In addition, our collaborating psychologists gave the suggestion that children in this age range love being a hero. Subsequently, we brought the suggestion into the design of our game story. Therefore, a main character (also called 'avatar' in a game) was introduced, so that a child could role play as this avatar.

There are also techniques when creating a character for a story (Miller, 2008, p. 103). For example, 1) each character should have a goal, a motive on what this character wants to do. 2) The character needs to be vivid, because the user needs to be able to "read" and get the idea behind the character quickly. 3) One should avoid stereotypes, make the character different. 4) Give the character a distinct look. 5) Give them a standout name.

A game story has a structure similar to a drama. In general there are two type of story structure: a *branching structure*, and a *linear structure* (Miller, 2008, p. 120-127). Branching structures give a player a number of choices, more experience, and more interactivity. When the player reaches a point where a decision is needed called a '*fork*', the player can make a choice. This could lead to the story of one player being different from that of another player, and keep the story interesting upon repeat plays. A linear structure conversely ensures that every player will have a single path from beginning to the end. It usually consists of a number of sub-sections similar to the chapters in a book. Players could explore freely in each section but the order of experience or progression in the story will be the same for all players. The player must finish the current section before entering the next section. Sometimes the player cannot enter a new part until every task in the prior one is completed. This type of structure is also called a '*string of pearls*'.

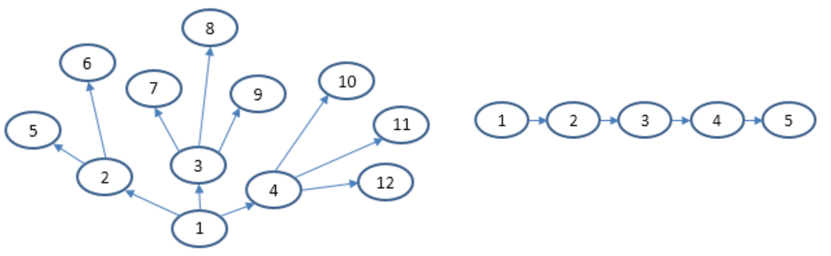


Figure 10 Branching structure (left) and Linear structure (right) (Adapted from Miller, 2008)

A game story could be created by starting from the plot of the story. A plot could be described as the skeleton that holds a story together (Appelcline, 2001). A plot generally has five stages (Gentry & McNeel, 2014): 1) introduction of the character, 2) an event occurring that builds up to a problem, 3) a dilemma or climax where something went wrong, 4) a resolution that solves the problem, and 5) an ending where the problem was resolved and lessons are learnt.

The first story iteration of the game was as follows:

[Intro]
Once upon a time there was a detective rabbit named 'Moby' who lived peacefully in an animal village. He loved mysterious things, curious, and brave. He usually helps others villagers.
One night a strange thing occurs, a carrot in the village's carrot garden disappeared. A carrot continues to disappear every night. But no one knew who stole them.
Villagers tried several times to catch the thief, but this cunning thief always avoids being caught by the village folk. The villagers gave up, but Moby did not.
[Tasks intro]
Moby went to see an Elder Turtle and asked for his suggestion. The Elder Turtle advised him to build a hideout to hide inside and waiting there to catch the thief. However, Moby must collect three things.
[Game play]

The first thing, he must gather planks of wood from a bear lumberjack who lived in the forest.

The second thing, he must gather nails from a crow's nest, which built on a very high tree.
The last thing, he must have a hammer from a cow who lived in a barn.
*After Moby collected all these things, he went to the carrot garden and started building a hideout. Then he went inside to wait for the thief. In the dark, there was a sound outside *Rumble* *Rumble*. Moby suddenly jumped out of the hideout and he successfully caught the thief.*
[Ending]
It was a mole who stole the carrots. The mole begged not to send him to jail, he promised to return all the carrots he stole. Moby freed the mole, and got all the carrots back. After that the villagers celebrated the heroic acts of Moby.
[End]

Figure 11 The first storyboard of game story

We combined 'zoo', 'play role', 'fantasy', and 'adventure' into a 'plot' of the first story— the story about "the detective rabbit that helped other animals catch the thief who stole the carrots." The structure of this story was a combination of the two aforementioned structures, because we wanted the child to select his own path to complete the tasks, and give the child a free of choice to explore the game world. In case that we would further develop our game as a training tool, the combination structure serves better than a linear structure, because the child could try another path instead of experiencing the same story multiple times.

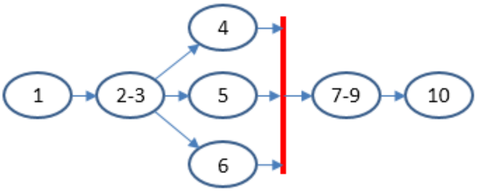


Figure 12 Our game story structure
(Children must finish section 4, 5 and 6 before they can proceed to section 7)

4.6. The game display

In the early idea, we wanted our game to display on a virtual reality (VR) head-mounted display. Using VR for children with disorders is not something new. Dating back to early 1997, the book "Virtual reality in neuro-psycho-physiology: Cognitive, clinical and methodological issues in assessment and rehabilitation" (Riva, 1997) had a collection of papers on the topic. One of the many examples is to use VR for the treatment of autism (Strickland, 1997). In 1998, McComas already provided an extensive overview on the use of VR for children with mental and physical disabilities (Mccomas, Pivik, & Laflamme, 1998). Some example benefits of VR are to provide opportunities to learn, to practice new skills, to improve social capabilities, and to improve communication skills. VR allows children with certain impairments to experience what could be difficult or even impossible for them in reality (Rose, Attree, Brooks, & Andrews, 2001). "Through its capacity to allow the creation and control of dynamic 3-dimensional, ecologically valid stimulus environments within which behavioral responding can be recorded and measured, VR offers clinical assessment options that are not available with traditional methods" (Schultheis & Rizzo, 2001).

Many more recent examples can be found in literature. Reid (2002) conducted an experiment with children with cerebral palsy using a VR system. Researchers also suggest that games with VR technology could transform a dull activity into a fun activity (Fairley, 2010). One of the examples is provided by Huber et al (2010), who looked at the feasibility of using gaming in VR technology at home, in order to address hand impairments in adolescents with hemiplegia due to perinatal stroke or intra-ventricular hemorrhage. They concluded that this was feasible and acceptable to clients.

The Virtual Reality Medical Center in San Diego put VR in medical practice for treating ADHD. It allows children to role-play in virtual classrooms where the therapists can make different situations for the children to practice their concentration stills. Noticeable is that ‘ADHD’ requires a multimodal treatment and VR can be easily combined with other psychological methods to provide comprehensive and effective interventions. It claimed that using VR as assessment consistent with that assessed by traditional paper and pencil measures involving learning and memory (Parsons, Rizzo, Bamattre, & Brennan, 2007).

For the display device, we were once looking for a device which gave us better immersion, so head mounted displays (HMD) came into consideration. However, regarding the requirement ‘*DI01 We must use non-intrusive technologies*’, we must design and select a technology which did not need to attach on the body of a child. After considering that the child must wear a rather heavy HMD on its head for around half an hour, for example Oculus Rift weighed 440g, it might at least leave muscle strain on the child’s neck or a more severe condition if it causes any damage to the neck bone of the child. Moreover, this device went into the child's body space where children with ADHD were easily irritated and did not prefer something within their body space; this made HMD an inapplicable option.

We changed from displaying the game in HMD to a wider computer screen monitor and discarded the idea of using virtual reality. HMD was only suitable for a laboratory setting environment, whereas a computer monitor was used everywhere. In addition to the economical aspect, it was cheaper and it was more portable than HMD.

4.7. Mini games

In the first design, regarding the requirement ‘*DI02 The game must be able to test more than one time aspect*’, there were three mini games corresponding with three time aspects:

1) To estimate time for a moving object.
2) To estimate time spent in order to complete an activity.
3) To remember and recall.

Mini game 1: Estimate time for a moving object: in the quest that the child (Moby) went into the forest to ask for planks of wood from the uncle bear (step 4 in Figure 11). The game’s sub-story continued as:

The bear told Moby to find an apple tree above the river. He continued, *"Its apples are very delicious, but it is impossible to reach the apple tree. Once ripe the apples will drop by themselves into the river, and float towards us. Therefore, the only way to have the apples is to wait for the apples to drop and pick them up from the river when the apple is within the arm-length." "Could you pick those apples for me?"* the bear asked.

In this mini game we designed to let the child (Moby) wait and estimate the time that the apple is traveling from the apple tree to the child. Then pick it up during it entering the designated range.

Mini game 2: Estimate time spent in order to complete an activity: in the quest that Moby went to ask for nails from a crow (step 5 in Figure 11). The game's sub-story continued as:

The crow told Moby, *"You can have all nails you needs, but they are kept in my nest."* Moby must climb up and get the nails from the nest himself. Unfortunately, the tree was so high that Moby cannot climb; he must find another way to reach the crow's nest. Moby found a balloon which could carry him up. The only thing to concern was not filling the air into the balloon too much or else it would blow away.

This mini game was intended to test the time estimation skill of the child by letting the child estimate a pre-defined time to fill the air into a balloon.

Mini game 3: Remember and recall: in the quest that Moby went to borrow a hammer from the cow (step 6 in Figure 11). The game's sub-story continued as:

The cow requested Moby to correctly match up analog and digital clock faces. Moby would get one score each time he made a correct match up. If Moby made adequate scores, the cow would lend him a hammer.

In this mini game we designed to test clock reading skill of the child.

4.8. Game world

The first idea about the game world was created reflecting on the story of the game (see Figure 13). The game world was an animal village which was in a farm. There was the barn where the cow lived, the windmill where the bear lived, and the high tree where the crow lived etc. The rapid prototype of the game world was made and presented to the psychologists. No avatar was implemented in this prototype. This prototype was to serve as a showcase of the *look and feel* of the game, and what *could technically be possible* to be further implemented.

Figure 13 Demonstration of the game scene in the early stage of collaboration.

4.9. Feedback from psychologists

The psychologists we collaborated with were content with the look and feel of the game world environment. The role of being a hero in the game was appropriate and it looked great for the story.

However, they had some remarks about the role-played of the child in the avatar of animals such as a rabbit. The story depicted the life of an animal, which was not suitable because it was too detached from the life of a child. Psychologists also commented that perhaps the game story was not suitable enough. A redesign was commenced towards a new game setting and story that were different from an animal village.

4.10. Follow up for the DI requirements

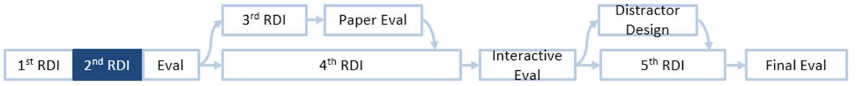
4.10.1. DI01 We must use non-intrusive technologies

The game would be displayed on a standard computer monitor. There was an exchange between more immersion using HMD and more general usage of standard computer monitor. The choice for the latter made the game available outside a laboratory setting environment.

Furthermore, we improved the user interaction by replacing the standard monitor with a touch screen. Touch interaction has become a standard for children nowadays since it was introduced with smart handheld devices. The children can use their fingers to touch the screen, where the game mechanism will interpret the touch input as a mouse click.

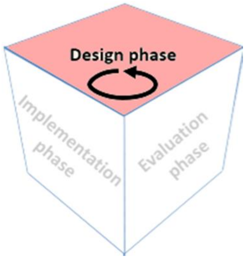
4.10.2. DI02 The game must be able to test more than one time aspect

As the general scenarios of software development, psychologists were incapable to tell us all what they needed and we were incapable to comprehend all the details that must be taken into account in order to design the correct system for the users. What we did was to take a lead in the design process. Therefore, it was mandatory for us as game designers to create and propose the game story up front. The story was formulated from the questions about time in the psychological test such as the WISC-IV (Wechsler, 2003), the Biber Cognitive Estimation Test (Bullard et al., 2004), and the children's time awareness questionnaire from Kempenhaeghe. At the moment three mini games were proposed reflecting on three time aspects. However, the final decision was not yet made, and psychologists would like to see what could be improved on the game story.



Chapter 5. Second RDI of the game

5.1. Introduction



After we had a conclusion on the display device of the game, the next RDI was commenced. The game story had to be improved because the story that the child would role play as an animal was detached from the average children's lives. Therefore, our second attempted was to change the role play from being the animal to being a child in a fantasy environment with some recognizable elements in order to be engaged with the game. Fantasy was still needed to create cognitive interest and engagement in the child (van der Spek et al., 2014), however as stated in the story section (4.5), it is also important that child can identify with the main character. Therefore, we chose to have at least a fantasy setting that the child could imagine. Three mini games proposed in the first RDI were designed for the previous game story, therefore, improve the game story meant that they should be re-adjusted to fit a new one. Keeping in our mind that the game should be easy to understand and play, we constructed additional design and implementation requirements.

5.2. Design and implementation requirements

5.2.1. DI03 The game story should be simplified

The game story should be easily interpretable by the children of four to seven years old. As adults we could understand a complex story; however, children in four to seven years old were not fully capable of that interpretation. We must take into account when designing a game story for children, and design it as a simpler narration.

5.2.2. DI04 The game must be easy to be understood

We must design a game that most children could understand what to do, and do not get lost while playing. The children must be able to initiate actions because they would have minimal supervision by psychologist while playing the game. There were two concerns regarding this requirement:

1) The visual perspective of the game must support the ease of understanding.
2) The ease of understanding of game objectives

5.3. Game story

We redesigned the game story based on the feedback from the previous stage.

[Intro]

A child (player) was sleeping in a bedroom. The bedroom was quiet, and comfy. One night there was an earthquake. This incident bended space and time around the child bedroom. The child had been transferred into another dimension as a result of space-time distortions.

<<Intermission>>

The child woke up and found that he was currently stranded on a strange island. All he saw was forest, heard the tidal sounds, and felt the winds coming from the sea. There was no one around. The child wanted to go back home, but did not know how. The child thought that it would be better to explore the island, perhaps he could find a way to get home. The child started walking into the forest.

<<Intermission>>

The child walked deeper and deeper into the forest. Then he sees a turtle! Yes, a turtle but there is something extraordinary. It dressed and could talking.

The turtle told the child that the child was sent here because of space-time distortions. Indeed the child did not understand what the turtle was talking about. So the turtle summarized in short that the child was lost but he could help the child to go back home.

The turtle continued talking that there was a timekeeper gate that was operated to maintain time of the universe. Furthermore it could send a person to anywhere, including the child's home. The turtle could use the time gate to send the child back home. However, the time gate was now running out of power. Four types of stars were needed to power the gate.

The turtle gave the child more information about how to get those stars. There were four challenges in the island that each challenge gave one type of stars as its reward. Moreover, each challenge gave the maximum of 5 stars as the reward (4

types x 5 stars= 20 stars in total). In order to operate the time gate, the child needed at least four stars of each type (16 stars in total).
The child then went solving each challenge on the island.
[Game plays]
Each mini game will be designed to fulfill in this section.
After the child had adequate stars, the turtle operated the time gate and sent the child back home. The turtle said goodbye to the child.
[Ending]
Before the child reached his home, there was an earthquake similar to the one he experienced.
<<Intermission>>
The child woke up in his bed, and found out that all of those adventures were no more than just a dream.
[The end]

5.4. Selection of visual perspective

We replaced the role play of the animal (rabbit) with the child in the new story, to strengthen the connection of story and the child. However, there was a question about the display perspective since the game could be designed to display either in a first-person perspective or a third-person perspective. We selected the first-person perspective for our game for the following reasons:

1) In first-person perspective (1PP) it is common that you cannot see yourself since you are looking out and see the world as likely the same view as you use your own eyes. In third-person perspective (3PP) it is common that you are given an avatar, your fiction character, or something acting as your representative. It is obvious that young children have less experience than adolescents. The world they mostly see is the 1PP. Therefore, regarding to this customary viewing perspective, choosing the 1PP for young children is the better choice than the 3PP.
2) Theory of Mind (TOM), is an ability that enables us to understand that others have other mental states such as belief, intents, desires, plans, hopes, knowledge etc. that are different from our own (Korkmaz, 2011; Melchior, 2011). Children develop this ability by the age of four (Korkmaz, 2011). Normal children will be able to think in a first-order thinking such as “I think what you think” by the age of three to four years old, and they will be able to think in a second-order thinking such as

"John thinks what Mary thinks" by the age of six years old. They are able to distinguish between the finding out from direct experience, and the finding out from being told. Korkmaz found that ADHD children show an impairment in this ability.

3) Normally, we only have a limited possibility to make a first-person reference from the third-person perspective (Melchior, 2011). Access to own self-knowledge is based on the idea that people can automatically access their own mental state with or without an additional mental state to refer to their own mental state. But nobody can use someone else's mental state to refer to some other thing. Therefore, to refer to another person's mental state, persons need to create an additional mental state. In general people see in the 1PP from their own eyes. Therefore, people who see the virtual world in the 1PP could directly access their own mental states. They do not have to create another mental state to refer to other person's mental states that have been presented as their representatives in the 3PP.

In addition, we also planned to use the same visual perspective if we were going to implement a game as a rehabilitation tool. Because learning through a simulator environment, the performance of participants performed in the 1PP had better memory for important tasks and task-related elements, had committed fewer errors, and exhibited less help-seeking behavior than participants who performed in the 3PP (Lindgren, 2012). The same author claimed that thinking and feeling play a major factor in the perceptions of the participants and the 1PP supports the notion of learning stances in three respects:

1) Selective attention and memory.
2) Sensitivity to important elements of simulation, and comprehension of the system as a whole.
3) Self-competence and self-confidence.

5.5. Game's world

The game's world was changed from a farm to an island because of the following considerations:

1) We wanted the game world to be isolated and self-contained.
2) The island has a natural boundary in the surrounding water. This can be self-explanatory to the child that he cannot go beyond that border.

3) We aim at a playful environment that children would want to play with, which was more fantasy and it was likely that anything can happen. This includes that we can put almost anything in each game's scene without a necessary backup reason. Regarding to the suggestion from a psychological expert, if something out of place was inside the game's scene, the child just knows that it was there, and he does not normally question why it was there.

5.6. Four mini games

At this point we had designed four types of mini games regarding the time aspects suggested from the psychologists. The four time aspects were:

1) Remember and recall
2) Time estimation
3) Reaction time
4) Response inhibition

5.6.1. Remember and recall

This mini game was designed to test the child his recognition/remembering skill. The game play of this mini game was to show many items to the child, give the child time to remember, hide the items, and then show the items again with some of them missing. Then there were choices of items that the child could see and make a selection on which item was missing.

<u>Game's scene</u>

There was one shelf in a room. It was a three-story shelf (alternatively, we can replace with one large bucket). There were various items arranged on the shelf on each story. Types of items could be an umbrella, vase, jug, ball, hat, cup, etc. (to name a few) — regarding to theory of memory span, they should be varied between 2-7 items.

<u>Play actions</u>

The child would be instructed to observe and remember those items. Then time would passed for a pre-defined duration that a psychologist set— 5 seconds, 10 seconds, or 1 minute. Suddenly, the mini game went black for a few seconds. When the mini game reappeared to the child, some items were missing. The child might select what the missing items from the given options.

Play condition

When the child was satisfied with his answer, he might be asked to check his answer. The mini game gave him score on the correct marked items. The mini game could let the child try until all missing items were found.

5.6.2. Time estimation

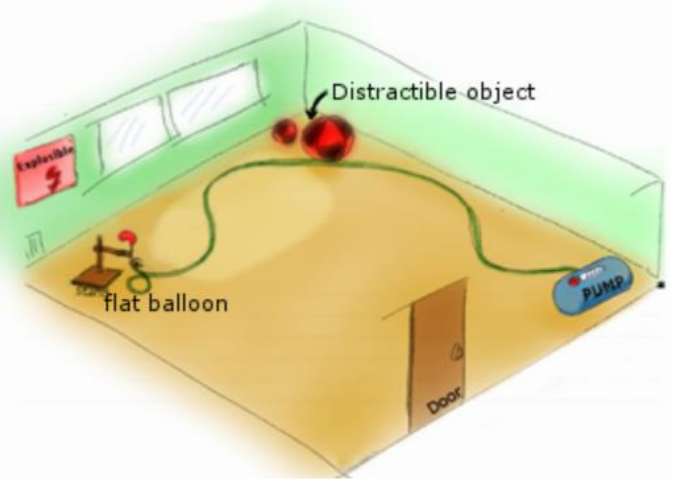


Figure 14 Concept artwork of the time estimation mini game

This mini game was designed to test the child's time estimation. The idea was to let the child estimate the time needed to inflate a balloon. We designed the game based on '*Moby's the estimate a time spent in order to complete an activity*' (see section 4.7) with changes of the game scene's setting. There was an air-pump and a nozzle connected with a balloon on the other side of the room. The child could input a time as a number on the pump and press a run button. The pump would pump the air into the balloon, and the child can go to see his result.

Game's scene

There was a large room somewhere on the island (see Figure 14). At one side of the room, there was a flattened large balloon on the floor. An air filler valve was attached to the balloon. At the other side of the room, a large hot-air pump was installed and it was waiting for an interaction with a child.

Play actions

The child might estimate the time to fill in the air into the balloon by entering a number in the hot-air pump. After that he might go to the other side to open the valve. The air would go through the valve, and the balloon was filled.

Play condition

If the number that the child entered was too short or too little, the balloon would not big enough to lift itself— it would go flat and the child might retry again. If the number entered was too long or too much, the balloon would blow up— the game would restart to let the child try again.

5.6.3. Reaction time

When it comes to the reaction time, the game called 'whack-a-mole' first appeared in our mind, a game that is wide-spread in amusement parks, in game centers, and also across the internet. The idea of this mini game was to make a reaction as fast as the player could, or the player would lose an opportunity to gain more scores. Therefore, this mini game was the resembled version of whack-a-mole.

Game's scene

There were holes on the ground, which moles came up. The child must stop their invading. The child was given a hammer.

Play actions

The child used the hammer to smash the moles as fast as they appeared.

Play conditions

The mini game counted, how many moles the child smashed in a pre-defined duration. The child would be given one point for each mole smashed. If the child spammed the hit button, the moles would not appear and they would hide in the holes until the child stopped spamming—the child needed a pre-defined seconds from the last hit in order to hit again.

5.6.4. Response inhibition

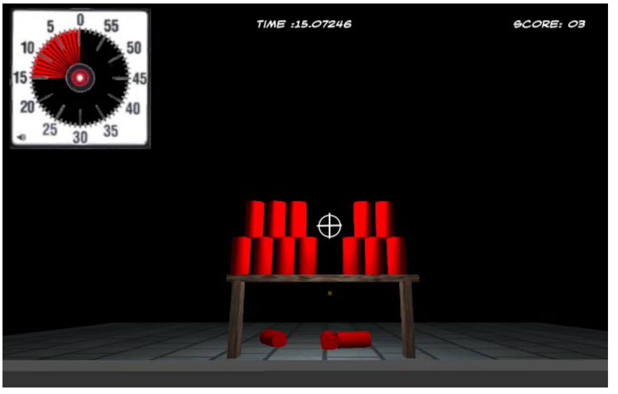


Figure 15 Concept idea of the response inhibition mini game

It was found that some of the children with ADHD have impulsive behavior. Children with impulsive behavior tend to make actions without waiting for a suitable time, and they are concerned less about the consequences of the action they made. Therefore, this mini game was designed to test impulsivity of the child. The idea of this mini game was to have the child wait for the 'Go' signal before making an action. If the child made any action during 'No-Go' signal, the child would receive a penalty.

<u>Game's scene</u>

Somewhere in the garden, there was a throwing range. There was a stand where a pile of cans/cubes/boxes were placed— they could be built into a pyramid (see Figure 15). Near the stand, there could be a basket full of balls, and a play area was marked on the ground.

<u>Play actions</u>

The child stood in the play area. The child was waiting for a specific signal. There could be two types of signal: 1) an auditory signal such as a beep. And 2) a visual signal such as a smiley face. The child could throw a ball to the cans and if the ball impacted with one of the can, it would fall.

<u>Play conditions</u>

The child obtained scores by the amount of cans that fell. If the child threw a ball during no signal, the possible consequences could be: 1) the ball went no further than a meter because it had no power, or 2) the child would receive a penalty, by deducting one score, or 3) nothing happened.

There were ideas of three possible mini games in additional to those four.

Reaction time: Catch the falling cat

We were aware that the mini game we designed resembled the commercial game which was already available in the market. A new idea was needed and here was an alternative choice. The gameplay idea of the reaction time was the same, the child should make a quick action or he would not be given a score. We designed another mini game that the child should press a button to move left and right and safe cats from falling down.

Game's scene

There was a building on the island. There were cats escaping from windows. They were jumping out of the windows.

Play actions

The child could move left and right to catch the falling cat.

Play conditions

The child must save a pre-defined number of cats in order to pass the mini game.

Time estimation: Prevent moles to steal carrots

This game play idea was derived from the study about road-crossing behaviors of adolescents with and without ADHD (Clancy et al., 2006). It was found that adolescents with ADHD made themselves more endanger due to their impaired time estimation. We designed this mini game to reflect upon the finding that it could be applicable for children with ADHD.

Game's scene

In an open grass field, there were carrots on the left side of the field, and there were a horde of moles on the right side of the field. Moles were moving from the right toward carrots on the left, in order to steal carrots.

Play actions

The child must throw projectile oranges at the moles to stop them. The child must estimate the time that each orange used to travel in the air before it landed on the mole.

Play conditions

The child should throw each orange prior to the movement of a mole. The child could not throw next orange right away. The child have to wait for pre-defined seconds before the next orange can be thrown— each orange, which hit a mole, gave one score. The child needed to save a pre-defined amount of carrots in order to pass the mini game before the time was up.

Remember and recall: Matching up

Instead of finding the missing items, we designed this remember game as a matching up mini game. The gameplay was quite simple. The child must match up all pairs of cards as fast as he could. The child should memory for the position of the card and items. We had an idea to make this mini game more challenging by gradually increasing the number of cards after the child completed the mini game, or by having a penalty system.

Game's scene

This mini game resembled a matching up game. There were items/cards faced down on a table.

Play actions

The child could open a pair of items.

Play conditions

If both selected items match, the child would receive one score as a result. Otherwise, both selected items would be faced down again— this mini game could be implemented for more challenge by deducting one score when the child made a wrong match up. Within a pre-defined given time, the child should match all the items as fast and correct as possible.

5.7. Feedback from psychologists

In this game story, we replaced role play from the animal to the child himself. We changed the visual perspective to display in the first-person perspective. Dr. Jos Hendriksen gave us feedback and there was also feedback received from Dr. Sam Nemeth, Prof. Matthias Rauterberg, Dr. Jun Hu, and Dr. Erik van der Spek, experts on game and entertainment design, which gave us useful comments regarding the design of aforementioned mini games.

1. In the time estimation mini game, there was an idea of using a two-story building to separate the balloon and the air filler. The experts suggested that using two corners of the room as a barrier and adding a

wall as a separator was better, because the child may navigate better on the same floor-level than up-and-down in the two-story building.

2. All mini games must be adjusted and configured to be a ‘fair’ setting.
3. Designing a game world as a single island leads to a more coherent experience than designing a game world as having many isolated islands.
4. In the mini game that the child should throw an orange, it should have a penalty for throwing the orange in a No-Go signal.
5. There was an idea about a shooting range mini game. Regarding the idea, the signal in this mini game could be a visual signal and the child should shoot at a certain type of target. A good guy acted like a ‘No-Go’ signal, which the child have to avoid shooting at. A bad guy acted like a ‘Go’ signal, which the child should try to shoot at.
6. The tasks in mini games could be related to day-and-night cycle by letting the child complete mini games in daytime only.
7. We could try to conduct a user test using a paper prototype. Although the children in the age range would have limited attention and little background experiences, and were too young to tell us in greater details, we could ask them about what activities did they do and what kind of game did they prefer.

5.8. Follow up for the DI requirements

5.8.1. DI02 The game must be able to test more than one time aspect

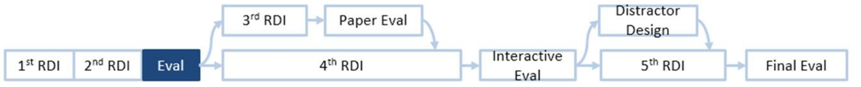
At the moment we had thought up four mini games reflecting on four time aspects. However, the final decision was still not made, and the psychologists liked to see what could be improved on the game story.

We had another idea to improve the time estimation mini game. Estimating time by specifying a number as input, was detached from the child's interaction. The psychologist suggested that the child would just guess the number and press a button to see the guessing result. Moreover, there was no need for other user interaction from the child rather than inputting a number. Therefore, to enrich user interaction, we redesigned the game so that the child should press and hold the button for the duration of the time estimated by the child, for example 10 seconds, and subsequently release the button. This way, the child's efforts to interact and estimate the time were needed simultaneously. This way the child would count 10-second time in his mind during the button was pressed, which was more connected to his body clock.

The design of our reaction time mini game was not something new at the moment. The mini game resembled a version of whack-a-mole and the alternative about saving falling cats was to involve both space and time rather than solely reaction time.

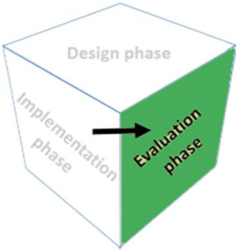
5.8.2. DI04 The game must be easy to be understood

At this point we believed that we designed to comply with this requirement. However, it was too soon to make a conclusion. Testing the mini game with potential users was the only way that could tell us how easy it is to understand our mini game, including the game story. Therefore, according to the feedback (number seven) received from the psychologists, we planned to conduct a user test using a paper prototype to measure how easy it is to understand of our game.



Chapter 6. User and context Study

6.1. Introduction



As we received the feedback from the previous chapter, we started a user study process (observation and interviews) to get familiar with the context at the Kempenhaeghe hospital and to identify the current needs of children and psychologists. At this stage a new member was added to the team to help with the tasks, PDEng student Christian Sallustro (Sallustro, 2013).

The first step consisted of an observation study in the Kempenhaeghe clinic with children and health professionals. Additionally, two interviews were conducted with mothers to have a better understanding of the daily routine of children in the family environment. The focus was to find out what children in four to eight years of age do during the day, and which video games they like. The data from the interview and observation were used to create personas for a complete overview of the users. Four personas, two females and two males were created to sort out the differences between children with ADHD and children without ADHD.

6.2. Design: user persona

Personas were fictitious characters created to represent a game with different user types and their associated demographics, and were the imaginary archetype of users, which represent real groups of users and their needs. Alan Cooper introduced the concept of using personas as a part of interactive design in his book “The Inmates Are Running the Asylum” (Cooper, 1999). Personas were general descriptions of persons, usage context, or usage scenario.

This usability evaluation method could be used in or between designing stages, although it was mostly be used in the beginning of the design process. The designer created user personas to get the ideas of possible users. This technique visualized concepts of users for the shared understanding of users among the design team.

6.2.1. Persona 1: Dirk, age 7 years 2 months*

"Dirk is a child that loves being outdoors. He likes to build huts, play football, or help his father on the farm. He has a lot of energy, is creative, funny and always enthusiastic about trying new things. Because he is so enthusiastic, he sometimes does not think enough and forgets to think about possible consequences. Therefore, he often has a lot of little accidents, but this does not hold him back a next time. Parents report that Dirk has always been a child that did not need a lot of sleep. It was difficult to get him to sleep when he was little. Still, he does not fall asleep early and he is pretty early awake in the morning.

Dirk has problems remembering what to do. Every morning mother has to guide him while getting on his clothes, because Dirk forgets what to do or is distracted by other, more interesting stuff. Furthermore, Dirk is a child that likes to talk a lot. During mealtime, parents have to stop him otherwise he forgets to eat.

While playing, Dirk cannot stay with one activity: he switches a lot between what he does. At home this is not a big problem, because there is a lot to do at home. However, at school this is a big problem. Dirk has trouble staying in his seat; he wants to walk a lot and uses excuses to get out of his seat. This is disturbing his classmates. Also, Dirk has difficulty waiting until the teacher tells him he can talk. Often, in his enthusiasm, he shouts answers through the class. The teacher has to grumble a lot. Furthermore, Dirk has difficulty in remembering the learned stuff. This has a negative impact on reading and mathematics. However, Dirk has average cognitive capacities, so this cannot be the reason for his learning difficulties. Dirk does not like to go to school, he is the most happiest when he is at the farm."

6.2.2. Persona 2: Thomas, age 6 years 8 months

"Thomas is in group 3 (first grade). He likes going to school, he has some nice friends and he likes that he finally learns to read. Mathematically,

* Parts of this section are based on PDEng student Christian Sallustro's report in which we collaborated (Sallustro, 2013).

however, is more difficult for him, but with hard work he manages. His favorite thing at school is drawing or gymnastics.

He lives at home with his mom and dad, and a younger brother (4 years 3 months). Although he likes to play with his brother, they sometimes argue. In his free time he plays with his brother, has play dates with friends. It is no problem for him to keep himself busy. He has a lot of interests and can play for hours. He likes building with Lego, and makes complete cities with Lego. Furthermore, Thomas is a member of the local judo club. Parents are proud of the fact that he is self-reliant. He can make his own sandwich in the morning. They do not have any big concerns about Thomas."

6.2.3. Persona 3: Emma, age 6 years 11 months*

"Emma is a six year old girl, living in a city with her parents and an older brother (Lucas, 10 years 2 months). She is a sweet girl, never getting into big problems. She has a few nice friends, with whom she has play dates. She likes to play, role play like mum and dad, or school. She wants to be a teacher when she is older. Her favorite color is pink and gold. When she is alone, she likes to draw or play with Barbie dolls. At school, she has a nice teacher, her grades are above average."

6.2.4. Persona 4: Natalie, age 5 years 4 months

"Natalie lives with her mother during the weeks, and on the weekends she lives with her dad. Her parents divorced two years ago. It can be difficult for her to adjust after a switch from houses, although parents are on speaking terms and try to make it as easy as possible. Natalie likes to dance. She is fond of music and has ballet training once a week. Although she likes this, it is difficult for her to remember what the steps of the dancing routines are. At school, the teacher mentions that she can be very dreamy. Often Natalie does not hear it when the teacher calls her name, because she is dreaming. Although she is a smart girl, she often forgets to keep on working. She starts enthusiastically with her assignments, but after a few minutes she stops and just looks outside. Therefore, she often

* Parts of this section are based on PDEng student Christian Sallustro's report in which we collaborated (Sallustro, 2013).

is not finished with her assignments when the other children are finished. This makes her insecure, although she is smart enough."

6.3. Daily routine interviews

Mother 1* (the real identity of the mother and the child must be concealed)

Giovanni, male, 7 years old without ADHD symptoms.
Character: a bit shy, curious, observer.
Hobbies: hockey and drum.
Like: Animals, nature, Lego, Risk, army, cars and Wii
Tablet: Angry birds, Sonic jump, Bubble balls, Contre jour
http://chillingo.com/games/contre-jour/

7:15 Parents wake up Giovanni. Mom prepares the breakfast while Giovanni goes to the toilet and play with toys.

7:35 Breakfast for around 20 minutes. Is forbidden to play during breakfast even though Giovanni insists to do so.

7:50 Giovanni goes to brush teeth and to dress up. He uses an hourglass of 3min to brush teeth while the mother prepares the clothes on the bed. Giovanni dresses by himself. The mother suggested that different sizes of hourglass (10, 5, 2 minutes) could be used for different tasks.

8:15 Go to school by bike or car if the weather is not good.

8:30 At school. Giovanni has a Montessori education and he is the group 3.

14:30 Back at home. Giovanni plays till 4 pm. He plays with Lego, toys and board game. No video game. If the weather is good they go to the park.

16:00 Giovanni prepares the sandwich under the supervision of the mother.

17 – 18:30

Option A: Sport activity two days a week.

Option B: If Giovanni does not have sport he continues to play. Sometimes he gets bored and he involves the mother in the game to find new alternative game.

18:30 Giovanni plays again. Only on Sunday morning he can watch a movie or cartoon on TV.

* Parts of this section are based on PDEng student Christian Sallustro's report in which we collaborated (Sallustro, 2013).

19:00 The mother prepares the dinner and sometime Giovanni helps her for the dinner or he plays with his toys.

20:00- 20:30 Giovanni goes to bed. One of the parents usually the father reads a story to him. Or they invented a story with the Pantomime game from the company Haba.

Mother 2* (the real identity of the mother and the child must be concealed)

Giuseppe, male, 6 years old with ADHD symptom
Character: active and intelligent
Hobbies: soccer
Like: Lego, cars and board game
Tablet: angry birds

Emma, female, 4 years old without ADHD symptom
Character: predominant and she wants conquer the world.
Hobbies: hockey and drum
Like: Animals, nature, Lego, Risk, army, cars and Wii
Tablet: Angry birds

7:30 Parents woke up the kids who go to the bathroom. They help each other for the toilet.

7:45 Breakfast ready (10/15min)

8:10 Kids dress themselves really fast so they can play 10/20 min. (No tablet) before going to school.

8:35 Go to school

15:15 Kids are back at home. Often they bring a friend or they go to the house of friends for the "Afspreken". During this time they play with board game, Lego or in the garden if the weather is good.

16:00 Snack break

17:00 Option A: Giuseppe goes to soccer three time a week and Emma to Swimming. They prepare everything them self.
Option B: children continue to play, but sometime they involve parents to play with them or to create new games and toys. Sometime they help mom to cook and prepare the table for dinner.

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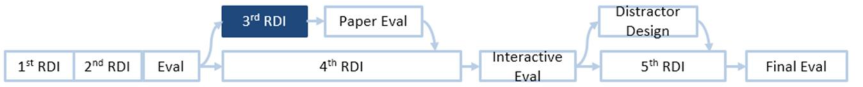
* Parts of this section are based on PDEng student Christian Sallustro's report in which we collaborated (Sallustro, 2013).

18:30	Back home if she did sport.
19:00	Dinner
20:00	Go to wear the pajamas
20:30	Read with dad comics/fables. In around 10/15 min they are sleeping.

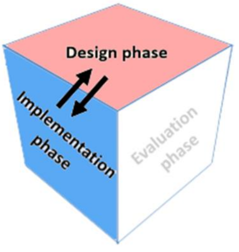
6.4. Evaluation conclusion

Interesting points were taken as inspiration for the storyline of the video game to develop from this exploration. Also, some fantasy environment would be added to the video game story, to make it more attractive and suitable for the target user group. The main points of the video game concept were generated from a regular daily routine of children. Because this increased ecological validity to the game, such as: dress up, preparing breakfast, going to school, coming back home, playing games, eating dinner and the bed routine. These activities were familiar to the children and gave us the possibility to eventually expand the game into a training program based on a real life situation—the idea to create a training tool from this game was returning in a number of time; however, that this is outside the scope of this thesis.



Chapter 7. Third RDI of the game

7.1. Introduction



We had the user and their contexts. This chapter describes how we made the paper prototype. Starting from the designing of the game's world, and improving the four mini games from the second RDI to six mini games. There was a new requirement from the psychologists to include a visual timer, which could tell the child how much time was left in each mini game. Furthermore, we changed the old game story about space-time distortions and time gates during the making of the user context because it was too science fiction, and we thought a game story about a daily routine should be a better fit. Therefore, we also improved our game story to make it simpler, general, and not limited to differences background experiences of each individual.

7.2. Design and implementation requirements

An additional design and implementation requirement was proposed:

7.2.1. DI05 The game must use a Time Timer

Figure 16 Time Timer

Dr. Jos Hendriksen suggested us to implement a 'Time Timer' (Figure 16) into the game. A Time Timer is a device that can help a child to visualize the flowing of time as it passes. It is a device in three sizes: 12-inch, 8-inch and 3-inch. It gives people of all age and ability levels the ability to visualize and manage their time (Grey et al., 2009). The Time Timer could easily be linked to the child because this device was introduced to some of parents to use it in the child's everyday life. Time Timer has a red filter which shrinks clockwise from the full 60 seconds down to zero. We wanted to include Time Timer in the game, accompanying with the ticking sound of a clock and also visible to show the child how much time was left.

7.3. Game story

Feedback from the previous chapter has been used to improve our game story. We changed the game story structure from combination (in section 4.5) to just a linear structure for the following reasons:

1) We wanted every children to experience the same story in the game for diagnosis. A single story made it easier to compare the performance of one child with another.
2) The child could not move freely in the game world. The time used in diagnostic tasks needed to be limited so the child would not get fatigued. Since the number of mini games could be added, the psychologists would decide for the suitable amount of time in each diagnostic session.

[Intro]

Timo was an alien that came from a really far away planet by a UFO.

The UFO ran out of fuel (stars) during an earth trip, so Timo and his friend must land the UFO on an island. Timo knew how to refill the UFO with stars, but he needed help from the child (player) to find the stars.

The stars were scattered around on the island and were collected one by one after the child completes each task.

The adventure started at the child's home and it continued outside, where exotic animals, a magic land, a river and funny avatars would try to distract the child in order to test the child's abilities.

[Game plays]

Each mini games' story will be designed to fulfill in this section.

Timo had enough stars to refill the UFO.

[Ending]

After the UFO was refilled, Timo rewarded the child with a pleasant gift.

He and his friends could go back home.

[The end]

7.4. Game world

The final game's world was the island. It was designed according to the general elements we found using a moodboard (see Figure 17). Our psychologists suggested that younger children have a tendency to prefer more cartoon graphics. On the other hand, older children have a tendency to prefer more realistic graphics. We took their suggestions and decided to balance and did not skew in any direction, thus the result could serve for all children in the age range.

Figure 17 Realistic style moodboard of the island (Sallustro, 2013)

The participatory design model had been utilized. Children were brought in, they were asked to draw and add elements that they thought should be included on the island. These are some core shared elements showed in their drawings (see Figure 18). The island could have a pathway along the coast, a house, and a forest etc. The drawings showed that the older the child, the more details in the elements were included in the drawing. The conceptual art of the island was shown in Figure 19.

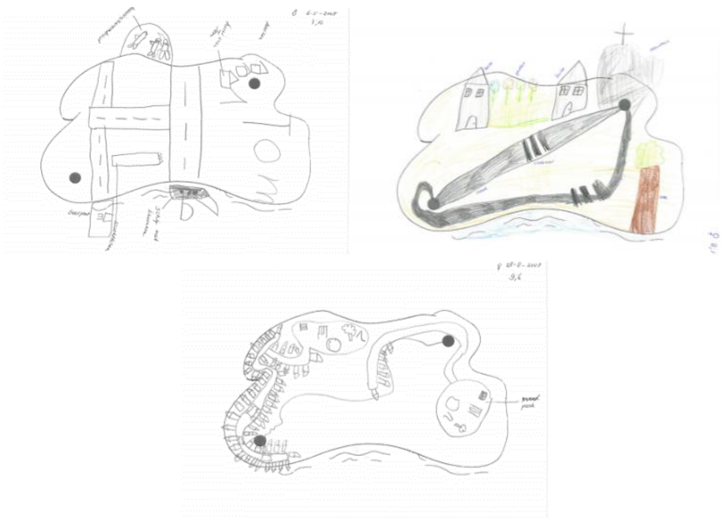


Figure 18 Islands from the drawings by children from participatory design (Sallustro, 2013)

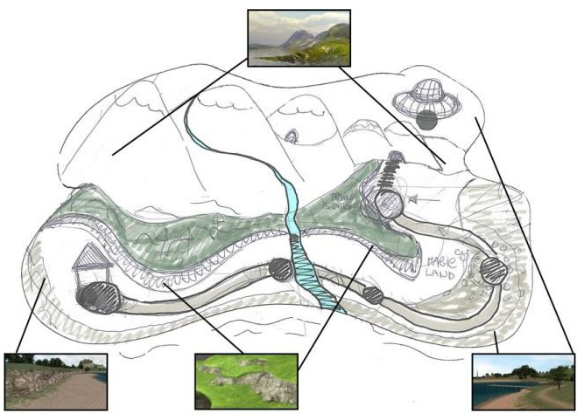


Figure 19 Conceptual art of the island (Sallustro, 2013)

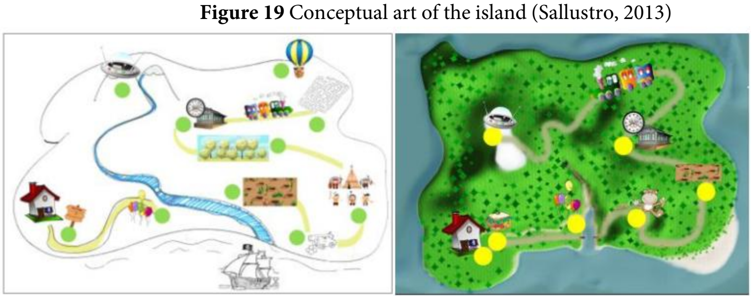


Figure 20 First sketch of the island, and a computer generated landscape (Sallustro, 2013)

We designed the island, placed some of the aforementioned elements, thought about what could be inside, and tailored the sequence of mini games that should be connected together. The first sketch of the island was shown in Figure 20, there were also some possible positions that mini games could be placed into.

7.5. Mini games design

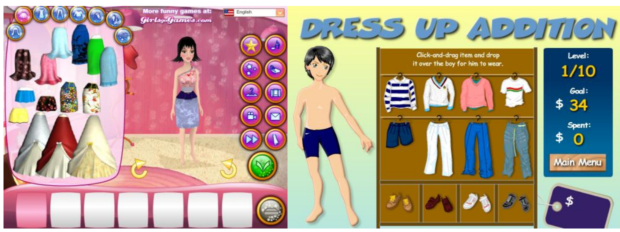
There were many games that we could freely access and play online. We searched the game for children to have better idea of game elements that children would get. Our searched was scoped down to the games for children that run on personal computer, not a handheld device including Google play, and Apple iOS game because of the screen-resolution differences between monitor and the handheld devices affected the design layout of games content (Albers & Kim, 2002). The game design elements from Dondlinger were found to be useful when applying in the design of our mini games (Dondlinger, 2007).

According to Zapata-Rivera and Bauer (Zapata-Rivera & Bauer, 2011), there are some important items that should be taken into account when designing a game:

1) Avoid to construct irrelevant content that needs knowledge or skills on the player's side that are unrelated to our assessment goal.
2) Limit other types of user interaction, but do not make the game boring or repetitive.
3) If we need more cognitive processing in working memory, we must introduce high interactivity and engagement.
4) Players need support from in-game tutorial to become familiar and know how to interact with the game environment.
5) Provide formative feedback to the players.

7.5.1. Dress up mini game

[2]



[3]

Figure 21 Sample screenshots of dress up games

The dress up game was designed to test how the child performed planning, which was under executive functions. Based on the game we could find on the internet, the dress up games were made in cartoon style. The common game element in dress up games was an avatar depicting the main character and a player might select a dress item which it would be shown on this avatar after the selection. The player could freely select any item and in any order. There was variance of dress items. If the player selected item that would be put on the same part of a body, the latter selected item would automatically replace the former one.

[2] (Left) School morning rush, http://www.y8.com/games/school_morning_rush
(Right) Goku Dress Up, http://www.minijuegosmario.com/2015/08/goku-dress-up.html

[3] (Left) 3D Fashion Model, http://www.girlsgogames.com/game/3d_fashion_model
(Right) Dress Up Addition, http://www.primarygames.com/math/dressupaddition/

7.5.2. Making sandwiches mini game

[4] [5]

Figure 22 Sample screenshots of cooking games

The making sandwiches mini game was also designed based on the requirement to test the capability of temporarily information stored in working memory, since working memory capacity in children with ADHD is found to be lower than in normal children (see page 20). We used the number of items that a child can hold onto and recall for our test. Making sandwiches was used to make a relationship of this mini game story with the rest. There were many cooking games online (Figure 22). We limited our searched and excluded the cooking games that focused on time management, because we focused on the visually presented items the child could remember to make sandwiches.

7.5.3. Cross the river mini game

There was a teaching strategy from New Zealand Ministry of Education ("Just a minute," 2015). Its purpose was to help students develop an understanding of the duration of minutes and seconds. A clock with

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[4] (Left) Ramen cooking game, http://www.dressupwho.com/ramen-cooking-game-173.html
(Right) Cooking Frenzy, http://www.games2girls.com/p/cookingfrenzyturkishravioli/

[5] (Left) Sara's Cooking Class, http://www.unity3dgames.eu/saras-cooking-class-banana-muffins.html
(Right) Kitchen Master Fever, http://play.mob.org/game/kitchen_fever_master_cook.html

second hand was needed in this teaching strategy. A teacher would let a student look at the second hand on the clock and observe how long does it take for the second hand to travel once around the clock. Then the student would standup and turn its face away from the clock. The teacher then asked the student to put its hand up when he thought 10 seconds has passed. Another one was a teaching idea about time estimation for the children age seven to eleven years old (Sellors, 2015). The idea was to tell the pupils that you are going to time a minute on your watch, and the pupils have to raise their hand when they have counted a minute in their heads. The closest one would be the winner.

The cross the river mini game was designed based on the requirement to test the child on time estimation (see page 21). We did not find any time estimation game on that we could base this mini game upon. Therefore, we designed this mini game based on the teaching strategies, with the design concept of "*Moby's the estimate a time spent in order to complete an activity*" (on page 55) and "*Time estimation mini game*" (see Figure 14, on page 64).

7.5.4. The monkey mini game

Figure 23 The Go/No-Go task

This mini game needed Go/No-Go signals. Similar to traffic light, the child should wait for the 'Go' signal before making any action, and the child should withhold to make any action during 'No-Go' signal (see Figure 23). The child should be able to learn about this two set of stimuli and react accordingly. We designed this mini game based on the suggestion of Barkley that response inhibition was one core deficit in children with ADHD (see page 22). Applied the design concept of "*Response inhibition mini game*" (see page 66), a monkey was introduced. We thought about how to present the signals in the form of a monkey. A monkey was more natural than using traffic light in this game because the game was surrounding with forest. We agreed to represent them using the behavior and the position of the monkey in the game with a mnemonically strategy (Lafayette, 1989). The monkey would be able to change between ‘Go’ and ‘No-Go’. It would represent ‘No-Go’ signal by blocking the pathway, and it would represent ‘Go’ signal when it moved away from the pathway.

7.5.5. Magic land mini game

[6]

Figure 24 Sample screenshots of Whack-a-mole

The magic land mini game was designed to test of warned reaction time (see page 23). Based on the reaction time game called “*Whack a mole*” (see Figure 24), we replaced the mole with stars because we were afraid that hitting an animal could constitute violence in this mini game. There would be magic geysers where stars would jump upwards in this mini game. The child needed to collect the stars by clicking at them. There would be a visual cue associated with the stars. The reaction time of the child would be measured.

7.5.6. Waiting mini game

This mini game should resemble a digital version of Stanford’s marshmallow experiment. The purpose of this game was to measure waiting behavior of the child. The child has two options: 1) a small reward, immediately, without waiting; or 2) a bigger reward after the child has been waiting for a sufficient period of time.

At this stage of development the scene of this mini-game was not yet defined, because it was not clear which kind of environment could be more appropriate for the children.

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[6] (Left) Whack a mole 3, http://www.funnygames.nl/spel/whack_a_mole_3.html
(Right) Quick Whack Mole, http://www.dofreegames.com/games/quick-whack-mole/

Here are the short summarized of our six mini games, which will be elaborated in later chapters.

	Theoretical constructs	Mini game	Main characteristic
1	(part of) Executive functions	Dress up	Planning and organizing
2	(part of) Working memory	Making sandwiches	Remember set of items
3	Time estimation	Cross the river	Reproduce a period of 10 seconds
4	Response inhibition	Monkey	Withhold response with Go/No-Go signals
5	Reaction time	Magic land	Motor reaction after warned signals
6	Waiting behavior	Waiting	Delay gratification, with a digital version of Stanford's marshmallow experiment

Table 1 Theoretical construct and mini game characteristic

7.6. Follow up for the DI requirements

7.6.1. DI02 The game must be able to test more than one time aspect

The reason behind this requirement was because we designed the game for testing various psychological aspects. Therefore, only one game cannot fit that entire requirement. The use of more than one mini-game additionally gives us the possibility to apply more than one diagnostic instrument; that was, one for each mini-game. Books were used to give us ideas when designing mini-games (Salen & Zimmerman, 2003; Trefry, 2010). We divided the game into smaller mini games and considered the linkage of each mini game with a single coherent story. After many iterations, there were six mini games in total. The six mini games for each time aspects were as follows:

1) The Dress up mini game was designed for testing some parts of the executive functions.
2) The Making sandwiches mini game was designed for testing the working memory.
3) The Cross the river mini game was designed for testing time estimation.
4) The Monkey mini game was designed for testing response inhibition.
5) The Magic land mini game was designed for testing reaction time.
6) The Waiting mini game was designed for testing waiting behavior.

7.6.2. DI03 The game story should be simplified

We had a game story which related to the child's everyday daily routine. However, having more than one mini-game did present us with a problem: if the player was able to choose the order of the mini-games, this could result in an incoherent storyline, which could in turn lower engagement and diminish the internal validity benefits of using a game in the first place. To solve this problem, we designed the Game story as a linear structure to ensure that every player would have the same storyline.

Moreover, instead of our first idea about creating the story up front, we used a loose framework as the theme of the game. Then we designed each mini-game to serve a diagnostic purpose and tailored it into a single story line. This process needs sub-iterations to fine tune each mini-game to work with the other mini-games. To create a good story, the book by C.H Miller, *"Digital storytelling: a creator's guide to interactive entertainment"* was found to be useful (Miller, 2008).

7.6.3. DI04 The game must be easy to be understood

The mini games were improved from four in the second RDI to six mini games. Almost all of the old concepts of each mini game were preserved but modified towards daily routine.

The dress up mini game was introduced, then the remembering mini game was redesigned to remember the ingredients for making sandwiches, the scene of the cross the river mini game was changed from inside the house to outside, the monkey mini game was the modified game play of the second RDI's response inhibition mini game, the reaction time preserved the old game play but with no violence, and the mini game for measure delay gratification was introduced.

We would have the answer on how easy to understand our game was from a user test.

7.6.4. DI05 The game must use a Time Timer

In order to use the Time Timer in the game, we must think about how to present the Time Timer. There were two different Time Timer to be displayed at this point. 1) A static Time Timer for the paper prototype, and 2) an interactive Time Timer for the interactive prototype.

Time Timer for the paper prototype

Static Time Timer was visualized. We agreed to place it on the upper right of the screen (see Figure 25). This design was tested in the user evaluation with a paper prototype.

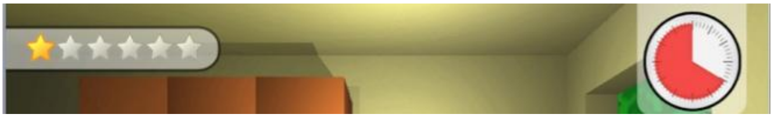


Figure 25 Conceptual design of Time Timer (Sallustro, 2013)

Throughout this thesis, conceptual screenshots of the interactive prototype were added with the conceptual design of Time Timer, so that the reader could easily see the differences of conceptual artworks and the final version of the design.

Time Timer for interactive prototype

Interactive display of Time Timer was needed in the interactive prototype and the final version of the game. Each Time Timer is shrinking clockwise from full 60 seconds down to zero. It means one cycle of Time Timer is one minute. In order to use the Time Timer in the game, we considered how to present the Time Timer for duration of more than 60 seconds. If the child has three minutes to complete each mini game we should present it in a way that the child must understand how much time was left.

Since the purpose of the Time Timer is to visualize the passing time. It must use the sound of the clock ticking, and also visible to acknowledge the child that it was running out of time. It could be modified to visualize more than one minute. The following possible solutions were considered:

1. Option one was to design a Time Timer that looks just like the original one, but erase the number from the Time Timer (see Figure 26). Furthermore, instead of completing a full circle in one minute, we modified to complete a full circle in three minutes. As the figure showed after one minute and 30 seconds passed the shrinking edge of the circle would reached at the middle of Time Timer.

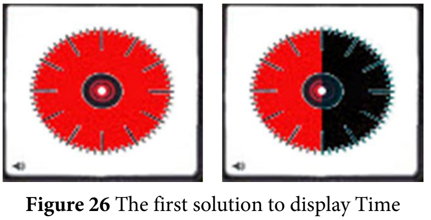


Figure 26 The first solution to display Time Timer

However, there was a disadvantage of this solution. Because we must ensure that every mini game would have exactly the same time to complete to eliminate the possibility that the child might not understand the difference of the same appearance of the Time Timer due to the different duration.

For example, if mini game A has a Time Timer which completes a full circle in three minutes, but mini game B has a Time Timer which completes a full circle in four minutes. After the child completes a mini game A, they will see exactly the same appearance of the Time Timer in mini game B, which could lead to misinterpretation by the child in that it might think that the Time Timer of mini game B runs exactly the same time as the previous Time Timer of mini game A.

2. Option two was to design the Time Timer like the normal one, but we added how many minutes were left as a small symbol of Time Timer at the bottom of it. When 60 seconds passed one symbol would disappear, and Timo would tell the child how many minutes were left (with or without his appearance). So after every minute that passed, Timo would remind the child and this could make the child feel that Timo was still there with the child. In this solution, the visibility of one second passed was clear, and we could vary the time to complete on each mini game, and no additional text added into the game.

Figure 27 The second solution to display Time Timer

However, there were still some disadvantages of this solution.

a. Timo's reminding sound could be counted as an auditory distraction.

b. Timo appearing to remind the child to keep an eye out for the time was indeed a distraction. However, we aimed to measure whether the child would be able to understand how much time was left without the reminder.

3. Option three was to design a Time Timer like the normal one, but using 'X' as a multiply symbol with a number— such as 'X4' for four minutes left. Again, the visibility of one second passing was clear, and we can vary the time to complete each mini game. However, there is an additional text added into the game and it also had the same disadvantages as the option number two.

Figure 28 The third solution to display Time Timer

In summary, it was important to use the sound of the clock ticking, and also make the Time Timer appear so the child could see that he was running out of time.

Solution for Time Timer

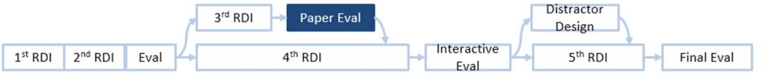
Our solution for the Time Timer to display a duration of more than 60 seconds was as follows:

1) The Time Timer will look like the original one. The child can see that he is running out of time, which was the most important reason why we display the Time Timer.
2) We introduced a shrinking bar to visually present the total time of each mini game.
3) We used the sound of the second ticking which will be played every second. The child will have this auditory synchronization for each second passed.
4) To avoid confusion, we set every mini game playing time maximum of four minutes.
5) Since every Time Timer is four minutes, we do not need text/number under the Time Timer.

Figure 29 The final solution to display Time Timer

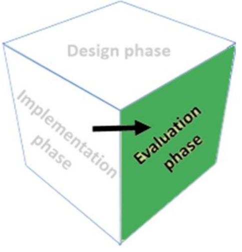
In the end, we chose to display Time Timer as shown in Figure 29. The remaining time would be displayed as a shrinking time bar on the left, and the old traditional (radial) Time Timer on the right. The shrinking bar could be set to represent the total remaining time of each mini game. While the old tradition Time Timer would run in full circle of one minute. There was a clock ticking sound for every second passed.

If we set the time of a mini game to four minutes (240 seconds), the shrinking bar would shrink from green to red in four minutes, while the red circle would run four times. This way the Time Timer served our needs to acknowledge the child that it was running out of time.



Chapter 8. User Evaluation 1 - Paper prototype

8.1. Introduction



The paper prototype provided useful feedback to improve the result of the video game. It saved time since it enabled the team to evaluate part of the video game before and during the implementation of the mini games. Moreover, it allowed all members of the team, including those with limited software skills, to take part in the design process. This task was done by PDEng student Christian Sallustro (Sallustro, 2013).

8.2. User evaluation

A paper prototype of the whole concept was made (see Figure 30) and were used with children to get us feedback, and listen to their ideas regarding the game design (subjective data), and to give the children the space to share their own ideas. The first concept evaluation focused on the content and visualizations. Were they clear and easy to understand, and was the flow between the mini games' scene smooth. The paper test also gave us subjective data from the children and showed how they could interact with the interface.

The interactive prototype was concurrently developing while we prepared the paper prototype materials. Therefore, the screenshots of the developing interactive were used in the paper prototype as the scenes of the video game, which colored print on an A3 format paper. This gave us more validity for the paper test.

We were not able to conduct a test with the inpatients of Kempenhaeghe due to lacking the approval from de Medisch Ethische Toetsingcommissie (METC; the medical ethical test committee). However, to save time for the project the test was conducted on volunteer children without ADHD in their family house for 30 minutes each.

Figure 30 The low fidelity prototype user test (Sallustro, 2013)

The user test was done with five children: two boys of six and seven years old, and three girls of four, six, and seven years old. All children were Dutch, Italian and English speakers, but the interview was in the Italian language (Sallustro, 2013). During the evaluation of the visualizations of each scene, the participants were provided with some tasks consisting of:

1) Making a choice for a profile and making a photo.
2) Evaluation for the look and feel of Timo, his friends and the island.
3) Evaluation for the interaction of 'dress up' and 'making a sandwich' tasks.
4) Thinking aloud about what to expect about the mini game 'cross the river', 'monkey banana' and the 'magic land'.
5) Create a scene/story of the waiting time mini game for participatory design.
6) Thinking aloud about what could be a reward when 'Closing' the video game.

The waiting time mini game at this stage was not tested because the concept was not clearly agreed upon. The thinking aloud method was used during the evaluation. The participants were free to ask questions if something was not clear. During the evaluation the interviewer did not disturb the participants unless they were stuck on one task for too long. Upon completion of each task, the participants were interviewed about it. All the participants received a voucher worth ten Euro for their participation. All the participants were volunteers and their mothers gave consent before the test started. These tests were done by PDEng student Christian Sallustro under the responsibility of TU/e.

8.3. Experts' evaluation

Four advanced students with a background in design, IT, psychology, and computer games were selected to participate in the paper prototype evaluation. All participants were students in the User System Interaction (USI) post-master program from TU/e and have worked with children in the past. Their expertise was helpful to validate the tasks' flow and to improve some technical details of the video game. The thinking aloud method was used for the expert evaluation, which took 30 minutes for each participant.

8.4. Summary of feedback from experts and children.

Feedback received from the children during the user test and from the advanced students has been brought into the team-discussion because it shows some differences in the understanding of the tasks. Screenshots of the video game were used in the test. They were shown in the same sequence to all the participants. All the participants appreciated the story of the video game and both children and adults really liked the design of Timo and friends (see Figure 31).

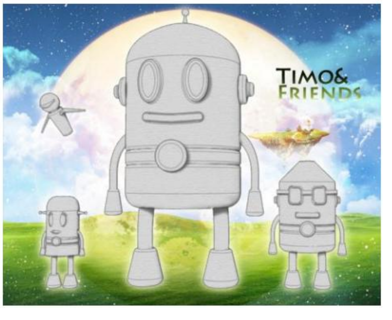


Figure 31 Timo and friends conceptual arts (Sallustro, 2013)

The outline of the gender selection was presented (see Figure 32). It was designed because some part of the game would be tailored and designed for each gender. Therefore, clothes and items in the bedroom must be changed to reflect the user's gender. The feedback revealed that the selection for the gender task was easy to perform and gave the user the impression to start the video game.

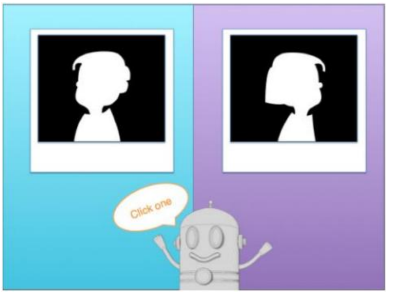


Figure 32 Conceptual screen of gender selection (Sallustro, 2013)

8.4.1. Dress Up.

Participants easily recognized the friends of Timo in the scene, but it was difficult to identify which one it was because of the same colors (please find more details about friends of Timo in Chapter 11 Distractors Design). So, different colors for each friend must be chosen. The clothes were easily found in the room, even though the majority said the environment was dark and the colors in the room could be improved. Adults said the room was messy, but the children said that it was empty. The children liked the objects in the room.

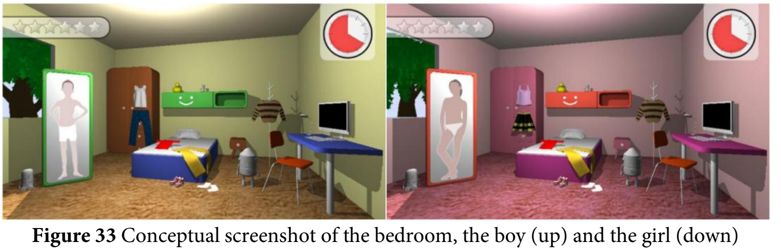


Figure 33 Conceptual screenshot of the bedroom, the boy (up) and the girl (down) (Sallustro, 2013)

All participates selected, each item with a pen and drew a line to the mirror in the order according to how they usually dress up at home (see Figure 30). The common order was: T-shirt, pants, pullover, socks and shoes. Most of participants chose the blue pants because they believed that it was better to wear blue pants for the adventure as stains are less visible in blue. All participants saw the stars and the timer in the scene and they understood their meaning.

8.4.2. Making sandwiches.

Figure 34 Conceptual screenshot of the kitchen (Sallustro, 2013)

The game's scene was a kitchen (see Figure 34). Participants understood the environment and recognized the avatars placed in the kitchen. They liked the scene and all gave positive feedback. They easily understood what the task was. The task linked with the previous mini game so they knew that were preparing for the adventure outside. Children easily recognized the ham, tomatoes, cheese, salami and cucumbers (from left to right). During the test, it was observed that the bread should be nearer to the user and the setting of the plates must be improved, as well as the food textures for a better visualization and interaction.

Feedback from the experts pointed out that the view could be improved for a child, we want the view of the child as if he was sitting near the table. The bread should be moved nearer to the child. We needed to think how we wanted the recipe to be shown such as a Post-it or Timo holds it.

8.4.3. Cross the river.

Figure 35 Conceptual screenshot of the cross the river mini game (Sallustro, 2013)

The game's scene was at a river bank in the game's world (see Figure 35). Participants immediately noticed the broken bridge and they understood that the task was to find a solution to cross the river. However, they did not know what to do at first glance. Participates did not understand what the machine does. Some participants thought the machine was a catapult or a robot could be able to repair the bridge. So the team agreed the design of machine and the remote control must be improved for a better understanding of the task. The majority was looking in for Timo and his friends in the scene and they asked why they were not there.

8.4.4. The monkey game.

Figure 36 Conceptual screenshot of the monkey mini game (Sallustro, 2013)

The children liked the monkey and supposed that it was stopping them to go forward (see Figure 36). The connection between the monkey and the bananas was not yet clear. The child needs to know that the monkey[7] was involved. Some of them think that they had to avoid the banana peels because the ground would be slippery, so if they step on the banana peel they would fall down and lose the game. Some children considered to throw bananas to the monkey so it would go away and they can continue the game. Participants admitted that the scene was dark because of the strong shadows on the environment.

[7] Monkey model from Sara Natkin, http://archive3d.net/

8.4.5. Magic Land.

Figure 37 Conceptual screenshot of the magic land mini game (Sallustro, 2013)

This mini game had received positive feedback from all participants. They assumed that something would jump out from the holes and they have to catch it. The children saw the holes/small volcanoes, but some of them thought that they have to avoid the holes otherwise they would fall down and lose the game.

8.4.6. Waiting

In the time of the paper test, the scene and concept of the waiting mini game were still under discussion. Therefore, we did not test the waiting mini game with a child.

8.5. Evaluation conclusion

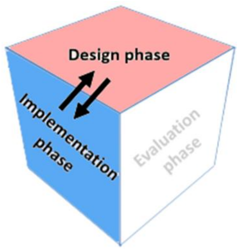
The outcome from the evaluation and the overall positive feedback confirmed that all participants liked the video game and the avatars. Some participants said that the scenes were dark, which the team took into consideration by improving the visualization of the video game. On the other hand, the team knew that this feedback was 'in part' caused by the quality of papers and printer. The final video game showing on the touch screen would be much brighter and colorful and the animation would make some tasks in the scene clearer. Some animation and sound effects should also be added to the scene to clarify some tasks and improve the interaction of the video game.

For diagnostic purposes, it was decided that the whole video game would be implemented in a linear manner so the test results could be compared between all children. Moreover, the whole game was targeted to last between 15 and 30 minutes, but certainly not longer than 45 minutes. Psychologists at Kempenhaeghe mentioned from experience that a duration above 45 minutes would be too difficult and tiring for the children, though to our knowledge this was the first time such a diagnostic computer game was made, so no hard scientific guidelines exist. Additionally, we decided to retain the possibility for children to choose their gender.

The task of ‘Waiting’ must be at the end, because otherwise the game would no longer be interesting for the children because the child has to wait for two minutes to accomplish the task. Based on the feedback the team improved the video game and all components, resulted in the interactive prototype for the next user test with children.

Chapter 9. Fourth RDI of the game – Interactive prototype

9.1. Introduction



This chapter describes the main improvements of the video game and how it became a higher fidelity prototype. We rapidly created a playable computer game with the necessary functionalities. This prototype was not complete, however it was intended to be used as a mock-up of the possible final version of the game. The designs of our six mini games were described thoroughly in this chapter.

9.2. Design and implementation requirements

Additional design and implementation requirements were proposed:

9.2.1. DI06 The game must be designed towards play, and to convince children that they are playing instead of being tested

The game we created would be used as a diagnostic tool. But it was important that the game would be designed in a way that child does not feel as if he was doing a psychological test.

9.2.2. DI07 The game must be child friendly

Child friendly means it was easy to use or it should be easy enough for the children to learn how to use by just observing the object, and it should satisfy users while playing. In this thesis the users of our game were psychologists and children. We considered the following sub-aspects of the children friendly.

DI07.1 The game should have a friendly look and feel for the children.
DI07.2 The game should have a friendly graphic user interface for children.
DI07.3 The game should have user friendly interaction with children.
DI07.4 The game should have friendly sounds for children.

9.2.3. DI08 No mini game lasts more than five minutes

From the feedback of previous evaluation, it was decided that the whole game needed to last between 15 and 30 minutes, but not longer than 45 minutes.

9.3. Game story

Feedback from the user evaluation has been investigated and details of the game story has been improved.

[Intro]

There was an adventure robot named ‘Timo’ (a storyteller) who like to travel across the universe by his rocket. He always travels with his friends, although his friends were so naughty and usually cause him trouble.

One of the examples, one day his friends forgot to refuel Timo’s rocket before they went adventuring, so the rocket fuel tank was nearly empty in the middle of the trip. He lands his rocket on earth. He must refuel the rocket or else he and his friends could not travel back home.

The rocket uses stars as its fuel. The star could be rewarded as a result, if someone did a good thing.

Timo found that there was a kind child (a player) near his landing site. He went to the child’s house before dawn to ask for help. Here was the beginning of his new adventure.

[Now there were six mini games with different sub stories to suit different time aspects. The child might play each mini game as a sequential order.]

In the end, the child successfully helped Timo to refill his rocket and Timo and his friends could travel back to their planet. Before Timo left, he brought the child back home and did not forgets to thank the child for kindly helped him.

9.4. Development of the interactive prototype

9.4.1. MINI GAME: Dress Up mini game

Timo woke up the child. The child was in underwear at the moment. It would be more appropriate to properly dress before the child goes outside of the house. This mini game was designed to test how the child organizes and plans in the selection of dress items, whether the order was as normal as it should be.

Mini game requirements

This mini game required the child to plan and organize things, using dressing up as the testing task. The only finish condition of this mini game was to select at least one item from seven choices. The psychologist suggested that we did not want the child to finish this mini game with no clothes selected. If the child did not select any item, it could be that he did not understand the instruction, rather than he has poor planning.

Therefore the simplified logic of this mini game was:

If The child selected at least one dress item **then**
    The child could pass to the next mini game.
Else
    Timo would not let the child pass yet, and he would repeat the instruction of this mini game.
End

Here were the important elements:

"The child knew that he should plan and select dress item in normal order as he dress himself, and touch Timo when he finished."

Structure of this mini game

Mini game's scene

The scene of this mini game was in the child bedroom. The bedroom reflected the gender that the child previously selected in the gender selection screen. In the bedroom there were many dress items placed all around the room. There also furniture and room decorations in the bedroom.

Play actions

The child would be instructed to select item to dress him/herself. Then time would passed for a pre-defined duration of the maximum of four minutes.

Play condition

When the child was satisfied with his selection, he might touch on Timo. If the child selected at least one item, Timo would bring the child to the next mini game. Otherwise Timo would repeat the instruction to the child for another once. If the child touched Timo the second time, Timo would bring the child to the next mini game immediately.

Story of Dress up mini game

The story of this mini game had derived from a child's general daily routines received from the interviews and personas. The routines were as follows:

(Start Daily Routines)

1. Rise up The alarm rings Going out of bed Go to the toilet Take of pyjama Take a shower Wash with soap Wash off Dry with towel Put on underwear Put on trousers Put on sweater Put on socks Put on shoes Combs hair (different options for clothes, for both boys as girls) (two different rooms, bedroom and bathroom, you can click on things like the clothes or soap)	**2. Breakfast** Putting a sandwich on the plate Choose what you want on your sandwich Make your sandwich Cut your sandwich Pour milk in a cup Eat your sandwich and drink the milk (the child can collect coins by pouring the milk in a right way, or small working memory tasks like passing stuff to parents)	**3. Brushing your teeth** Get your tooth brush Do some toothpaste on your brush Brush your teeth Open the tap Rinse your mouth with water Close the tap Put your toothbrush back in the cup
4. Go to school Pack your bag Put on your coat Say goodbye to mom/dad Walk or ride your bike to school (walking will take longer than using your bike)	**5. After school** Put down your bag Hang your coat Drink and cookie with mum Do your homework (for children above 7 years)	**6. Dinner** Eat your dinner Drink water (the child can collect coins by passing stuff to parents, or pouring the water)

<u>7. Go to bed</u>
Go to the bedroom
Take off your shoes
Take off your clothes
Put on your pyjama
Brush your teeth (see above)
Go to the toilet
Bedtime story by mom
Sleep

(End Daily Routines)

We selected sub daily routine number one 'Rise Up' and developed the story for this mini game.

<Begin of this mini game story>

The child woke up and saw a robot. The robot introduced himself, "*Hi, I am Timo! I am an alien from a planet far away from here. With my rocket I flew here.*" He said further, "*But now I need your help! My rocket cannot fly anymore, because I ran out of fuel stars. Can you help me by collecting new stars?*"

The child agreed to help him. Timo said, "*Before we can start with our adventure, you need to get dressed. Find the clothes you want to wear, and touch them. When you are ready, or when I have to explain it once more, touch me.*"

[The child might get dressed and be ready.]

The child touched Timo and accompany with him to a kitchen.

<End of this mini game story>

Moodboard for Bedroom

Figure 38 Moodboard of the bedroom (Sallustro, 2013)

The scene of this mini game was in a bedroom. Therefore, we designed a typical bedroom belonging to children of four to eight years old. To help generate the ideas, we used a moodboard to provide us with the shared elements of the bedroom. We used a moodboard because we were going to design something that exists in reality. A model of the bedroom had been created according to the moodboard and the style of the game (see Figure 38). Each item was designed and placed in the bedroom to create a friendly environment. This was to make children identify and select the clothing items in the room more easily.

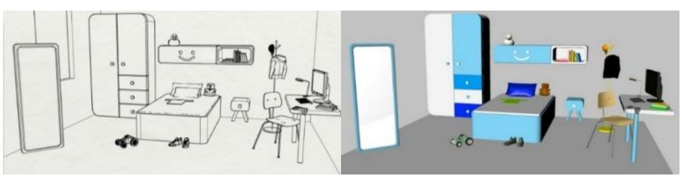


Figure 39 Conceptual artworks of the bedroom (Sallustro, 2013)

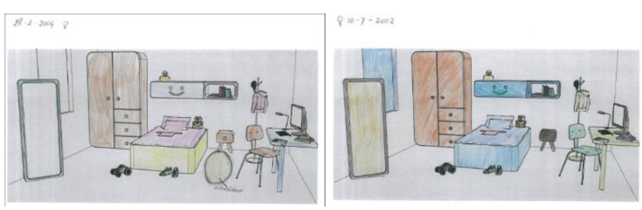


Figure 40 Participatory design of bedroom (Sallustro, 2013)

The 3D rendering (see Figure 39) gave an example of the room colors. The color and some items were changed depending on the gender of the user. Although Pomerleau stated that there was little difference in children's color preferences, but parents and other adults usually put color preference for their children regarding the traditional gender stereotype: pink for girls versus blue for boys (Pomerleau, Bolduc, Malcuit, & Cossette, 1990).

But we believed that children could tell us better. Therefore, we referred to the colors preferences from children's drawing we received from participatory design and made the bedroom in the mini game as shown in Figure 39. The boy room was in earth tone, but the girl room was in purplish/pinkish tone. This was the view that children could have during the test. The focus of the test was to understand how children interact with the interface and how they recognize items.

We decided to remove the cap, gloves, toy on the floor, and a teddy bear from the scene and replace a jacket with a pullover. Because our psychologists suggested that these items were uncommon for every child. For example, not all the children usually put on caps while going outside, and it was rare to put on gloves especially for boys. The toy on the floor was more tending towards boys than girls. We needed to balance the items in the bedroom to be a verisimilitude as much as we could. This designed was to neutralize the gender differences items and changing environmental colors in the bedroom to reflect with the gender of the player.

Figure 41 Boy's bedroom (left), and girl's bedroom (right)

Dress Up items

A kid must dress up before he can go to the next mini game. Therefore, a 3D model of clothes must be designed and placed in the bedroom for the child to make a selection. A moodboard had been made to visualize the idea of what they looked like. The moodboard was a collection of picture/image with which a designer could look for the consistency between elements. It showed us the similar characteristics and what seems to be out of the place.

Figure 42 Moodboard for trousers (left), and skirt (right)

The trousers of a kid were shorter than older children. The child ages in our target group vary from four to seven years old. The trousers should be longer than a kid's trousers, but not as long as an adult, and its knee should not be curvy which could be seen in kid's trousers. Its color could vary from gray to blue. But the gray color would be less visible when placed on the bed in the mini game scene, whereas the blue would be misleading to a jean. So we chose yellow as its color.

Figure 43 Moodboard for pullover (left), and undershirt (right)

The pullover was a sweater usually worn by donning it over the child's head. Sometimes it has horizontal strips. The boys' pullovers were woven with more texture than the girls'. However, to make it neutral for both genders, we decided to make it look like the pullover as in the bottom middle of the moodboard.

The undershirt was underwear usually worn to protect from body sweat and odors of the user. Undershirts of a child often have a light color and must look clean. We could see from the moodboard that it was woven from a soft cotton thread, and have short sleeves or be sleeveless. We modeled the undershirt of both genders as sleeveless, with a white undershirt for boys and light pink for girls.

The dress items were modelled with Blender 3D and added into the room. There were seven items placed in the mini game scene. There were common items for both gender ex. T-shirt, Pants, Pullover, Socks, and Shoes. The difference of boy dress and girl dress were Undershirt and Jeans for the boy or Skirt for the girl. We did usability tests for its visibility and found that the child could see where the dress items were placed on the screen.

Reflection of the child in the mirror

The view inside the game was the first-person perspective; therefore no child's avatar could be seen. However, to make dress up more relevant to the child, and to make the child a little bit more immersed, a child's reflection in the mirror was introduced in the bedroom.

The models were made in Blender. The posture of each gender was different. These were the results of different posing position of Armatures (Bones) applied as an idle position to the model (see Figure 44).

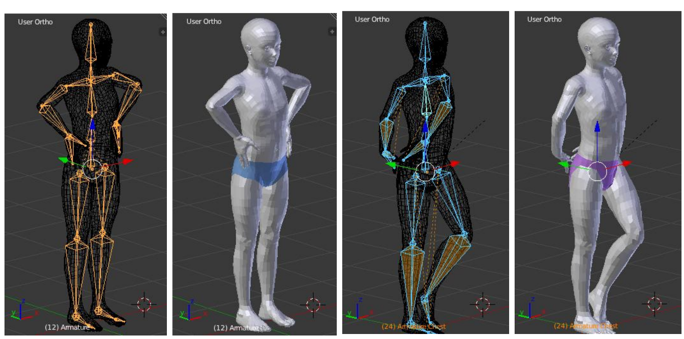


Figure 44 Idle position of a boy model (left) and a girl (right)

The girl looked more girly than the boy. All the models were posted in a reference T-shape at the beginning, from which they would be animated to pose in the idle position.

The mirror in the bedroom acted as a projection screen. It was filled by a '*Render Textures*' from another Camera in the game engine. Render Textures were special types of Textures that were created and updated at runtime. The other camera was stationed and aimed at the dress room, which would send the view from the dress room to the mirror.

Later, distractors and a GUI were added into the mini game scene. The distractors were placed spread out in the mini game scene (please find more details about distractors in Chapter 11 Distractors Design). According to the paper user test, the child could clearly see all the distractors. In the high fidelity, the distractors were colored so it gave better discrimination between different distractors in the scene. The complete game scene of the dress up mini game could be found in Figure 45.

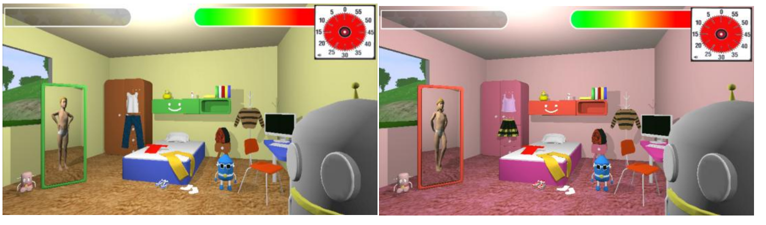


Figure 45 Final bedroom scene

Dress item's behavior

Dress items would move towards the player (the child) and were displayed on the avatar in the mirror. This would let the child know that the clothes now belong to the child and did not just disappear from the game's scene. The child might select another item until the child was satisfied or no more items could be selected. But only six items could be selected to dress. This was because there was one overlapping item. There were two options for boys to select either Jeans or Trousers, and two options for girls to select either a Skirt or Trousers. The child might select only one item to suit his/her preferences.

Regarding the mini game's speech dialogue, the child could touch Timo before he made any selection of clothing items to let Timo re-explain the mini game's objective, or after he was finished selecting at least one piece of clothes to signal Timo that the child was ready for the next mini game.

The flow of the 'Dress up' mini game

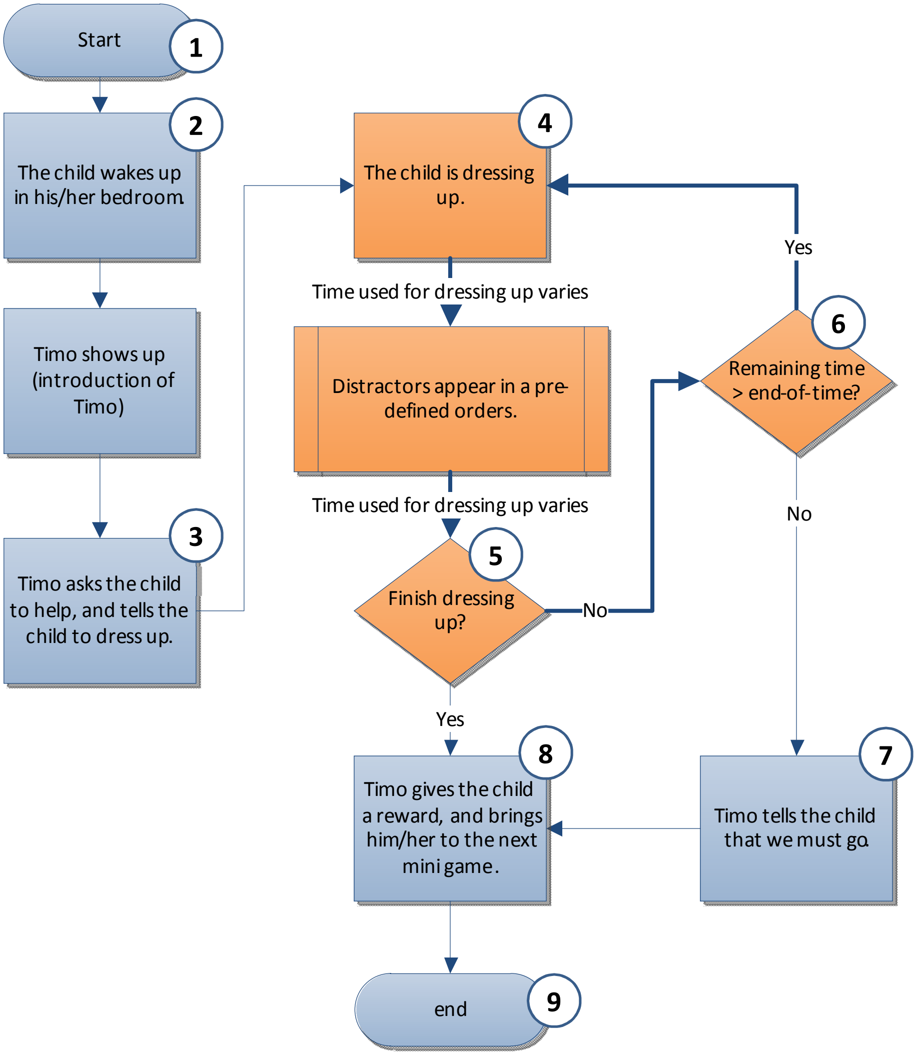


Figure 46 Flow of the bedroom mini game

The flow of dress up mini game was as follows:

1) The mini game was started and took place in the child's (artificial/virtual) bedroom.
2) The child would see a robot standing in front of him/her. The robot would introduced itself. Its name was 'Timo'.
3) The robot had a problem and needed help from the child. But before they went adventuring, the child needed to prepare him/herself by dress up.

4) The child dressed up.
5-7) At this time the game would check for whether the child finished dress up, and how much remaining time. If the time was out, Timo would tell the child that there was no time left, and they must go.
8) The child would receive a reward.
9) The mini game ends

Hypothesis of possible variables to measure ADHD

The possible variables we could collect from this mini game were:
(Main variables hypothesized to discriminate ADHD)

1. The score which would be calculated from the correct selected order of the dress items. The order of selected dress items would be recorded in the log files. Those items would then bring to calculate for a dress score.
2. Average selection time. Each time the item was selected, it would be recorded with timestamps that we could calculate for the average time the child spent to select all items after the first item was selected.
3. Number of clicks in this mini game.

(Additional variables)

4. Time spent in this mini game.
5. Number of dress items selected.

9.4.2. MINI GAME: Making sandwiches mini game

Timo and the child must prepare sandwiches for the journey to Timo's rocket. They were five persons in the group, including the child that waiting for a delicious sandwich.

Mini game requirements

This mini game required the child to remember sandwich ingredients, and to make sandwiches with those ingredients as exactly as they were shown in the recipe. On top of that, the psychologist could enable an option to ask the child to select ingredients in exact order from left to right as were shown in the recipe. There were five sandwiches, which the child could make within 240 seconds. The first sandwich must be a trial without any time pressure.

The simplified logic of this mini game was:

If The child made five sandwiches for all group members **then**

The child would be able to pass to the next mini game.

Else

The child might try until the time was out, and then he could pass to the next mini game.

End

Here were the important elements:

"The child knew that Timo would show a recipe once, and he must remember the ingredients and the order they appeared in the recipe. The child knew that he should make a sandwich with those ingredients, and with the correct order."

Structure of this mini game

Mini game's scene

The scene of this mini game was at a kitchen. There would be a table in front of the child. On the table, there were plates full of ingredients. Each plate contain one type of ingredients. Timo and his company were hungry. He appeared and asked the child to make sandwiches for them.

Play actions

The child might select the ingredient one by one. The ingredient would move and stack up on the bread. The child might select the next ingredient until he satisfied, then he might select the top bread to finish making sandwich.

Play condition

If the selected ingredients were matched with the recipe that Timo showed, Timo would give positive feedback, and ask the child to make another sandwich. If the selected ingredients were mismatched with the recipe that Timo showed, Timo would tell the child to try harder before asked the child to make another sandwich.

Story of Making sandwiches mini game

The story of this mini game was also derived from a child's general daily routine which the psychologist already suggested on page 104. We chose sub daily routine number two 'Breakfast' and developed the story for this mini game.

<Begin of this mini game story>

Timo said, *"We need to make a sandwich. Before going adventure. First, I will show you, look! Timo shows the child how to make a sandwich. Timo touches what needs to be on his sandwich, and says, when everything is on it, I touch the other sandwich and my sandwich is finished."*

He showed the child one recipe and said, "*Make a sandwich for you with the following ingredients."*

After the child finished making the sandwich for him/herself, Timo asked for another sandwich for himself, "*Now make a sandwich for me with the following ingredients."*

After the child finished making the sandwich for Timo, he asked for another sandwich for his (visual distractor) friends, "*My friends also would like a sandwich."*

After the child finished making the sandwich for his (visual distractor) friend, he asked for another sandwich "*Now a sandwich for her."*

After the child finished making the sandwich for his (auditory distractor) friend, he asked, "*And finally one last sandwich, then we are ready."*

After the child finished making the sandwich for his (combined distractor) friend, then Timo and the child were ready for adventure, *"Now we have enough sandwiches, so let's start with the adventure! Let's go!"*

<End of this mini game story>

Moodboard for Kitchen

Figure 47 Moodboard of the kitchen (Sallustro, 2013)

There were some consistent elements for the kitchen such as a cabinet or shelf, a bath sink, a stove, and an oven. The color of the kitchen must be in light color and must look clean. There should be a few condiments and utensils on the shelf. The stove of the moodboard was electric, and there usually consists of more than one stove as a set. Under the stoves was a cabinet, which was replaced by a microwave oven. Adjacent to the stoves was a bath sink. The sink was equipped with a faucet with dual water system.

We could see that the kitchens in the moodboard were not equipped with any table. Therefore, to serve the mini game's objective, we implemented a table inside the kitchen (see Figure 48). There were five ingredients laid on cutting plate, and pieces of bread. Each ingredient has six items. The ingredients from left to right were: Ham, Tomato, <Bread>, Salami, Cheese, and Cucumber. All those mentioned items were visible to the child.

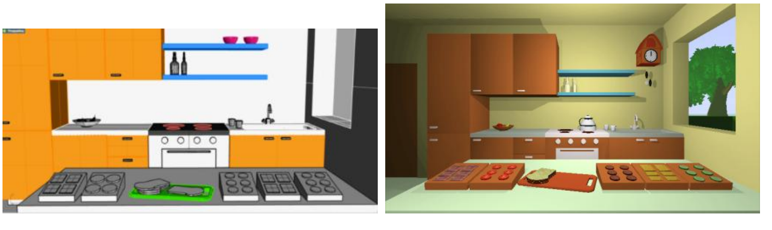


Figure 48 New concept of the kitchen (left) (Sallustro, 2013), scene of the making sandwiches mini game (right)

Sandwich's ingredient

One of the design concerns was to make the child recognize the ingredients. Here the ingredient models were textured mapping to make it look more natural and this made them stand out than using only plain color. We also used this texture as an ingredient image in the recipe. We did a usability test and found that children capable of recognize for what it stand for.

Figure 49 Sandwich's ingredients

Another thing we found from the user test was that the color of tomato and salami seems similar in the first time of our design. We changed the color of salami to be more red and pale off the color of tomato to make them easier to differentiate.

Ingredients Layout

The test of working memory was to remember and recall the ingredients shown by Timo. There were two things to test:

1) Test that the child can correctly remember the ingredient items.
2) Test that the child can correctly remember the order of the ingredient items.

There were three possibilities to lay the ingredients for a child. Two of them were discard (Figure 50) and one accepted design.

Figure 51 shows the layout of the ingredients we used to show the recipe to the child. We equally distributed all the ingredients from the center of the recipe to serve the purposes of testing for ingredients correctness and ordering correctness.

The discarded former designs

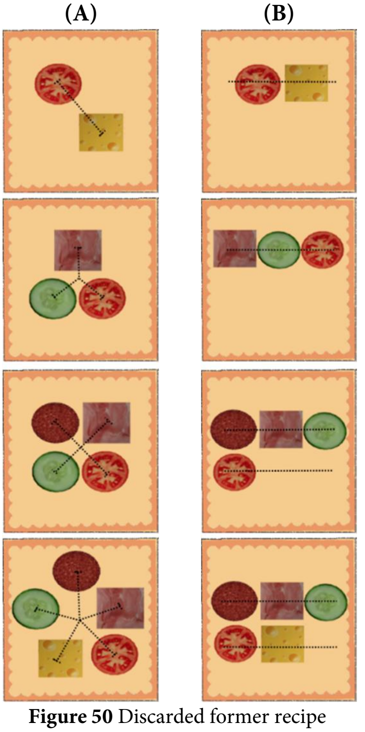


Figure 50 Discarded former recipe designs

(A) Equal distance from the center of the recipe

- The child might find that all the ingredients were weighted equally from the center of the recipe. However, it was confusing for the child to know what the first ingredient was. The child might not be clear did the order was clock wise or counter clock wise.

(B) Two lines, placed from left-to-right

- The child might find that there were two rows of ingredients in the recipe. However, confusion in the order could happen. Was the order read from up to down on the single ingredient, one after the other, or was the intended order to finish the upper row first then the lower row.

The accepted design

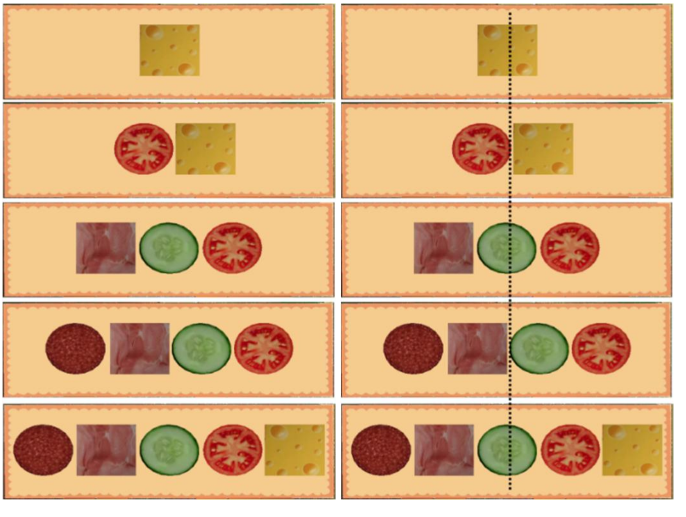


Figure 51 Ingredients design layout

The flow of the 'Making sandwiches' mini game

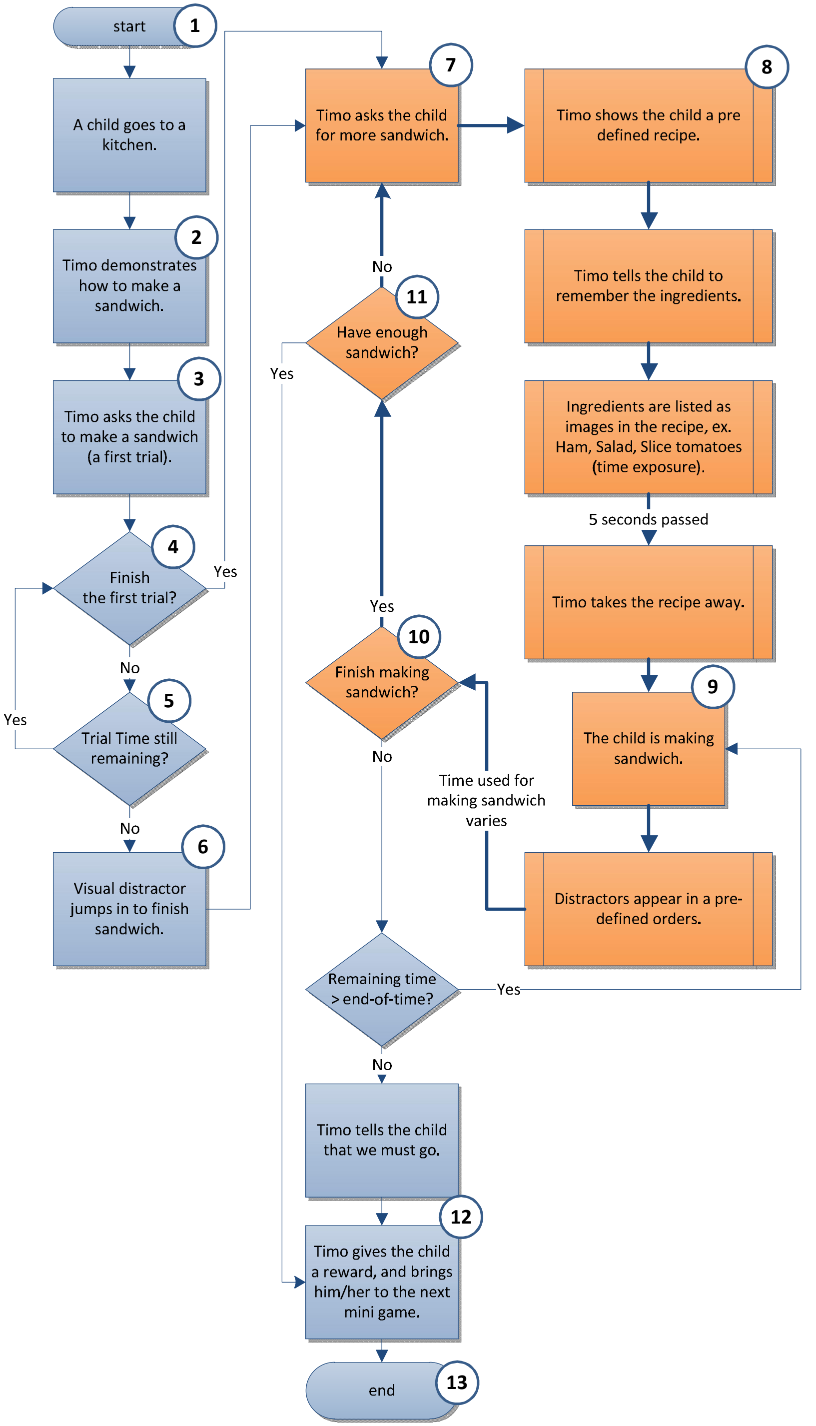


Figure 52 Flow of the making sandwiches mini game

The flow of the making sandwiches mini game was as follows.

1) The mini game was started in the kitchen. The child would see six ingredients on the table in front of him/her. Timo would be standing a little further from the table.
2) Timo would demonstrate how to make a sandwich to the child.
3) Timo then asked the child to make the first sandwich.
4-6) At this time the game would check for whether the child finished the first sandwich, and how much remaining time was left. A visual distractor would finish the first sandwich for the child if the time was up. This was a failsafe to ensure that the game would be able to continue even if the child has a very poor performance, or the child did not cooperate.
7) Timo would ask for more sandwiches.
8-9) Timo would show the child a recipe. In this recipe it shows what ingredients were needed for the child to remember and make the sandwich. The recipe would be shown for 5 seconds and would then be hidden again. The child subsequently has to make the sandwich. During this time, attention distractors would be played.
10) The game would check for whether the child finished making sandwiches, and how much remaining time. If the time out, Timo would tell the child that there was no time left, and they must go.
11) In case that there was time remaining, the game would check whether the number of finished sandwiches was enough. If the number of finished sandwiches was not enough (lower than 5 in total), Timo would request for more sandwich with another pre-defined recipe.
12) The child finished enough sandwiches or when time runs out, whichever comes first; he would receive a reward.
13) The mini game ends.

Hypothesis of possible variables to measure ADHD

The possible variables we could collect from this mini game were:
(Main variables hypothesized to discriminate ADHD)

1. Total number of sandwiches with correct sequence.
2. Total number of sandwiches with correct ingredients.
3. Number of clicks in this mini game.

(Additional variables)

4. Time spent in this mini game.
5. Number of ingredients selected per sandwich.
6. Total number of ingredients selected.
7. Average time used to select on the ingredients per sandwich.
8. Total time used to select the ingredients.

9.4.3. MINI GAME: Cross the river mini game

After Timo and the child left the house and walk from the house to Timo's rocket, they encounter a bridge at the river. They must cross the river, but the bridge was broken, so the child must find another way to cross the river.

Mini game requirements

This mini game required the child to estimate the duration of 10 seconds. There should be a small threshold around 10 seconds, so this mini game would not be too difficult. The mini game story was created to link the need of time estimation. But we should not show the progress of estimating time to the child. The child needed to use his mental capability to estimating the time.

The simplified logic of this mini game was:

If The child estimated the time within threshold of 10 seconds **then**
 The child would receive a good balloon.
Else
 The child would receive an unusable balloon, and needs to estimate another.
End

Here were the important elements:
"The child knew that he should make balloons to cross a river. The estimated duration of 10 seconds was needed for a usable balloon."

Structure of this mini game

<u>*Mini* game's scene</u>

The scene of this mini game was at a river shore. There was a broken bridge so the child could not cross the river. The river was too deep, and the tide was too strong. It was too dangerous for the child to swim. There was also a balloon making machine placed near the river. There was a remote control placed next to the machine. Timo had a nice idea, where he would teach the child how to cross the river with this machine.

Play actions
The child has to estimate the time of ten seconds using a remote control of the balloon making machine. One click to begin, another click to finish.

Play condition
When the child clicks to finish, a balloon was made. The balloon size would depend on the time the child estimated. If the time was within an acceptable range, the balloon would be usable. Otherwise, it would fly away (time was too long) or disappear in the river (time was too short). The child could try to make three balloons within four minutes.

Story of cross the river mini game

<Begin of this mini game story>

After walking for a while, Timo and the child reached a river, however a wooden bridge was broken so they must find another means of transportation to cross the river. "*Oh dear, we need to cross the river, but the bridge is broken! Thankfully, there is a balloon making machine. With this machine we can inflate balloons and then we can fly over the river.*" said Timo.

Timo demonstrated how to use the machine, "*Look, I push the button and keep on pushing and count till ten. If you let go after exactly ten seconds, we will get a good balloon.*"

The balloon was taken by one of Timo's friends to show how it worked to cross the river, *"Look, you can fly with it like this!"* He then encouraged the child to try inflating a balloon for the journey party.

<End of this mini game story>

Cross the river mini game scene

Figure 53 Cross the river mini game scene

A broken bridge featured in this mini game. The child must estimate the time spent to inflate balloons, and used these balloons as a means of transportation to cross a river. After consultation with the experts, we decided that the child must press a button to start counting time of 10 seconds. The child must press the button again when he think 10 seconds had passed.

The child needed a maximum of three balloons to lift him across the river. However, the minimum number of one successful balloon was needed. The child could retry estimating the time as much as possible within four minutes. However, if the estimated time did not fall between the acceptable range of 10 seconds +-0.5 seconds threshold, the balloon would not be usable.

If the time spent pressing the button was too short, the resulting balloon would end up as small, weak, and would not be able to lift itself. If the time spent pressing the button was too long, the balloon would fly away.

If the child could not make any balloon within four minutes, regardless of the time estimated by the child, the mini game enabled a fail-safe where the last attempted balloon that the child made would be usable regardless of the time the child estimated. This was to preserve the continuity of the game story because the child could at least use that balloon to cross the river and continue to the next mini game.

No balloon was displayed during the time estimation task. This was to ensure that the child must estimate the time in his mind instead of 'cheating' by looking at the changing size of the balloon and judging accordingly when he should stop pressing a button. An animation of the blowing balloon was played only after the child finished estimating the time.

Cross the river mini game

A balloon making machine was placed in the center of the screen (see Figure 53). It was introduced to circumvent the following problems:

1) The psychologists suggested us to display the balloon by holding a balloon in both hands while blowing it up. This idea was discarded because when inflating the balloon it would grow bigger and ultimately block the child's view in the game.
2) Another possible idea was using an air pump to pump air into a balloon. This was not chosen either, because the pump must move up and down. For example, if each pump movement takes one second, the children might count the number of pumps instead of using his thought to estimate the time.

We designed a remote that once pressed, its button automatically went down, and the child must continuously press to keep it down. The child releases the button when the child was satisfied with the length of time he estimated the button should be held to inflate the balloon. The button would pop back up and the balloon appears. The remote did not intuitively link to the balloon maker, so we implemented that the combined distractor would fetch a remote and gave it to the child in an introduction of this mini game, where Timo would demonstrate how to use it.

Children with ADHD have problems with motor control and persistence, this might be problematic if we require ADHD children to press and hold a button over long durations (Barkley (1997a) as cited in West et al., 2000). Therefore, we changed it to a lever instead, which needed to be clicked once to start and clicked again to end. To conceal the balloon size until it was done, the balloon making machine would tremble as a feedback when it was working.

The flow of the 'Cross the river' mini game

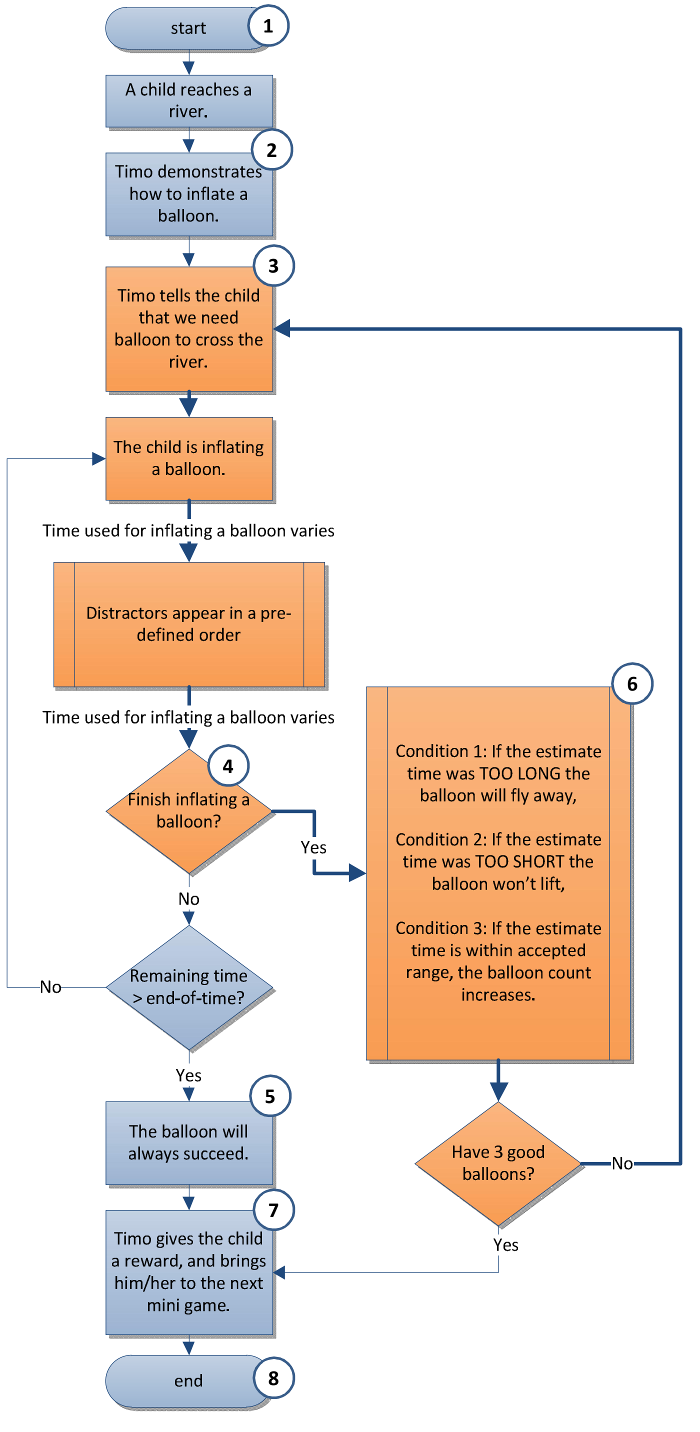


Figure 54 Flow of the cross the river mini game

The flow of the cross the river mini game was as follows.

1) The mini game was started after the child and Timo walked past a valley in the game world. There was a river with a broken bridge. So they must find another way to cross the river.
2) Timo said that his friend and the child could cross the river using an inflated balloon. He demonstrated how to inflate a balloon.
3) Timo then asked the child to make a balloon.
4) Every time when the child finished inflating a balloon, the game would check for whether the child finished in the correct timing (10 seconds +-0.5 seconds), and how much the remaining time was.
5) If the time was up, the next balloon would always succeed. This was a failsafe to ensure that the game would be able to continue, even though the child has a very poor performance, or the child did not cooperate.
6) Otherwise the finished balloon would be checked. The game would reject a balloon when its estimated time was less than 9.5 seconds, or more than 10.5 seconds. And also checks whether the child successfully made three balloons within the accepted range (9.5 to 10.5 seconds).
7) The child would receive a reward.
8) The mini game ends.

Hypothesis of possible variables to measure ADHD

The possible variables we could collect from this mini game were:
(Main variables hypothesized to discriminate ADHD)

1. The average estimation time when creating balloons.
2. Number of balloons made.
3. Number of good balloons. The number of balloons that their estimated time were in between ten seconds with +-0.5 seconds threshold.

(Additional variables)

4. Time spent in this mini game.
5. Number of clicks in this mini game.

9.4.4. MINI GAME: Monkey mini game

Timo and the child could cross the river with balloons. However, that was not the only obstacle because right after they crossed the river and walked past a hill there was a banana forest where a naughty monkey lives.

Mini game requirements

This mini game required that the child needs to do a conditional action.

The simplified logic of this mini game was:

If The child cleared a banana peel while the monkey was guarding the pathway **then**

  The monkey would throw one banana peel as a replacement.

Else

  The banana peel was cleared.

End

Here were the important elements:

"The child knew that he must clear all six banana peels. He could clear the banana peels only when the monkey was hiding behind a leftmost banana tree."

Structure of this mini game

Mini game's scene

The scene of this mini game was in a banana forest. The forest was in between steep hills. Walk through this forest was the only way that the child might do to reach Timo rocket. There were few monkeys living in this forest. They threw six banana peels on the way and its leader was blocking the way.

Play actions

The child might clear the banana peels from the way by clicking at the banana peel.

Play condition

The monkey would know that the banana was clear when it was not hidden behind the leftmost banana tree. If the child cleared banana peels when the monkey was observing, the monkey would throw more banana peels. The child might clear six banana peels within four minutes.

Story of Monkey mini game

<Begin of this mini game story>

After having successfully crossed the river, Timo and the child were confronted with a monkey who's blocking a pathway. It ate bananas and left their peels on the pathway. Timo foresees that it could lead to an accident, if the child walks over a banana peel. He said, *"Look, the monkey has thrown banana peels on the pathway. We need to throw them away, otherwise we cannot go further."* There was however a small catch of doing that, *"However, you should only throw away the banana peels when the monkey is hidden behind the tree and he cannot see you. Because if he sees that you are touching his bananas, he will call upon his friends and they will throw new banana peels on the pathway." Timo warned the child.*

<End of this mini game story>

Monkey mini game scene

Figure 55 Monkey mini game scene

The scene of the monkey mini game was set in the banana forest. Regarding the feedback from children in the previous chapter that the former design was too dark with strong shadows, we lowered the intensity of the shadows in the scene. The leftmost banana tree was improved with larger leaves for the monkey to completely hide. We removed the far behind banana tree to make the scene clearer and the child could have a better sight. The connection between the monkey and the banana was implemented with the monkey leader standing in the center of the screen. The monkey was cunning, and blocking the child. It would play peek-a-boo and observing the banana peels so no one could clear them, if it found out it would signal his underlings to throw more banana peels as a replacement.

The flow of the 'Monkey' mini game

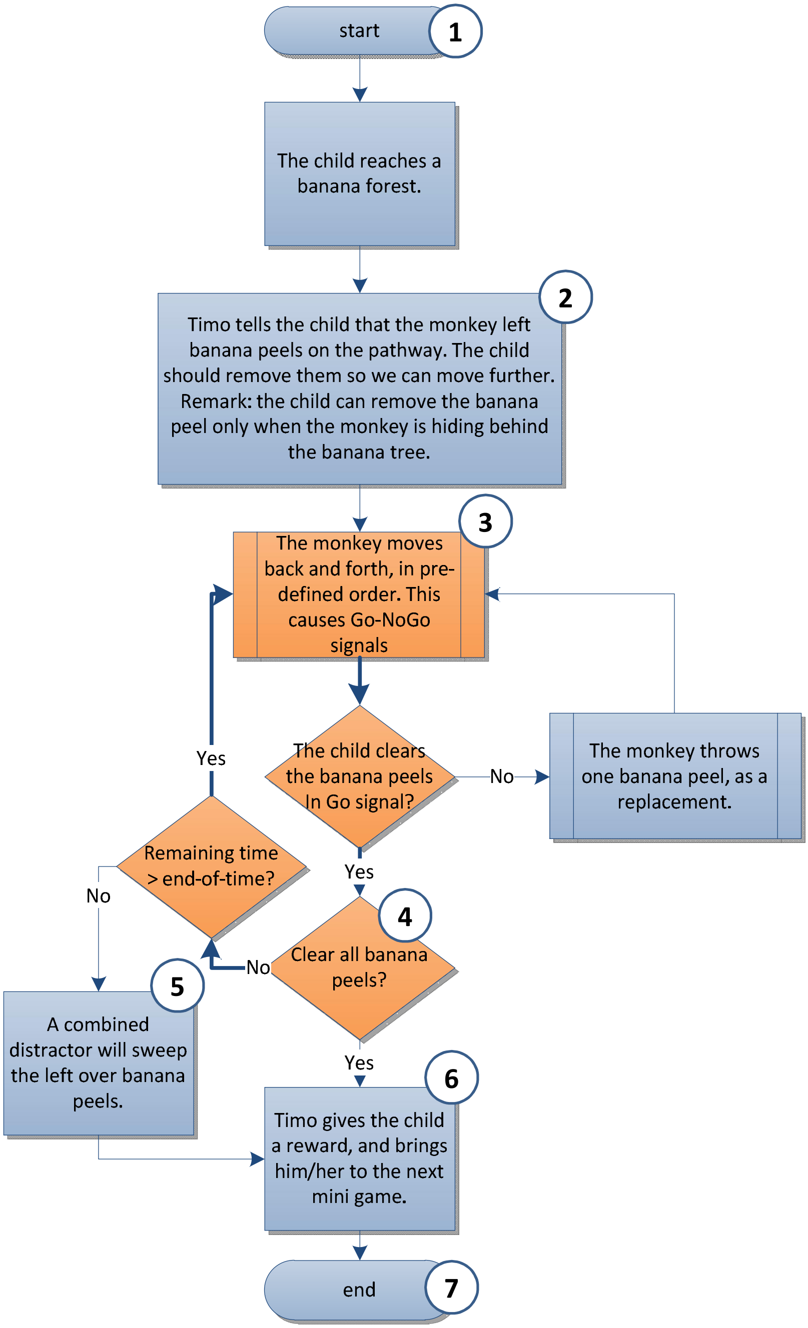


Figure 56 Flow of the monkey mini game

The flow of the monkey mini game was as follows.

1) The mini game started after the child and Timo successfully crosses the river. There was a banana forest where a naughty monkey lives.
2) Timo said that the monkey threw banana peels on the pathway which blocked them from walking through. The child must clear the way so that they could continue their adventure. But the monkey was observing the child therefore it should clear the banana peels only when the monkey was hidden behind the banana tree.
3) The monkey would move back and forth between the pathway and banana trees. The child might clear banana peels when the monkey runs facing to the tree, where it no longer focus its attention on the banana peels. If the monkey saw the child pick up banana peels, it would throw in banana peels to refill the empty spots.
4-5) The game would check for whether the child finished clearing all the banana peels, and how much remaining time was left. If the time nearly ran out, the combined distractor would sweep the left over banana peels for the child. This was a failsafe to ensure that the game would be able to continue although the child had a very poor performance, or the child did not cooperate. Otherwise the child might continue playing.
6) When all the banana peels were cleared. The child would receive a reward.
7) The mini game ends.

Hypothesis of possible variables to measure ADHD

The possible variables we could collect from this mini game were:
(Main variables hypothesized to discriminate ADHD)

1. Number of bananas cleared in No-Go signal— number of failures clearing the bananas.
2. Time spent in this mini game.

(Additional variables)

3. Number of bananas cleared in Go signal— number of successes clearing the bananas.
4. Average time used to clear each banana.
5. Did the child finish the mini game before the time was up?
6. Number of clicks in this mini game.

Go/No-Go sequence

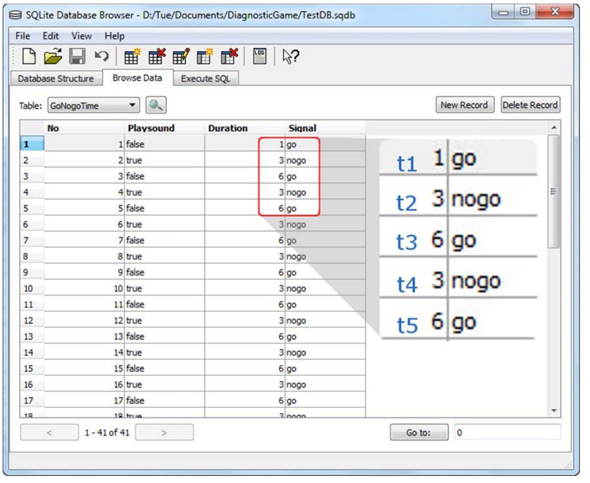
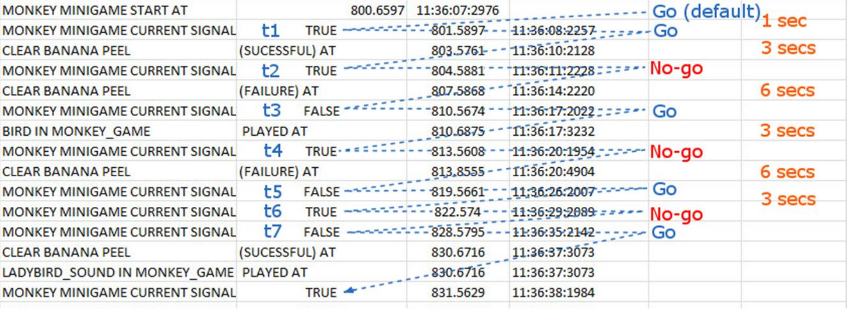


Figure 57 Go/No-Go sequences

This was the sequences of changing between Go and No-Go. The orders of signals were loaded from SQLite database file.

t1: after a second from the mini game start, the signal would turn to 'Go'.
This signal was mandatory because the monkey would start from hidden behind the banana tree (Default starting position). And it used approximately a second to move from the center of the screen to the tree.
t2: 3 seconds later, the signal would turn to 'No-Go'.
t3: 6 seconds later, the signal would turn to 'Go'.
t4: 3 seconds later, the signal would turn to 'No-Go'.
t5: 6 seconds later, the signal would turn to 'Go'.



MONKEY MINIGAME START AT		800.6597	11:36:07:2976	Go (default)	1 sec
MONKEY MINIGAME CURRENT SIGNAL	t1 TRUE	801.5897	11:36:08:2257	Go	
CLEAR BANANA PEEL	(SUCESSFUL) AT	803.5761	11:36:10:2128		3 secs
MONKEY MINIGAME CURRENT SIGNAL	t2 TRUE	804.5881	11:36:11:2228	No-go	
CLEAR BANANA PEEL	(FAILURE) AT	807.5868	11:36:14:2220		6 secs
MONKEY MINIGAME CURRENT SIGNAL	t3 FALSE	810.5674	11:36:17:2022	Go	
BIRD IN MONKEY_GAME	PLAYED AT	810.6875	11:36:17:3232		3 secs
MONKEY MINIGAME CURRENT SIGNAL	t4 TRUE	813.5608	11:36:20:1954	No-go	
CLEAR BANANA PEEL	(FAILURE) AT	813.8555	11:36:20:4904		6 secs
MONKEY MINIGAME CURRENT SIGNAL	t5 FALSE	819.5661	11:36:26:2007	Go	
MONKEY MINIGAME CURRENT SIGNAL	t6 TRUE	822.574	11:36:29:2089	No-go	3 secs
MONKEY MINIGAME CURRENT SIGNAL	t7 FALSE	828.5795	11:36:35:2142	Go	
CLEAR BANANA PEEL	(SUCESSFUL) AT	830.6716	11:36:37:3073		
LADYBIRD_SOUND IN MONKEY_GAME	PLAYED AT	830.6716	11:36:37:3073		
MONKEY MINIGAME CURRENT SIGNAL	TRUE	831.5629	11:36:38:1984		

Figure 58 Go/No-Go in a log file

In the log file, the signals would reflect on the Go and No-Go changing mechanism.

9.4.5. MINI GAME: Magic land mini game

The magic land was a place between the banana forest and a hill where Timo's rocket landed. It had magical geysers that spawned stars from the ground. The magical stars would disappear after several seconds. The child could harvest as many stars as it could. These stars would be a souvenir for Timo and his friends.

Mini game requirements

This mini game required the child to react as fast as possible after something appeared. The child might not be given an immediate reward if he delayed his action or was too slow. This mini game was designed to test the child's warned reaction time. Warned reaction time would have a signal before the stimulus appeared. In this mini game there was always a white vapor emitted from a geyser before a star would spawn at the geyser. Therefore, the child could see this warning signal and waited to catch a star coming up from the geyser.

The simplified logic of this mini game was:

If The child touched the spawned star before its lifetime end **then**
    The child would receive an imaginary star, and the game would play a caught sound.
Else
    The star would disappear, and the game would played a missed sound.
End

Here were the important elements:
"The child knew that there would be a star followed a white vapor, and the child knew that he should catch star as fast as he could before it disappear."

Structure of this mini game

<u>*Mini* game's scene</u>

The scene of this mini game was a magical land. There were five geysers on the ground. Each geyser had smoke flowing up from its funnel. There were stars jumping from the geyser. The stars lasted four seconds, after which they would disappear in the air with a low pitch sound.

Play actions
The child might try to catch stars jumping up from the geyser as fast as he could.

Play condition
The stars caught before they disappeared would make a sound with a higher pitch. There was no penalty for the missed stars caught.

Story of Magic land mini game

<Begin of this mini game story>

When Timo and the child reached a magic land, they saw smoke flowing up from the ground in this special place. Timo said, "*We are in the magic land. Here, stars jump from holes in the ground.*" He encouraged the child, "*If you catch enough of them, you will earn another star. So do your best!*" The child catched stars as fast as he could before they disappeared in the air. There were so many stars caught by the child. Timo said, "*Wow, that was great! You've earned another star!*" They left the magic land and headed to Timo's rocket.

<End of this mini game story>

Moodboard for magic land mini game scene

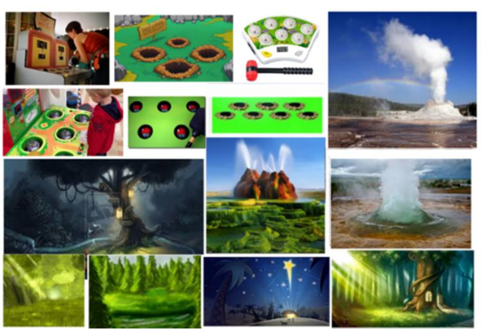


Figure 59 Moodboard of the magic land mini game

From the moodboard, the game named 'whack-a-mole' was a reaction-time related game.[8] There were holes and the game objective was to let a player use a hammer to smash moles which emerged from the hole as much as he could.

The 'whack-a-mole' game could to some degree induce aggressive affect in the child. So we changed it from smashing an animal into something less harmful. One thing that our mini game differed from whack-a-mole was our user interaction. The child would use his/her finger to directly touch the object emerging from the hole instead of using a hammer. Another thing was we replaced the holes with geysers. Geysers had been put into the moodboard and we found the similarity between them and the holes in the 'whack-a-mole' game. Furthermore, instead of an animal emerging from the holes, we changed it to the stars instead. The geysers were capable of injecting vapor into the air, and we applied this for displaying a signal. The signal would be played at the geyser shortly before a star would be spawned. This visual cue could give the child a clue of where to look to next (a so-called warned signal).

Figure 60 Magic land mini game scene

The scene of the magic land resembled a forest. The shadows were made lighter to avoid possible scariness of the scene. There were five geysers which would spawn stars. The geysers were distributed evenly and could clearly be seen from the child's view. The environment or natural distractors were used in this mini game. For example, there were many fruit on the tree and there was a tree with a hole, where we placed a multimodal distractor inside.

[8] ref: http://en.wikipedia.org/wiki/Whac-A-Mole

The flow of the 'Magic land' mini game

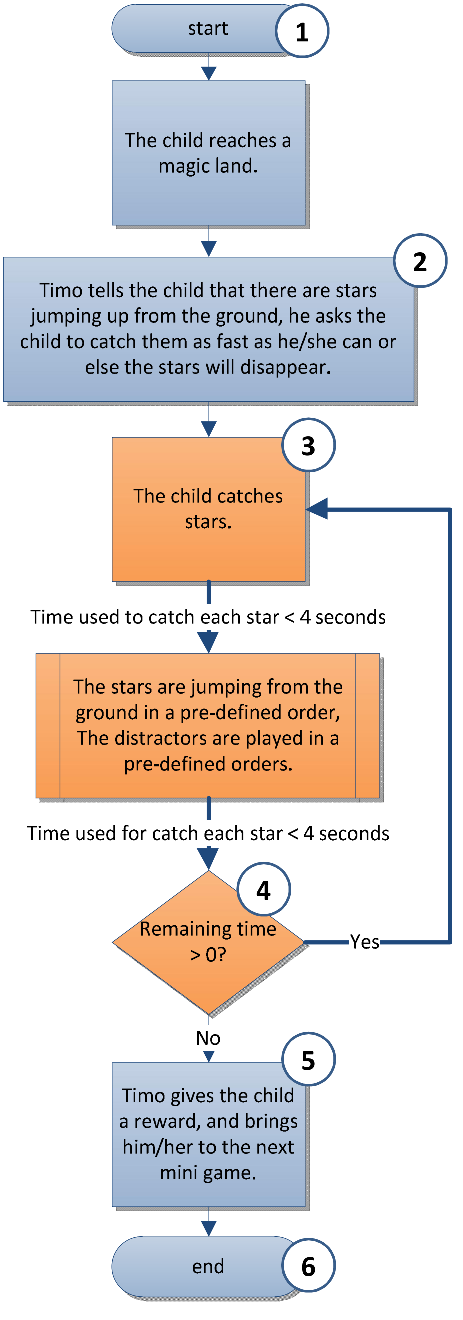


Figure 61 Flow of the magic land mini game

The flow of the magic land mini game were as follows.

1) The mini game started after the child and Timo successfully finished the monkey mini game. They walked on and reached a magic land where there were magical geysers.
2) Timo said that these magical geysers would spawn stars from the ground. He asked the child to collect stars as fast as he could, or else the stars would disappear.
3-4) The child might try to collect stars by touching the screen. The stars would be spawned in a predefined order. Until all the spawning orders were played.
5) The child would receive a reward.
6) The mini game ends.

Hypothesis of possible variables to measure ADHD

The possible variables we could collect from this mini game were:
(Main variables hypothesized to discriminate ADHD)
1. Number of stars caught.
2. Average reaction time. The average reaction time the child succeeded in catching stars.

(Additional variables)
3. Number of clicks in this mini game.

9.4.6. MINI GAME: Rocket mini game (formerly called the Waiting mini game)

A rocket has been chosen because the results from the first evaluation showed that Timo and his friend were looking like robots instead of aliens, and children associated the rocket with robots.

Mini game requirements

We brainstormed about the waiting mini game. This mini game resembled Stanford's marshmallow experiment (see section 2.5.3). The child was well informed about the following information:

1) If the child waited until the rocket was finished refueling, Timo would fly the child around the island before bringing him home. Although the child knew about this, Timo did not tell him for how long the child has to wait.

2) Timo emphasized that the kid must not touch or click any object on the screen.
3) Timo also told the child that in case that the child was too tired of waiting, he could bring the child home any time by simply touch or click any object on the screen.
4) While the game was running and counting down the time, the only animation showed to the child was the animation of the refueling process. This served as the only visual feedback to the child to let the child knew that the game was still running.
5) When the rocket was ready, it could give the child feedback that this was the end of the waiting period.

The simplified logic of this mini game was:

If The child touched the screen earlier than the designated time **then**
The game would end with a SMALL reward.
Else
The game would end with a BIG reward.
End

Here are the important elements:
"The child knew that it would have a small reward immediately, or it has to wait and get a bigger reward. The child would not know how long it needs to wait. There must be something happening on the screen, otherwise the child would think the game has crashed and would turn towards the psychologist. In the marshmallow experiment, there was no other distraction except the marshmallow."

Structure of this mini game
Mini game's scene
The scene of this mini game was in front of Timo's rocket. It landed on a hilltop. The scene was clear and there were only two objects in the scene: Timo, and his rocket.

Play actions
The child might wait until the rocket was fully refueled. There was no further action.

Play condition

If the child touched Timo at any time before two minutes. Timo would bring the child home immediately. Otherwise, if the child waited for two minutes, the rocket would fully refuel and Timo would bring the child home by his rocket.

Story of Rocket mini game

The scene took place at the rocket. The rocket was not broken, but it was out of fuel. Friends of Timo were busy converting the stars that the kid has previously collected, and refueling the rocket.

<Begin of this mini game story>

Group of Timo and the child reached the rocket. "*Look, there is my rocket.*" said Timo. "*We've earned so many stars! My friends can put them in the rocket, and then it can fly again. We have to wait until my friends are ready.*" He proposed, "*If you wait until they are ready, then we can make a tour in my rocket. But if you do not want to wait, you just have to touch the screen. But then you cannot make a tour in the rocket!*" Finally, he summarized, "*So you can choose: you can wait until they are ready and we will fly in the rocket, or you do not wait but then you cannot fly in the rocket.*"

Now the child could choose to wait until it completely refuelled, or not to wait in which Timo could bring the child home by his teleportation device.

Remark either ways, Timo would successfully bring the child home. He thanked the child, "*Look, you are back home. Thanks so much for your help! Now I can fly back home in my rocket, because you have collected so many stars for me. Thanks! Bye, see you next time!*" Then he would go back to his home-world.

<End of this mini game story>

Rocket mini game scene

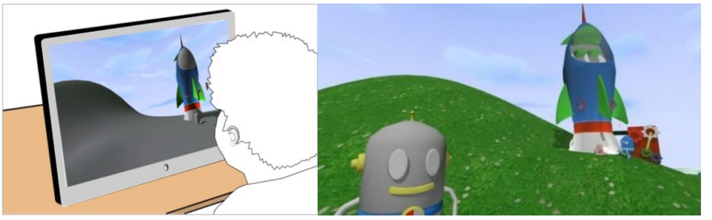


Figure 62 Conceptual design (left) (Sallustro, 2013), rocket mini game (right)

The rocket landed on the grass hill, and it was colored like a toy. From a user's point of view, the screen could be divided into two equally split sections. The left part of the screen displayed Timo, and the right part of the screen displayed the rocket and friends of Timo.

Timo would explain that the rocket was refuelling and the child should be waiting. Timo emphasized that the child should not touch the screen, but Timo also explained to the child that he could bring him/her home by simply touching the screen if the child was tired of waiting. The distractors were gathering near the rocket, but there would not be any animation from them. This was to strengthen the child feeling that the friends of Timo were here and the child was not being left behind. There was no further distractor played in this mini game. The only animations in the scene were rotating gears. We were aware that this could be another distractor but it represented a refuelling process and to make the child know that the game was still working and the game was not crashing or hung. Therefore the child would not turn towards the psychologist.

This mini game was based on the 'Stanford marshmallow experiment' explained previously. The child did not know how long he needed to wait, however the child did know that he would get either a small reward if the screen was touched immediately (went back home with a teleportation device) or a big reward if the child waited for two minutes (made a tour over the island on the rocket proceeded by went back home).

The flow of the 'Rocket' mini game

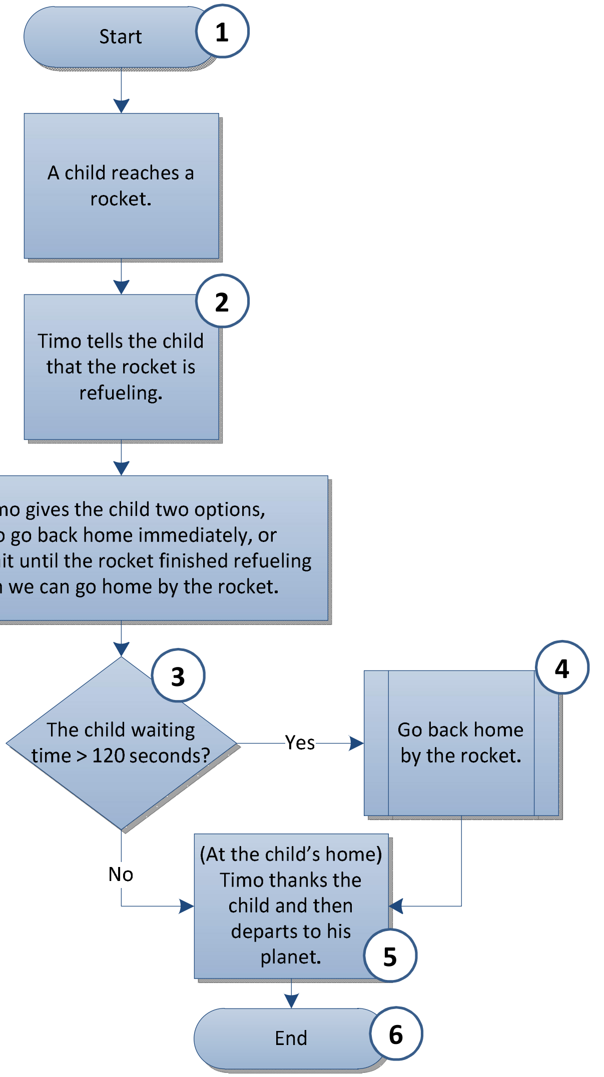


Figure 63 Flow of rocket mini game

The flow of the rocket mini game was as follows.

1) The mini game started after the child and Timo finished collecting stars from the magic land. They reached Timo's rocket.

2) Timo said that now the rocket was refueling. And he could bring the child home with his teleportation device, or the child could wait until the rocket had finished refueling, then he would bring the child home by his rocket.

3-4) During 120 seconds, the game would check whether the child made a click or not. If the child was waiting without doing anything, he would be carried by the rocket and fly to the child's home.
5) Otherwise Timo and the child would be teleported to his/her home. Timo would thank the child and say goodbye for the good help he received from the child before he left for his planet.
6) The mini game ends.

Hypothesis of possible variables to measure ADHD

The possible variables we could collect from this mini game were:
(Main variables hypothesized to discriminate ADHD)

1. Time that the child waited.
2. Final reward that the child had been given.

9.5. Follow up for the DI requirements

9.5.1. DI04 The game must be easy to be understood

From the user evaluation (paper prototype), we found that the game was easy to understand by itself. However, to ensure that the child would understand what the objective of each mini game was, for each mini game, there should be a brief introduction from Timo. This introduction was a second foolproof that each child would at least be informed. So the factor that could affect their understanding of each mini game objective was their attention paid as well as their individual differences.

9.5.2. DI06 The game must be designed towards play,

It was important that the child must not feel as if he is doing a psychological test. We designed that the game had a first impression in which it could draw the child's attention, and this was a game not a test. The game title screen was created to serve this purpose (see Figure 1). Computer games were considered to be fun due to their ability to provide children (as well as adults) with an interesting fantasy world to explore and play in (van der Spek et al., 2014). Moreover, the child would motivate to play and receive interactive feedback in the game.

9.5.3. DI07 The game must be child friendly

We agreed with Greenberg (Greenberg, Sherry, Lachlan, Lucas, & Holmstrom, 2010) that there is no game that fits all age groups, the diagnostic game should be tailored to match the specific age group. The elaboration of this requirement was as followed:

DI07.1 The game should have friendly looks and feels to children.
Violence was not allowed in our game. It was still debatable and evidence was lacking whether violence would carry over from watching television and playing video game. However, some of the research found that late teenagers who played violent video games for merely 15 minutes had higher heart rates due to arousal, and had aggressive feelings and thoughts that lasted for nearly four to nine minutes later (Barlett, Branch, Rodeheffer, & Harris, 2009). We wanted to prevent designing something that could be harmful and stimulated violence, as well as caused an uneasy feeling for the parents of children who play our game. Therefore, there was no blood or gore, no weapons, and no animal has been hurt in the game.

DI07.2 The game should have a friendly graphic user interface for children.
The graphic user interface (GUI), and head-up display (HUD) were visual information displayed to the player as part of the game's user interface. They must be simple and consistent for all mini games. The collected/given stars would be placed in the upper left corner of the screen. The Time Timer and the remaining time would be placed in the upper right corner of the screen. We used this as the only HUD layout that the child would see for all mini games.

Figure 64 GUI layout

User friendly in this game included the picking of colors to use for models, and the game environments. The colors used in the game were a cartoon style and not too much realism. We used the plain tone color for one object and minimized the use of realistic texture mapping.

DI07.3 The game should have user friendly interaction with children.
One of the requirements was that the user interaction must be simple and consistent for all mini games. To design complying with this requirement, we used only click/touch for the interaction in the game, and preserved this consistency for all mini games. This means that once the children learned how to interact with the game, user interaction was no longer a factor that could affect the child's performance.
In the future work we were thinking about introducing drag and swipe in some of the mini game, for example, the dress up and the monkey mini game. We could do the comparison between different user interactions in the later stage.

DI07.4 The game should have friendly sounds for children.
The background music used in the game was the instrumental version of nursery rhymes[9] such as 'Twinkle Twinkle Little Star', 'Ten Little Indians', 'Baa, Baa, Black Sheep'. This music was usually being played for a child in a nursery, and the children would have heard and be familiar with this background music. We thought it was appropriate for younger children.

9.5.4. DI08 No mini game lasts more than five minutes

Children with ADHD were sensitive to the effects of fatigue after a long battery of cognitive tasks, this possibly relating to their problems with cognitive processing (McGee, Brodeur, Symons, Andrade, & Fahie, 2004). We believed that 30 minutes was the appropriate time for an overall diagnostic session. If the child performed very well in the game, the child could finish all six mini games earlier. On the other hand, if the child performed very poorly in the game, the child could retry the six mini games with no more than 30 minutes in total (see Figure 65).

[9] http://www.karaoke-version.com/free/karaoke_kids.html

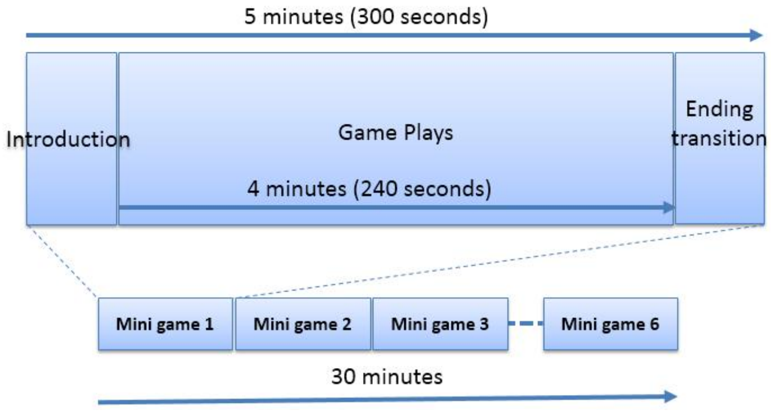
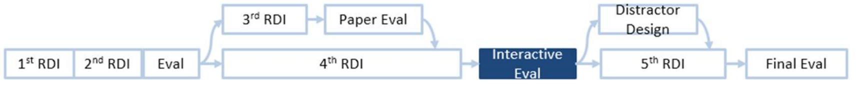


Figure 65 Mini game's time

Each mini game was allocated to complete within four minutes. This was chosen because:

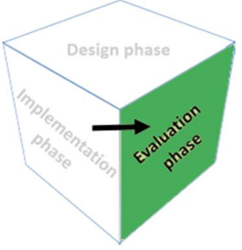
1) At this point we have six mini games; therefore there would be five minutes for each mini game.

2) However, we needed to dedicate some time for the introduction and for the transition between each mini game. Therefore, we agreed that one minute would be deducted from each mini game.



Chapter 10. User Evaluation 2 - the interactive prototype

10.1. Introduction



For the first evaluation of the interactive prototype a qualitative method was used to explore and evaluate the video game. Four Dutch children without ADHD symptoms between the age of four and seven were asked for the pilot test. This test aimed to observe the usability of the game, to give participants real tasks to accomplish, to enable the team to observe and record the actions of the participants, and to obtain data which would be discussed and make changes to the design accordingly. This task was done by Janneke Peijnenborgh.

10.2. User evaluation setting

The test was set up at Kempenhaeghe and it was in Dutch. There was only one psychologist in the room with the participant. The duration of the test was set to 30 minutes per session so the child would not get too tired. The interactive prototype of our diagnostic tool was set with a controlled linear story. This was to make sure that every child who plays our diagnostic tool would receive the same sequence of the tasks. To avoid external interference during the test, two cameras were placed in the room to record the experiment (see Figure 66). The video tapes allowed the rest of the team members to observe and furthermore to discuss about the performances of children.

Figure 66 Interactive prototype testing (Sallustro, 2013)

10.3. Feedback from watching video records

1. Boy, 7 years old
Technology familiarity: Never played on an iPad or a tablet, but likes to play Mario.

Impression: He likes the game very much. There are no mini games he did not like. It was easy to play, but not too easy which made it fun to play.

Usability of the game: He thought he needed to start the game from the rocket mini game. This boy mentions that there is no visual signal in the magic land game. During the waiting time mini game, he asked “Shall we wait for two minutes? Can you tell us when we have waited for two minutes?”

He suggested that the end can be “Timo gets into the rocket and flies to his planet”. The boy asked if he can play it again someday.

2. Boy, 6 years old
Technology familiarity: This boy likes reading more than playing computer games. He sometimes plays Mario, he likes this because you can drive a shopping kart. Never to be played on an iPad, or a tablet.

Impression: He likes the game, especially catching the stars. He tried to catch stars using multiple fingers, but this was difficult. He thought that he needed to start the game from the magic land mini game.

Usability of the game: He did not see the friends of Timo. During the dress up mini game, he forgets to put on his shoes. And during the cross the river mini game, after several trials he complained, “I can never do this.” In the monkey mini game, he tried to swipe one banana peel every time the monkey went hidden. Therefore, he did not have enough time to swipe all the banana peels. He waited for 18 seconds in the waiting time mini game.

Everything was fun. He suggested that the end can be “a happy ending, everyone plays with each other”.

3. Girl, 6 years old

Technology familiarity: This girl sometimes plays Mario. She likes playing computer games with her brother. She also never played on an iPad or a tablet.

Impression: She likes the game, and there was nothing that she did not like. The most difficult part was the balloon. She was very successful with the monkey, and wants to see what happens if you make a mistake.

Usability of the game: She did not see the friends of Timo. She thought he needed to start the game from the rocket mini game. During the dress up mini game, she wanted a skirt and trousers, and also mentioned that the girl in the mirror was bald. During the making sandwiches mini game, she said "Where is the bread?" then started by touching the incorrect bread. The cross the river mini game seemed too difficult for her. She pressed the button, without waiting for the button to come back up. She asked "How long are ten seconds?" In the monkey mini game, she swiped one banana peel per trial, but she could swipe all the banana peels in the time. She waited for 34 seconds.

She suggested that the end can be "we go back home".

10.4. Feedback from psychologists

For the test, the map of the island, the choose gender screen and all the mini games were implemented but without the transition between them. Those features were important because the health professionals could observe how the child acts during a no-action phase.

The psychologists found that the game was easy to understand by itself. However, in this stage of the implementation, Janneke did the instruction of the tasks. For the next iteration, there would be a brief introduction from Timo for each mini game.

Timo and friends were not colored and animated, but 80% of the higher fidelity prototype was completed as part of the final video game. The animation of Timo and friends would be added in the next iteration.

An introduction would be created to ensure that each child should understand what the objective of each mini game was. This introduction was a second fail proof that each child would at least be informed. So the factor that could affect their understanding of each mini game objective was the attention paid as well as their individual differences.

The transitions were part of the video game where the child was not playing actively but just observing the animated cinematic between the mini games. This feature could not be ready in the current prototype for the user test, but the transitions would be added in the next iteration.

10.5. Evaluation conclusion

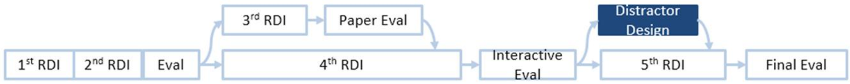
The team watched the videos and started the discussion about the performance of the children. From observation, it was obvious that the age of the child plays a major role in his/her performance: the older the child, the better the performance. All children liked the story of the video game, Timo and his friends, and to play the mini games.

Some remarks were found such as:

1) The graphic design of the map should be more colorful and clear. Additionally, the map must be designed as a first person perspective instead of bird-eyes view perspective.
2) The mini-games “Dress up”, “Making sandwiches”, “Monkey” and “Magic land” were easily played and completed. Only the mini game “Cross the river” was difficult to complete because it was hard to estimate ten seconds to inflate a balloon.
3) Some children did not understand that they needed to close the sandwich by clicking on the other sandwich. One psychologist suggested that this was a cultural aspect, because people in the Netherlands normally do not close their sandwich but fold the bread together instead.
4) The end of the monkey game was incomplete in the interactive prototype. We would implement that when all the banana peels were removed, the game needs to end. Alternatively, the child and Timo can walk through the pathway.
5) The background music was too childish and needed to be changed.
6) The socks were not visible enough in the dress up mini game. So we added a glowing color to make it stand out in the shadow.
7) The specified estimation time for the balloon of 10 seconds was okay for the older boy, but very difficult for the younger children.

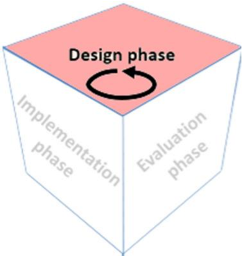
8) Every mini game should end with a successful trial, even if the performance of the child was not good enough.
9) In the cross the river mini game, the button needs to react immediately at the touch by going down.
10) None of the children said that our game was a test, but believed that they were playing a game.

Those feedbacks move forward the project progress to the final implementation.



Chapter 11. Distractors Design

11.1. Introduction



Distractors were designed concurrently with the fifth RDI. We designed them so that the distractors are played after the introduction in the game. The reason that we did not put distractors in the introduction part was to let the children fully focus their attention on the understanding of each mini game's objective. As the objective was narrated in the introduction of each mini game, introducing distractions in this crucial part would only raise the question whether the performance of children was affected because of the distractor, or that they did not understand the mini game's objective in the first place. Subsequently, we can make the assumption that each child was well informed about the mini game's objective. Therefore, if the child has low performance in the mini game, it would result from his/her own playing skills, and/or the effects of distractor which played during he was playing the game.

Moreover, we want to measure the time on task and the time after being distracted and returning to the task. Therefore, there was a data log of when the distractor was played and we could see the time of the next interaction/action of the child in the log file. Another solution was to observe the child while he was playing the game by watching video records provided by the eye tracking software.

Distractors could be customized to be played more than one time. This repeatable distractor enabled us to re-test the distractor for its effectiveness. (The mechanism of enabling the distractors to play at various times was explained in Setting playing time for distractors on section 11.2.4).

11.2. Distractor designs

The distractors were designed because the psychologists would like to measure external stimuli to determine to what extent they would distract the attention of the child, and how long it takes for the child to refocus on the task. Furthermore, distraction during the presentation of a time interval has been found to decrease the accuracy of children's time reproductions (Zakay, 1992).

We aimed that with this distractor, the child's performance would be decreased. We believed that a child with ADHD would be more affected by the distractor than a child without ADHD. The distractor causes the child to switch his/her attention from the relevant current task to a different irrelevant task, and if the child was slow in returning his/her attention to the current task, his/her performance in the game should decrease.

Children were asked to collaborate on a participatory design session to create Timo and friends. Children used a baseline (see Figure 67, left) to sketch their ideal avatars (see Figure 67, right). This session served as an inspiration for further ideas and especially to adapt the distractor more to an appearance the children like, since they are the target group of this project.

The result of the participatory design session shows that children usually added the distractors with arms and legs, funny facial expressions and colorful and round shapes. We also found that female and male distractor must be considered because children drew both genders during the participatory design session.

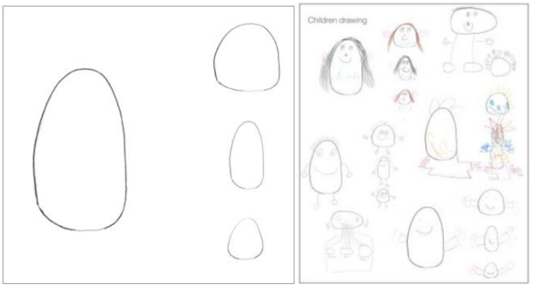


Figure 67 Baseline for the participatory design (left), some children's sketches (right) (Sallustro, 2013)

From the team ideas and children's sketches the final Timo and his friends were designed, keeping in mind the feasibility of 3D models and animations to implement it into the interactive video game (see Figure 68).

"The Fly" was designed as a visual distractor because it could fly around the scene without emitting sounds (100% visual).

"The Girl" was designed as an audio distractor; she would emit sound during the video game tasks. She would also cause a little visual

interference (90% auditory, and 10% visual) to assist the identification of the avatar in the scene.
"The Nerd" was the distractor that produces both sound (50%) and visual (50%).

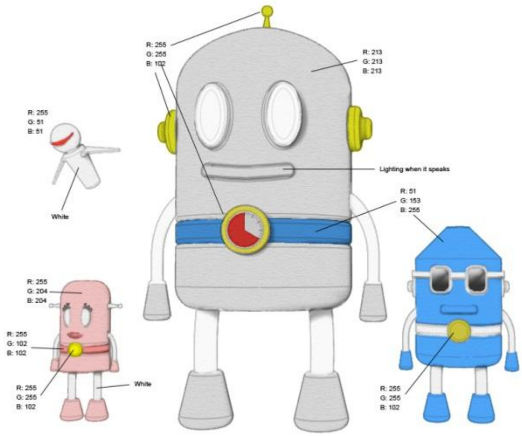


Figure 68 Timo and his (distractors) friends (Sallustro, 2013)

According to the psychologists at Kempenhaeghe, distractors could be better displayed in the following sequence: first the visual, secondly the sound, and finally the combined. They would appear in a variable interval of seconds between each other during the entire task.

However, they reported after many trials with children that the friend of Timo served as distractors were not distracting enough. We needed more distractors in the game. Therefore, additional natural distractors had been designed in the game. The natural distractors were distractors in the form which the child could find in nature. We categorized distractors into three categories to make a clear cut about the characteristics of the distractors (Table 2).

Category of distractor	Characteristics
1. Visual distractor	A distractor which could animate without making a sound
2. Sound distractor	A distractor which could make sound without an animation
3. Combined/Mix distractor	A distractor which could both make sound and animation

Table 2 Category of distractor

11.2.1. Visual distractor

Distractors in this category would produce visual stimuli while a child played the game. The visual distractor possessed only its appearance. It could draw the child's attention to shift the focus of his/her attention to looking at the distractor. It would be placed somewhere both inside and outside the mini game scene. The visual distractor would play when the mini game's local time reached a specific time we set. It would move within the mini game scene or move from outside into the mini game scene where it should easily be seen.

We designed 14 distractors which fitted into this category.

DIST_DRESS_VISUAL DIST_KITCHEN_VISUAL DIST_BALLOON_VISUAL DIST_MONKEY_VISUAL DIST_MAGICLAND_VISUAL	These distractors featured one of the friends of Timo—'the Fly' (see Figure 68). One was placed in each mini game. The only thing that this distractor capable to do was to fly around the mini game scene and this would attract the child's visual attention.
DIST_DRESS_COMPUTER	This distractor was a computer in 'Dress up' mini game, which initially has a blank screen, and suddenly flashes for several times then turns blank again.
DIST_BALLOON_BIRDGULL	This distractor was originally placed outside the mini game scene in the 'Crosss the river' mini game; it was a large sea-gull flying form outside the scene crossing the computer screen caused its shadow moving on the ground along its appearance.
DIST_BALLOON_FISH	This distractor was a red fish jumping from location to location in the 'Cross the river' mini game, and caused splashing water.
DIST_MONKEY_BIRD	This distractor was originally placed outside the mini game scene in the 'Monkey' mini game, it's similar to the gull in the 'Cross the river' mini game.

DIST_MONKEY_LADYBIRD	This distractor was originally placed outside the mini game scene in the 'Monkey' mini game; there was a pair of parrots flying together along the pathway from the far side of the mini game.
DIST_MONKEY_MOUSE	This distractor was placed on the ground outside the mini game scene in the 'Monkey' mini game; it was a gray little mouse running from the left to the right of the mini game scene.
DIST_MAGICLAND_BUTTERFLY	This distractor was placed outside the mini game scene in the 'Magic land' mini game; it was a yellow butterfly flying across the mini game scene.
DIST_MAGICLAND_LEAVES_L	This distractor was a group of leaves which falling from the leftmost tree in the 'Magic land' mini game.
DIST_MAGICLAND_LEAVES_R	This distractor was a group of leaves which falling from the rightmost tree in the 'Magic land' mini game.

11.2.2. Sound distractor

Distractors in this category would produce auditory stimuli while a child plays the game. It could draw the child's attention to find out, or to start looking for the source of the audio. The audio naturally has no physical entity shown in the mini game. Indeed the source of the auditory stimuli could come from an entity with an appearance; however the distractor that fitted into this category should not show its appearance in the mini game and only make sounds. The distractor which fitted into the design was multiple sources of sound that originate outside the mini game scene. Given a bedroom scene as an example, a storm occurring outside would let the child to hear the sounds of heavy wind from outside his/her bedroom, or the child might hear birds singing in the early morning although he did not see where the birds were.

We designed seven distractors which fitted into this category.

DIST_DRESS_DOORBELL	This distractor imitates the ringing sound of a doorbell when there was somebody visiting the house in the 'Dress up' mini game.
DIST_KITCHEN_OVEN	This distractor mimics the beeping sound of an oven when it finished heating up food in the 'Making sandwiches' mini game.
DIST_BALLOON_BOAT	This distractor occurs somewhere in the far away ocean in the 'Cross the river' mini game, it was the horn sound of a cargo ship.
DIST_BALLOON_BIRDSND	Another distractor in the same mini game, it was a singing sound of a bird.
DIST_MONKEY_WIND	It was the sound of strong wind passing the scene in the 'Monkey' mini game.
DIST_MAGICLAND_WIND	This distractor was placed in the 'Magic land' mini game; it was also the sound of strong wind move passing the scene.
DIST_MAGICLAND_BIRD	It was singing sounds of a bird in the 'Magic land' mini game.

11.2.3. Combined distractor

Distractors in this category would produce both visual and auditory stimuli while a child plays the game. With these multimodal capabilities, the combined distractor was likely the most powerful distractor among three categories.

We designed 14 distractors which fitted into this category.

DIST_DRESS_MIXED DIST_KITCHEN_MIXED DIST_BALLOON_MIXED DIST_MONKEY_MIXED DIST_MAGICLAND_MIXED	These distractors feature one of the friends of Timo—'the Nerd' (see Figure 68 Timo and his (distractors) friends). One was placed in each mini game. This distractor was capable of moving and making sounds. Within the game setting in a house, it could dance or cheer the child along. However, contradicting to its appearance, when it

	came outside of the house, this distractor was running around and was curious about everything. It was observing near the river while the child was inflating a balloon in the 'Cross the river' mini game, it annoyed the monkey in the 'Monkey' mini game, and it ran trying to catch a butterfly in the 'Magic land' mini game.
DIST_DRESS_BOOK	It was the red book which initially sits stable on a bookshelf in the 'Dress up' mini game, but later dropped from the bookshelf and made a noise when impacting the floor.
DIST_DRESS_RADIO	A Philips radio 'Chapel model' in the 'Dress up' mini game. It was initially silent, but later there was music with key notes broadcasting from the radio.
DIST_KITCHEN_KETTLE	This distractor was placed on the backside of the kitchen; it was a boiling kettle which produced smoke and noise.
DIST_KITCHEN_CUCKOO	It was a cuckoo clock placed on the kitchen wall in the 'Making sandwiches' mini game. It plays music and has a cuckoo bird popping from its little window.
DIST_BALLOON_WHALE	This distractor was a large whale in the 'Cross the river' mini game, it was initially submerged, but would be emerged with a splashing water, made sounds, and sprayed water in the sky. It would then submerge into the water again.
DIST_MONKEY_SQUIRREL	It was a squirrel hidden inside the garbage bin in the 'Monkey' mini game. It would jump up and down while makes noises.

DIST_MAGICLAND_OWL	This distractor was an owl hidden in the large hole in the rightmost tree. It was shy so initially it would not show itself to the child. However, sometimes it came out and making noise.
DIST_MAGICLAND_SQUIRREL	The old distractor from the monkey has followed the child to the magic land mini game. It was hidden on the leftmost tree but sometimes it fell down from the branch. It would make noises before climbing up again.
DIST_MAGICLAND_APPLE	One of the apples in the 'Magic land' mini game that could fall down with a falling sound.

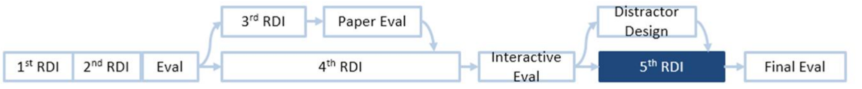
There were five more distractors which moved from the sound distractor into this category. In the previous design we have a friend of Timo, and one of his friends was designed to be a sound distractor. This distractor was sitting idle in the mini game scene and made sounds only. However, it had a physical appearance in the mini game, and it had added more visual features to make it stand out when it made sounds; by enabling its mouth to blink rapidly. Therefore, it lost the characteristics of being a sound distractor and better fitted into this category instead.

DIST_DRESS_SOUND	The girly robot in 'Dress up' mini game.
DIST_KITCHEN_SOUND	The girly robot in 'Making sandwiches' mini game.
DIST_BALLOON_SOUND	The girly robot in 'Cross the river' mini game.
DIST_MONKEY_SOUND	The girly robot in 'Monkey' mini game.
DIST_MAGICLAND_SOUND	The girly robot in 'Magic land' mini game.

11.2.4. Setting playing time for distractors

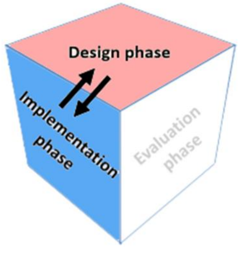
The distractors could be played at a specific time after the mini game starts, by setting its time in a file (see page 170). The file was a text file serving as a lookup table format. It contains name pairing with its value in each row. The file would be read immediately after the game was launched. Time values would be stored in a list, and waiting to be looked up when needed in each mini game.

In each distractor value, comma ',' could be inserted to separate each specific playing time of the distractor. With this psychologists could control the number and order of distractor of each mini game. However, distractors would not be played, in case that the child finished the game before reaching the playing time of the distractors.



Chapter 12. Fifth RDI of the game

12.1. Introduction



The interactive prototype was tested with children and it gave us valuable feedback. There were also some remarks from psychologists, which we used to fine tune the game.

This iteration was mainly concerned with improving the technical functionality of the game. The data logging mechanism had been improved by adding more log values and enabled more flexible to set the playing time of distractors in each mini game. Each mini game was designed based on a design pattern. Moreover, there was an overall structure of the game which enabled all mini games to work in a seamlessly unison.

12.2. Design and implementation requirements

12.2.1. DI09 The game should preserve continuity when changing between each mini game

We should design to preserve continuity in the game story and retain engagement. If the game has more than one mini game, all the mini games should be seamlessly connected and give a continuous game feel when changing between each mini game.

12.2.2. DI10 The game must be able to record user interactions

This requirement was kept in the design of the game and implemented while we did the interactive prototype. It was brought here instead of being mentioned prior in the previous chapters to improve readability.

The game we created will be used as a diagnostic tool. Therefore, more than being a game that a child can play, it must be able to do a job which it was designed for. It was mandatory that the game can log user actions while playing. This was one of many important functions that the game must provide.

12.2.3. DI11 The game must have verbal/voice instructions from Timo

In the evaluation of the interactive prototype, psychologists from Kempenhaeghe served as the instructor of the tasks. An automatic brief introduction by Timo for each mini game was needed.

12.2.4. DI12 Each mini game must always lead to success for the child

There was no punishment in the game, the child should feel successful and be able to proceed even if it was really poor on his performance. The child must be able to pass the game from the first mini game to the last mini game. The reason was to ensure that the child would have only positive feedback regardless of his/her performance. Moreover, the game was designed specifically for a psychological test and we must control the equal time that the children can play in each mini game. Performance was a dependent variable, whereas time in each mini game was independent. It was to have a baseline which we can compare the performance of the child in each mini game. Indeed, we would use the child's performance as one of the diagnostic variants, but the child should feel positive.

12.2.5. DI13 Psychologist(s) must be able to modify game parameters without the need of a technical expert

We were designing the game for psychologists, so they can use our game to support in a diagnostic process. This feature enables a psychologist to modify parameters of the game and conduct a compared diagnosis process without the need of technical experts.

12.3. Feedback after interactive version and multiple tests

The game was concurrently tested with children under Kempenhaeghe supervision during the implementation of the game. These gave numerous feedbacks to the psychologists by observing children playing the game. This section shows the effect of participatory design model where psychologists received those feedbacks and later relayed these back to us to design the improvement of the game.

1. The frequency of each distractor was set to one in the previous game. Sometimes the child did not notice that there was a distractor. Therefore the psychologists required the implementation that distractors could be

played several times during each mini game. Moreover, the playing frequency of distractor must be configurable.

2. In the scene transition, the simulated first-person perspective walking speed was appropriate. However, pause time after reaching the next mini game should be decreased.

3. In addition the map should move faster in the transition scene. Psychologists were concerned that the child might lose his attention.

4. There should be a repeat of instruction from Timo in case that the child does nothing within 20 seconds.

5. There were still problems with the voice of Timo. The emphasis in a lot of words and sentences were not as clear as they should be in Dutch. Therefore, some instructions did not make sense, which we thought of using the voice of a real person at that time.

6. Two children did not understand what to do with the gender selection screen. We should include an instruction.

"Kies de jongen of het meisje om het spel te spelen" ("Choose the boy or girl to play the game")

7. Timo also needs to mention that the child needs to put the ingredients in the same order as the picture in the making sandwiches mini game. This instruction could be enabled and disabled regarding the setting of parameter in the game properties file (see page 168)

"Maak een boterham voor jezelf met de volgende dingen. Let op dat je ze in dezelfde volgorde doet als op het plaatje staat." ("Make a sandwich with the following ingredients. Make sure that you put them in the same order as seen on the picture").

8. In the example made by Timo, it would be good to include a ticking sound, which guides the child and explains how long 10 seconds will last. This should naturally not be included in the trials by the child.

9. If the children made a good balloon in the cross the river mini game, it would be good to add a confirmation by Timo (for instance: "Goed gedaan, je hebt een goede ballon!" "Good job, you have a good balloon!").

10. And after the child made a good balloon, it would be better to add an instruction from Timo to make another balloon ("Maak er nog één", "Make another one").

11. In the monkey mini game, could the monkey run hide-and-seek faster? Because some of the children thought that they could not clear bananas when the monkey was walking towards the tree.
12. After the child waited for two minutes in the waiting mini game, Timo mentioned that the rocket was ready. But now the game waits for the child interaction. It should be better that after Timo said that the rocket was open, the child should automatically enter the rocket.

12.4. Follow up for the DI requirements

12.4.1. DI07 The game must be child friendly

Regarding 'DI07.4 The game should have friendly sounds to children', the background music we selected was too childish and needed to be changed. Indeed, it was appropriate for a younger child. However, for the older children in 6 to 8 years old, the background music was too childish and no longer appropriate. Therefore, we have changed the background music. However, it was difficult to find appropriate background music for free.

Our solution for this issue was to purchase background music from a commercial provider. We purchased looping background music from http://www.playonloop.com/. The reason for selecting this site was because it provided good music quality. More importantly, our psychologists agreed that it was suitable for the game, with a reasonable cost.

12.4.2. DI09 The game should preserve continuity when changing between each mini game

The following solutions were implemented to preserve continuity of the game experience.

1) Fading the whole screen could easily be detectable by a player, and this could cause disengagement between a player and the game. Therefore, no fading of the screen was used during the game play. Fading was used outside of game play, before the introduction of the first mini game and after the last mini game ended.

2) Simulated movement of a player in the first person perspective. This could be implemented by changing position and degree of rotation of the game's main camera.

3) There was a map shown to the child while the child changes mini game scene outside the game's house. There are nine maps in total. Each map shown gradually changes leading from the in game's house to the landing site of Timo's rocket. The map was another feedback from the game to the player. To keep the player informed and also represent a signal that it was time to change mini game scene/location.

Figure 69 Revealed sequence of game's map

On the first map, the child would see lots of hidden mini game scenes, marked with a question mark (see Figure 69). This was to draw attention from the child and make the child curious of what would be the next mini game. After the child finished the current mini game and mini game ending was played, the scene transition would be played next. In the scene transitions, the game would show a path on the map shaped in red footsteps from the current mini game to the next mini game. The facing direction of footsteps guided the direction of the current mini game to the next. Once the child reached the next mini game scene, the game scene transition would show the map again. This time the hidden mini game symbol behind the question mark would be revealed. Moreover, this was to let the child keep track of how many mini games he already finished.

Figure 70 Clearly visible game's map

The final map reveals all the mini game scenes (see Figure 70). It shows the bird eyes view of the game's world in two dimensions. The color was in a cartoon style. With this the child may feel like he was going to explore the Treasure Island and this could make the child feel adventurous.

12.4.3. DI10 The game must be able to record user interactions.

In order to fulfill this requirement of being a diagnostic tool, we implemented a logging mechanism. It was designed to automatically log data into text files while children play the game, providing more accurate time than manually collecting data using a stopwatch. Data in the log files were event based, filled with quantitative data and comments. These raw data had comments and timestamps of events for human readability.

Detailed information about the logging mechanism can be found in ‘Chapter 14 Data logging mechanism’ on page 183, and ‘Appendix III: Data logging mechanism’ on page 232.

12.4.4. DI11 The game must have verbal/voice instructions from Timo

We used computer generated sounds as the voices of Timo. The voices came from text-to-speech (TTS) software. There are free trial TTS web applications on the internet which anyone can type in 200 characters and let the computer read/speak it out aloud. We recorded the voices with a microphone and saved them for use in the game.

The file format for the speech was .wav which was clearer and jitter-free when used in the game compared with an mp3 file. The voices we recorded from the TTS were not suitable at first because they were the voice of an adult, and needed some modification. Adults generally have lower-pitched sounds and children generally have higher-pitched sounds. Child speech frequency ranges from 250-400 Hz (notes B_3 to G_4, adult females tend to speak at around 200 Hz on average (about G_3), and adult males around 125 Hz (or, B_2) (NCVS, 2012). Overall, mean speech frequency range for children is approximately 225-360 Hz (Trollinger, 2003). Therefore, we changed the frequency of the voice files we recorded to better fit for a child’s voice, by applying higher pitches to the sound files.

12.4.5. DI12 Each mini game must always lead to success for the child

This requirement was also related to '*DI09 The game should preserve continuity when changing between each mini game*'. We implemented that each mini game has an end-of-time checker as the fail proof mechanism to be ensured that every player can proceed to the next mini game regardless of its playing performance (see Figure 71). The mechanism was to have one of the distractors complete the mini game's objective for the player, and with apologies from Timo that we were running out of time and must prepare for the next mini game.

For example, the fly distractor would finish making a sandwich for the player in the kitchen mini game; or the combined distractor would sweep all left over banana peels on the floor for the player in the monkey mini game; or after the player waited for 120 seconds in the rocket mini game, but did nothing for the next 60 seconds, he would be able to board the rocket and fly back home by default.

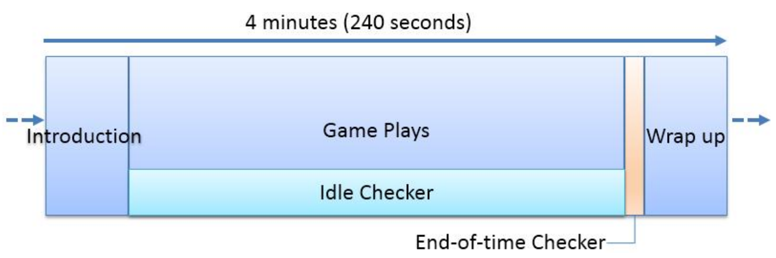


Figure 71 Mini game structure

12.4.6. DI13 Psychologists must be able to modify game parameters without the need of a technical expert

In order for the diagnostic process to be conducted by non-technical experts, and to comply with the design requirement, we enabled the game to be customizable. By reading a text file containing keywords and values. If there was no file found to read, the game will use its default value already assigned in the game code. However, if the properties files have been found, the game will read them, match up the value of a keyword, and override its default value been programmed in the game. This enables the user to customize the game without asking for an implementer to make changes and recompile all the game code.

The customizable game's parameters are in two distinct files: *GameProperties*, and *DistractorProperties*.

GameProperties

The GameProperties was a text file which keeps all the variable parameters that can change how the game will run. It will be loaded in the configuration phase of the game before the game starts.

In the GameProperties file, the keywords and values are listed in a Tab-Separate-Value (.tsv) formatted: [**PROPERTY_NAME**]**<tab>**[**VALUE**]

Here are the keywords and their purpose:

For Game play

Name	**TIME_BEFORE_INACTIVE**	Value	20
Purpose	The time interval in seconds that if a kid has no clicking action inside the game, Timo will repeat an instruction. This will tell the kid to do something.		
Name	**SANDWICH_TRIAL_TIMEOUT**	Value	60
Purpose	The time interval in seconds that lets the kid try to make the first sandwich, after Timo has demonstrated how to make one, and finish a sandwich. If the kid does not finish a sandwich within this time, a visual distractor will come to finish the sandwich so the game can continue with the test.		
Name	**CHECK_FOR_CORRECT_ORDERING**	Value	0 or 1
Purpose	**For sandwich mini game:** The flag to set whether we want to check the finished sandwich for a good order (i.e. the order shown on the recipe) or not. 0 = Do not check 1 = Check		
Name	**CHECK_FOR_CORRECT_INGREDIENTS**	Value	1 or 0
Purpose	**For sandwich mini game:** The flag to set whether we want to check the finished sandwich has complete ingredients as shown on the recipe or not. 0 = Do not check 1 = Check		
Name	**FIRST_TRIAL_GIVES_FEEDBACK**	Value	1 or 0
Purpose	**For sandwich mini game:** The flag to set whether we want the first trial of making the sandwich to give feedback when		

	it was with incorrect ingredients or in the incorrect order as shown on the recipe or not. 0 = Do not check 1 = Check		
Name	**ENABLE_TOGO_WITHOUT_UFO**	Value	0 or 1
Purpose	**For UFO mini game:** The flag to set whether we want the kid to be able to make a selection/choose to go without the UFO when he receives the big reward. 0 = Disable for selection 1 = Enable for selection **Remarks:** select to go without the UFO was the default value, if the kid does not select any option within 60 seconds.		
Name	**AVERAGE_BALLOON_TIME**	Value	10
Purpose	The balloon estimating time for a normal balloon, must be 10 at the moment.		
Name	**BALLOON_THRESHOLD**	Value	0.5
Purpose	The acceptable range on both sides from the average balloon time. Set this to 0.5 means the acceptable estimated time for a normal balloon was from 9.5 – 10.5 seconds.		
Name	**BALLOON_END_TIME**	Value	210
Purpose	The allotted time for the cross the river mini game, before the mini game end. Any estimation time in this time will result in a normal balloon, so the kid can have at least 1 balloon to cross the river.		
Name	**BALLOON_LASTCHANCE_TIME**	Value	20
Purpose	The allotted time for the last chance after time-out that a kid can make a balloon. If a kid does not finish any balloon during this time, Timo will make a balloon for the kid, so the kid can have at least 1 balloon to proceed to the next mini game.		
Name	**TIME_FOR_WAITING**	Value	120
Purpose	The time for waiting before the rocket was fully refueled. If the kid succeeds in waiting, then the kid will have a big reward. If the kid fails to wait, he will receive a small reward.		
Name	**REWARD_PATH_01_TIME**	Value	30
Purpose	The time the rocket uses to complete flying in the first section.		
Name	**REWARD_PATH_02_TIME**	Value	25
Purpose	The time the rocket uses to complete flying in the second section.		

Name	**PLAY_MUSIC_IMMEDIATELY**	Value	0
Purpose	Interrupt playing the scene's background music without waiting for the end of previous scene's background music.		

For debugging purposes

Name	**SHOW_RERUN_BUTTON**	Value	0 or 1
Purpose	The flag to set whether we want to show a rerun button on the screen. For debugging purpose.		
Name	**SHOW_SCENE_TRANSITION**	Value	0 or 1
Purpose	The flag to set whether we want to play scene transition or just teleport to the next mini game. For debugging purpose.		
Name	**SHOW_DEBUG_LOG**	Value	0 or 1
Purpose	The flag to set whether we want to show a debug text or not. For debugging purpose.		
Name	**SHOW_HIGHLIGHT**	Value	0 or 1
Purpose	The flag to set whether we want to show an orange highlight on the spot where the kid click on the screen or not. For debugging purpose.		

Please see the example of GameProperties on page 229.

DistractorProperties

The DistractorProperties was a text file which keeps all the variable parameters that can control the time, which we want the distractor to play. It will be loaded in the configuration phase of the game before the game starts.

In the DistractorProperties file, the keywords and values are listed in a Tab-Separate-Value (.tsv) formatted:
[PROPERTY_NAME]<tab>[VALUE_1,VALUE_2,VALUE_3,…,VALUE_N]

PROPERTY_NAME : was linked to the specific distractor in the game. It starts with 'DIST' then name of mini game and its name.

VALUE_1,VALUE_2,VALUE_3,…,VALUE_N : are the time in seconds that the distractor will start playing. Please use comma ',' without a space between them to separate the time.

'Time used' was the time a distractor need to complete playing. When inserting a value for them to play, the time for next distractor must be incremented by equal or more than the 'time used' to prevent the unexpected display.

Repeatable Distractors

Name	**DIST_DRESS_DOORBELL**	Time used	5
Purpose	The time to start playing a doorbell sound after the dress up mini game started.		
Name	**DIST_DRESS_COMPUTER**	Time used	10
Purpose	The time to start playing computer flashes after the dress up mini game started.		
Name	**DIST_DRESS_RADIO**	Time used	12
Purpose	The time to turn on Philip Chapel radio after the dress up mini game started.		
Name	**DIST_DRESS_SOUND**	Time used	5
Purpose	The time that the Sound distractor start giggling after the dress up mini game started.		
Name	**DIST_DRESS_VISUAL**	Time used	10
Purpose	The time that Visual distractor will fly outside the room and fly back afterward after the dress up mini game started.		
Name	**DIST_DRESS_MIXED**	Time used	10
Purpose	The time that Mixed distractor will dance after the dress up mini game started.		
Name	**DIST_KITCHEN_OVEN**	Time used	15
Purpose	The time to start playing microwave oven sound after the making sandwiches mini game started.		
Name	**DIST_KITCHEN_KETTLE**	Time used	20
Purpose	The time that the water in a kettle boiled, and displayed stream of vapor after the making sandwiches mini game started.		

Name	**DIST_KITCHEN_CUCKOO**	Time used	10
Purpose	The time to start playing a cuckoo clock after the making sandwiches mini game started.		
Name	**DIST_KITCHEN_SOUND**	Time used	10
Purpose	The time that the Sound distractor start giggling after the making sandwiches mini game started.		
Name	**DIST_ KITCHEN _VISUAL**	Time used	10
Purpose	The time that Visual distractor will fly outside the room and fly back afterward after the making sandwiches mini game started.		
Name	**DIST_ KITCHEN _MIXED**	Time used	10
Purpose	The time that Mixed distractor will dance after the making sandwiches mini game started.		
Name	**DIST_BALLOON_FISH**	Time used	10
Purpose	The time to start playing a jumping fish from the river after the cross the river mini game started.		
Name	**DIST_BALLOON_BOAT**	Time used	10
Purpose	The time to start playing ferry/boat horn sounds after the cross the river mini game started.		
Name	**DIST_BALLOON_BIRDSND**	Time used	15
Purpose	The time to start playing bird sounds after the cross the river mini game started.		
Name	**DIST_BALLOON_BIRDGULL**	Time used	10
Purpose	The time to start playing a gull flying across the screen after the cross the river mini game started.		
Name	**DIST_BALLOON_WHALE**	Time used	20
Purpose	The time that a whale emerges from the river and spray water after the cross the river mini game started.		
Name	**DIST_BALLOON_SOUND**	Time used	10
Purpose	The time that the Sound distractor start giggling after the cross the river mini game started.		

Name	**DIST_BALLOON_VISUAL**	Time used	10
Purpose	The time that the Fly distractor start to fly after the cross the river mini game started.		
Name	**DIST_BALLOON_MIXED**	Time used	10
Purpose	The time that Mixed distractor trying to cross the river after the mini game started.		
Name	**DIST_MONKEY_BIRD**	Time used	15
Purpose	The time to start playing bird sounds after the monkey mini game started.		
Name	**DIST_MONKEY_LADYBIRD**	Time used	10
Purpose	The time to start playing ladybird flying toward a player after the monkey mini game started.		
Name	**DIST_MONKEY_WIND**	Time used	15
Purpose	The time to start playing a strong wind sound after the monkey mini game started.		
Name	**DIST_MONKEY_MOUSE**	Time used	10
Purpose	The time to start playing a mouse running at the bottom of the screen after the monkey mini game started.		
Name	**DIST_MONKEY_SQUIRREL**	Time used	5
Purpose	The time to start playing a squirrel jumping from a garbage bin after the monkey mini game started.		
Name	**DIST_MONKEY_SOUND**	Time used	10
Purpose	The time that the Sound distractor start giggling after the monkey mini game started.		
Name	**DIST_MONKEY_VISUAL**	Time used	10
Purpose	The time that the Fly distractor start to fly after the monkey mini game started.		
Name	**DIST_MONKEY_MIXED**	Time used	15
Purpose	The time that the Mixed distractor start planking the monkey at the greater distance after the monkey mini game started.		

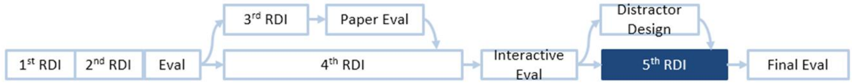
Name	**DIST_MAGICLAND_BIRD**	Time used	15
Purpose	The time to start playing a bird sounds after the magic land mini game started.		
Name	**DIST_MAGICLAND_WIND**	Time used	15
Purpose	The time to start playing a strong wind sound after the magic land mini game started.		
Name	**DIST_MAGICLAND_OWL**	Time used	10
Purpose	The time to start playing an owl showing himself from the hole in the tree on the right after the magic land mini game started.		
Name	**DIST_MAGICLAND_BUTTERFLY**	Time used	10
Purpose	The time to start playing a butterfly flying across the geysers after the magic land mini game started.		
Name	**DIST_MAGICLAND_LEAVES_L**	Time used	15
Purpose	The time to start playing falling leaves from the tree <u>on the left hand side</u> after the magic land mini game started.		
Name	**DIST_MAGICLAND_LEAVES_R**	Time used	15
Purpose	The time to start playing falling leaves from the tree <u>on the right hand side</u> after the magic land mini game started.		
Name	**DIST_MAGICLAND_SQUIRREL**	Time used	10
Purpose	The time to start playing a squirrel falling from the tree, and making sound after the magic land mini game started.		
Name	**DIST_MAGICLAND_SOUND**	Time used	10
Purpose	The time that the Sound distractor start giggling after the magic land mini game started.		
Name	**DIST_MAGICLAND_VISUAL**	Time used	10
Purpose	The time that the Fly distractor start to fly after the magic land mini game started.		
Name	**DIST_MAGICLAND_MIXED**	Time used	10
Purpose	The time that the Mixed distractor start running after a butterfly after the magic land mini game started.		

Unrepeatable Distractors

These distractor was used one-time only.

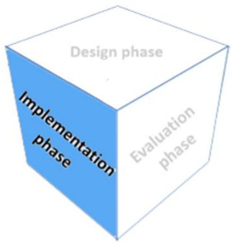
Name	**DIST_DRESS_BOOK**	Time used	10
Purpose	The time that the book in the book shelf will fall after the dress up mini game started.		
Name	**DIST_MAGICLAND_APPLE**	Time used	10
Purpose	The time to start playing falling apple after the magic land mini game started.		

Please see the example of DistractorsProperties on page229.



Chapter 13. Game architecture design

13.1. Introduction



Each mini game was designed with similar architecture design. There are two levels of architectures described in this chapter. The lower architecture for each mini game, and the upper one covered all six mini games, which enabled all mini games to work seamlessly in unison.

Moreover, the discussion of how these architectures served the purpose of a diagnostic tool is mentioned.

13.2. Architecture of each mini game

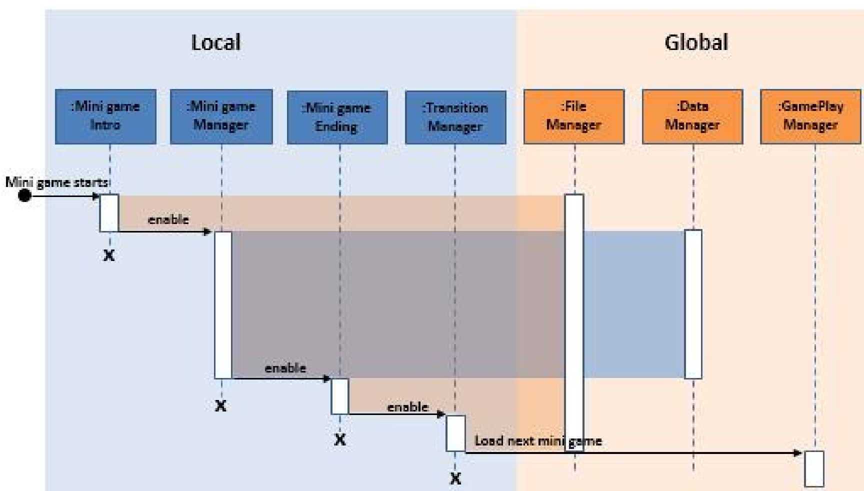


Figure 72 Mini game's design pattern

There were many *Managers* in our game. *The manager* managed other sub *GameObjects* into a single harmony. Local managers were per mini game specific modules. Global managers were shared between all mini games on the concept of '*singleton*' instances (Maclean, 1997; Nystrom, n.d.), which reduced memory needed and provided global access to other game objects.

1) The local managers of each mini game were: *Mini game intro*, *Mini game Manager*, and *Mini game ending*. These managers were essential for the runnable version of each mini game. They provided easier debugging when implementing each mini game.
2) Transition Manager was responsible for the smooth change between mini game's scenes.
3) Three global managers kept shared data and provided an access point for all mini games, they were: *File Manager*, *Data Manager*, and *GamePlay Manager*.

13.2.1. Mini game Intro

Based on the game story and to fulfill the requirements of '*DI04 The game must be easy to be understood*', each mini game would have a different introduction. The introduction was the first called module and takes no more than 30 seconds, dedicated to the demonstration of the mini game's objectives. This introduction was designed to draw the child's attention into each mini game. It acts as an instructor for the mini game to prevent the child being clueless about the mini-game. It will narrate dialogue and briefly explain the mini game objective. Furthermore, it will run animations to explain something abstract; for example, how to use the balloon maker to inflate a balloon. This module enables *Mini game Manager* to allow the child to play the game after the introduction finished.

13.2.2. Mini game Manager

Mini game Manager manages each mini game's rules. It was the core module that calculates the child scores in each mini game. This module also controls how Time Timer would show and keep counting down the allocated time for the mini game.

It also had an idle checker to detect whether the child does nothing for a specific period of time, which the psychologist can define, such as 20 seconds. The idle checker will control Timo to repeat what was the mini game's objective to the child.

In addition, it has sub functions controlling how the distractors should be played in its scene. This includes how distractors should move, and emit sounds. It gets the time related data of when the distractors should be played from *the Data Manager*.

In case that the time would nearly run out in the mini game, this module would do three things:

1) Wrapping up by Timo by telling the child that the time was running out.
2) Prepare the child for the next mini game by instigating a fail-proof mechanism that clears the left-over tasks of the mini-game's objectives.
3) Enable *Mini game Ending*.

13.2.3. Mini game Ending

This module would be called when the child had finished the mini game, or when the time in each mini game has run out, according to which event comes first. The *Mini game Ending* was created to smoothly end each mini game while the scene did not change. Timo would tell the child about another star received. It acts as a middle man/mechanism before enabling *Transition Manager*.

13.2.4. Transition Manager

Regarding the requirement '*DI09 The game should preserve continuity when changing between each mini game*', Transition Manager was created to smoothly change the scene in 3-dimensions from current mini game to the next. This includes changing the mini game's scene, by simulating the view of walking from the current mini game to the next mini game scene across the terrain of the game world in first-person perspective. This manager also displays the map of the game world when the changing of mini game's scene occurs outside the house of the child. The child might see the current location and where the next location in the game world is. The Transition manager would trigger the global *GamePlay Manager* to load another mini game scene after the child reached the destination.

13.2.5. File Manager

Prepare and write logging data to the files. This module provided the other managers a global share point for registered and store logging data. It would periodically make a copy of the logging data, flush the shared space, and write the copied data into files in a settable time manner. For more details please find ‘*DI10 The game must be able to record user interactions.*’ on page 166.

13.2.6. Data Manager

Connect to SQLite database to access the Go/No-Go signals for the monkey mini game, and sequence of spawning stars of the magic land mini game. Read configuration files and keep the data in the memory for latterly be used by others managers.

13.2.7. GamePlay Manager

Regarding the requirement ‘*DI02 The game must be able to test more than one time aspect*’, *GamePlay Manager* was created to easier control what mini game to load next. This module was also responsible for the bedroom selection, depending on the child’s selected gender, and controls the playing of background music.

It provides an order of which mini game to be played next that can be changed. This module was designed for the case that if we implement this game further to the point that we enable the child to move freely by itself and be able to select the next mini game in later versions. We could just remove the Transition Manager, add a checker for which mini game the child has selected, and have to minimally modify the rest to make all modules works as they were.

13.3. Overall game architecture

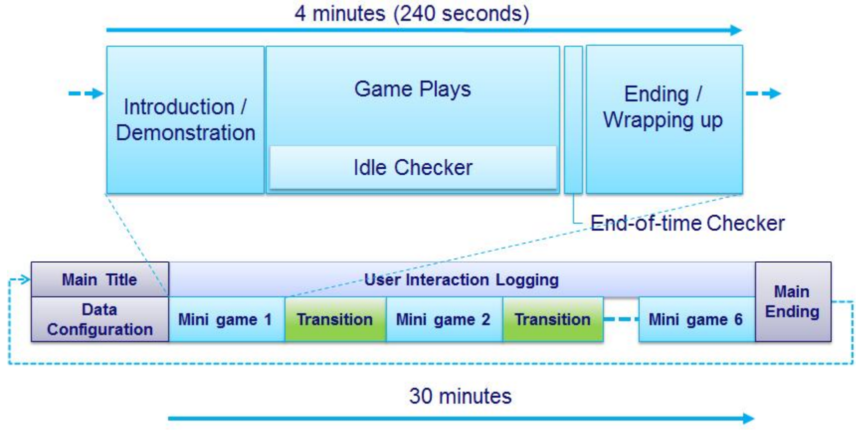


Figure 73 Overall game architecture

In overall, there was a main title screen, which waited for an interaction from a psychologist to start the game (see Figure 1). Here was the first attraction for the child to see and encourage a desire in the child play the game. The title screen consists of many mini game aspects of the child to see and guess what could be inside. We believed that foreshadowing by showing parts of the later game does increase curiosity and leads to more engagement (Wouters, van Oostendorp, Boonekamp, & van der Spek, 2011). Each mini game would be revealed in a linear format, so the child did not have any choice for selection of the order of playing each mini game.

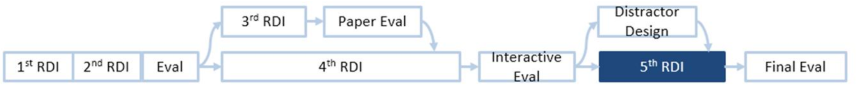
In the title screen, the game would configure its own required data and prepare every mechanism for getting data, in order to secure the smoothness of game play. It reads the data for distractors and makes a logging file ready for the storing of log data.

After the child finished all six mini games, we have the final ending waiting for the child. This ending was designed to sum up for the child that the game would be ending soon. It was the last stage before we bring the child back to the title screen.

13.4. Discussion on our game architecture

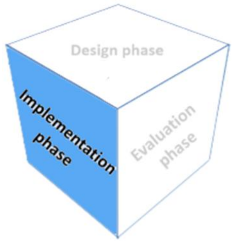
Singleton was the ideal choice for developing a game that did not have so much complexity. A game where one person can understand every aspect of its architecture, or was developed by a small number of developers.

Designing the architecture to be similar for all mini game, made it possible for some of the modules to be reusable. This saved us from writing multiple codes for each mini game. The difference and specific module for each mini game was its own manager, which needed to be coded differently to serve the mini game's purpose as a diagnostic tool. Implementing modules to be configurable empowered us to set different parameters, such as different winning conditions per mini game.



Chapter 14. Data logging mechanism

14.1. Introduction



The data logging mechanism was fully implemented in the fifth RDI to automatically log data into the text files while children play the game, to fulfill the requirement of a diagnostic tool. It provides more accurate timing than manually collecting data using a stopwatch. The log files were event based filled with quantitative data. These raw data had comments, and timestamps of events for human readability. The data could export into a mapping application to pre-post process into highly structured data. The processed data could be imported into the statistical application to analyze.

14.2. Data logging mechanism

The logging mechanism was quite straight forward. It was a singleton GameObject that was programmed to provide access from another GameObject. It would wait for messages from another GameObject, and it would be append-written into the corresponding files every five seconds—before the writing process, the logging mechanism would firstly make a copy of the current data where it would send to write into files, and it would clear all temporary data from its container for new events registering. Please find more details of the logging mechanism on page 232, (Appendix III: Data logging mechanism).

14.3. Structure in the log file

The log file was a chronological event based logging in tab separate value format (.tsv). It logged from the beginning that the child clicked on the start button until the child finished the game (or the game automatically moves itself to the end).

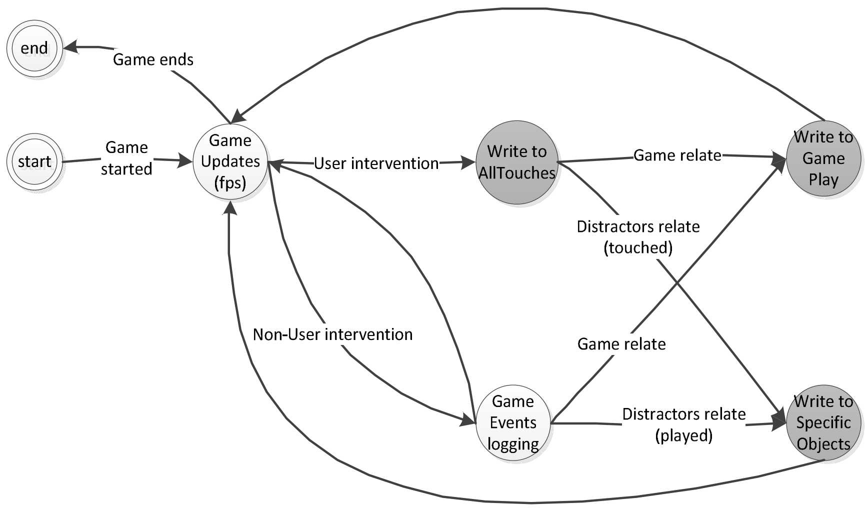


Figure 74 Data diagram of the game logging mechanism

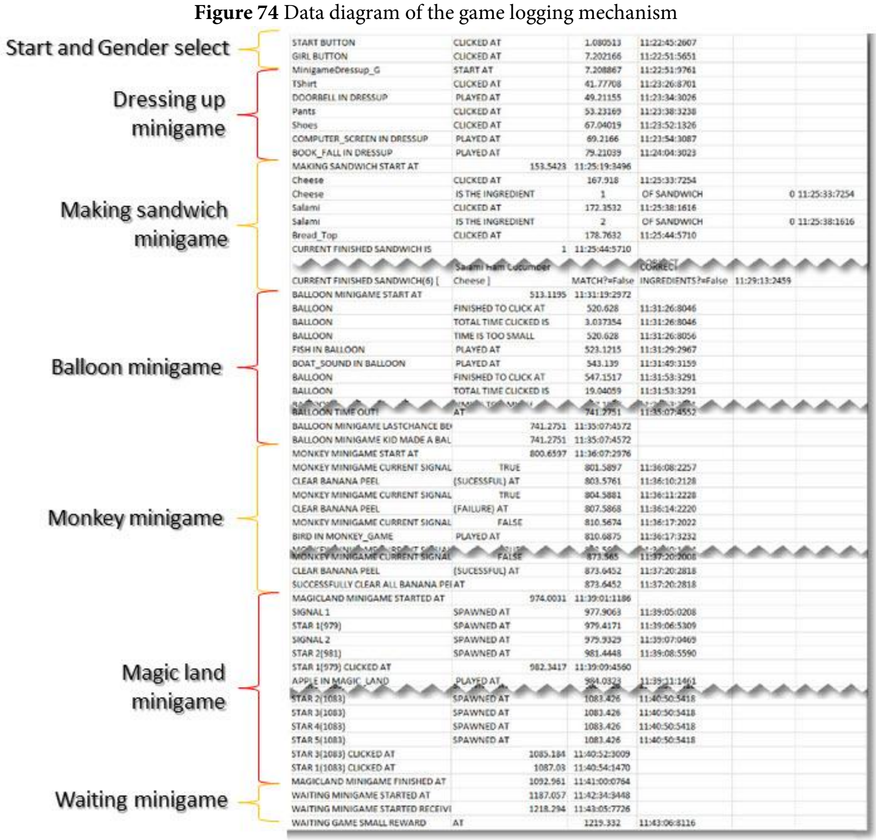


Figure 75 Structure in the game's log file

The game play log file could be divided into 7 parts. The first part was the two top most logs which were the time when the child started the game and when the child selected his/her gender. The six remaining parts were from each mini game.

14.4. Semi-automated data mining application

Logged data were written to three separate files ‘GamePlay’, ‘AllTouches’, and ‘SpecificObjects’ for different aspects of data. GamePlay kept all mouse clicks/touch events related to game play. AllTouches kept all mouse clicks/touch event occurring inside the game. And SpecificObjects kept all mouse clicks/touch event that interacted with game objects and distractors in the game.

For a single participant, psychologist could manually open and trace and select the data from those three log files. However, this practice was not recommend because human error could occur at any time. In addition, when the number of participants increased, a manual selection of data was no longer a practical choice.

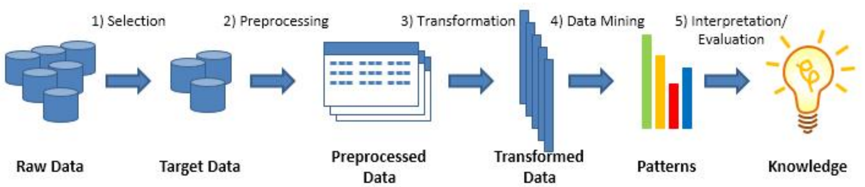
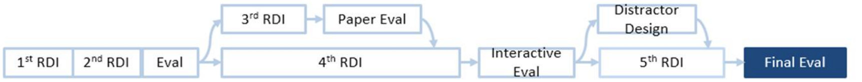


Figure 76 KDD process

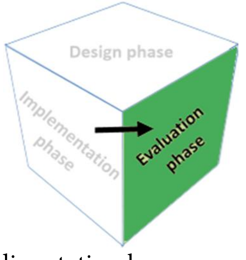
Semi-automated data mining applications would perform the first three basis steps of the Knowledge Discovery in Databases (KDD) process (Fayyad, Piatetsky-Shapiro, & Smyth, 1996), says Selection, Preprocessing, and Transformation, of log data and put it in an Excel file.

The selection of data worked from reading records from those three files and combining them into one dataset. Each record of logged data had timestamps, which make them sortable. The duplicated record, as well as the comment records intended to increase readability, would be filtered out from the sorted data. The application then processed this sorted data. All data of the six mini games were in this filtered data file. Since the mini games were played in linear fashion, the application would read from the first record to the last. If the read record contained keywords reflecting the mini game it belongs to, such as *‘BALLOON MINIGAME’*, *‘MONKEY MINIGAME’*, the application would distribute the record to a corresponding container. The next step was done automatically in the application by its writing method to transform this processed data into a more usable format and return the data back as Microsoft Excel file. This application provided accurate and timely savings of the manual selection of enormous quantitative data. Please find more details of the semi-automated data mining application on page 233.



Chapter 15. Evaluation

15.1. Introduction



The evaluations of the game with children from several schools were under the responsibility of Kempenhaeghe—the samples of children included the children in elementary school and children with mental disorders. Tests of Timo's Adventure were performed in conjunction with other diagnostic tasks. For this dissertation however, we will focus solely on the results of the game. We analyzed possible variables collected from the mini games in SPSS. Our game could be used to discriminate between normal children and children with ADHD. The classification results showed that overall 87.9% were correctly classified.

15.2. Participants

We filtered outliers out of the sample. These consisted of participants who did not finish the game, had impossible scores (such as waiting times longer than the maximum mini-game time, or clicking more than twice a second for the entire duration of the game). After this outlier removal, we had a Valid N of 118 children. There were 97 normal children and 21 children with ADHD. Of the participants in the no ADHD group, 48 were a girl and 49 a boy. Of the participants in the ADHD group, 7 were a girl and 14 were a boy. Eight children were confirmed with ADHD, eight children with ADHD that also had a comorbidity with Autism Spectrum Disorder (ASS), four children were assumed but not yet confirmed with ADHD, and one child with ADD (without hyperactive).

The mean age of children was lower for the children without ADHD (M = 5.96, SD = 1.346) than for children with ADHD (M = 7.05, SD = 0.740). The reason why the children with ADHD were older was because psychologists usually give a diagnosis for ADHD with the children above six years of age. Within this group, there were 10 children off-medication, and 11 children on-medication. Of the children on-medication, nine children had ADHD medication, one child had ADD medication, and one child had ASS medication.

15.3. Procedure

The tests were approved by the Medical Ethical Testing Committee of Kempenhaeghe and the Medical Ethical Testing Committee of Maastricht University. Each test had a code of conduct protocol which every examiner followed. The procedure was broadly as follows:

1. A small classroom was prepared for the test. Any clocks and posters on the wall were removed.
2. A child would be taken from class and directed to the experiment room.
3. The child received a short introduction, and was made sure it did not have to go to the toilet.
4. A verbal fluency test was administered.
5. Timo's Adventure was played
6. Miscellaneous other small tasks and tests were performed.
7. During the course of the test, the child would receive a lot of positive reinforcements and get a sticker for their effort afterwards.

15.4. Test of possible variables to measure ADHD

The selected variables we collected from all mini games, filtered the outliers out of the sample, and were analyzed in SPSS.

15.4.1. Dress up mini game

The dress scores of the sample were calculated and tested using independent samples T-tests (see score calculation formula on page 236). The result showed that there was no significant difference between groups (ADHD or no ADHD) in the dependent variable dress score $t(115) = 1.12, p > 0.05$.

The calculated dress scores of the sample were categorized into two groups, "Considered as dress normal" and "Considered as dress abnormal". The sample's dress score in groups was tested using an independent samples T-test. The results showed that there was no significant difference $t(31.19) = 1.71, p > 0.05$.

We also performed an independent samples T-test with the total number of clicks in this mini game. The result showed that there were equal variances among the two groups, and there was a borderline significant effect of ADHD on number of clicks $t(116) = -1.98$, $p = 0.05$, with the total number of clicks in the mini-game being lower for the non ADHD group (M = 21.72, SD = 21.60) than for the ADHD group (M = 32.48, SD = 26.70). In addition, the Cohen's d of this effect was $d = -0.44297$ and Pearson $r = 0.21624$.

15.4.2. Making sandwiches mini game

The total number of sandwiches that were made with the correct sequence was tested using an independent samples T-test. The result showed that there was no significant difference between groups in correctness of the sequence $t(25.41) = -1.59$, $p > 0.05$.

We did an independent samples T-test with the total number of sandwiches that were made with the correct ingredients, and the total number of clicks that were made during this mini game. The result showed that the total number of clicks during this mini game did not have equal variances (Levene's test $F = 41.97$, $p < 0.001$), and ADHD had a significant effect on the total number of clicks ($t(20.87) = -2.21$, $p < 0.38$), with participants in the non ADHD group clicking significantly fewer times in this mini game (M = 97.87, SD = 83.31) than the children with ADHD (M = 226.71, SD = 264.17). In addition, the Cohen's d of this effect was $d = -0.44297$ and Pearson $r = 0.21624$.

15.4.3. Cross the river mini game

The total number of made balloons was tested using an independent samples T-test. The result showed that there was no significant difference between groups $t(116) = -0.84$, $p > 0.05$.

We did an independent samples T-test on the total number of good balloon made. The result showed that the total number of good balloons made in this mini game did not have equal variances (Levene's test $F = 10.31$, $p < 0.01$), and ADHD had a significant effect on the total number of good balloon made ($t(49.28) = -3.41$, $p < 0.001$), with participants in the non ADHD group making a smaller number of good balloons in this mini game (M = 2.04, SD = 1.13) than the children with ADHD (M = 2.67, SD = 0.66). In addition, the Cohen's d of this effect was $d = -0.67796$ and Pearson $r = -0.32104$.

We did an independent samples T-test with the average time estimation. The result showed that the average time estimation in this mini game did not have equal variances (Levene's test $F = 5.71$, $p < 0.05$), and ADHD had a significant effect on the average time estimation ($t(87.27) = 2.65$, $p < 0.01$), with participants in the non ADHD group found to be waiting longer (overestimating the ten seconds) in this mini game (M = 11.05, SD = 4.28) than the children with ADHD (M = 9.58, SD = 1.59). In addition, the Cohen's d of this effect was $d = 0.45554$ and Pearson $r = 0.22209$.

15.4.4. Monkey mini game

The total number of clicks in this mini game was tested using an independent samples T-test. The result showed that there was no significant difference between groups $t(116) = -5.62$, $p > 0.05$.

The total number of bananas cleared during No-Go signals was tested using an independent samples T-test. The result showed that there was no significant difference between groups $t(20.87) = -1.18$, $p > 0.05$.

The time the child spent in this mini game was tested using an independent samples T-test. The result showed that there was no significant difference between groups $t(116) = 1.65$, $p > 0.05$.

15.4.5. Magic land mini game

We did an independent samples T-test on the average reaction time in this mini game. The result showed that the average reaction time in this mini game did not have equal variances (Levene's test $F = 17.85$, $p < 0.001$), and ADHD had a significant effect on the average reaction time ($t(86.87) = 5.43$, $p < 0.001$), with participants in the non ADHD group slower in average reaction time (M = 3.38, SD = 2.37) than the children with ADHD (M = 1.69, SD = 0.88). In addition, the Cohen's d of the effect was $d = 0.94627$ and Pearson$r = 0.42768$.

We did an independent samples T-test with the total number of stars caught in this mini game. The result showed that the total number of stars caught in this mini game did not have equal variances (Levene's test $F = 18.31$, $p < 0.001$), and ADHD had a significant effect on the total number of stars caught in this mini game ($t(77.23) = -6.51$, $\underline{p} < 0.001$), with participants in the non ADHD group caught less number of stars in this mini game (M = 31.73, SD = 14.20) than the children with ADHD (M = 44.33, SD = 5.88). In addition, the Cohen's *d* of the effect was *d* = -1.15927 and Pearson *r* = -0.50148.

15.4.6. Rocket mini game

The total time the child waited was tested using an independent samples T-test. The result showed that there was no significant difference between groups $t(114) = 0.31$, $p > 0.05$.

The total time the child waited was categorized into two groups, "Received a big reward, waited for two minutes or longer" and "Received a small reward, waited less than two minutes". The kind of reward was tested using an independent samples T-test. The result showed that there was no significant difference between groups $t(114) = -0.15$, $p > 0.05$.

15.5. Discriminant analysis

Unweighted Cases		N	Percent
Valid		107	92.2
Excluded	Missing or out-of-range group codes	0	.0
	At least one missing discriminating variable	9	7.8
	Both missing or out-of-range group codes and at least one missing discriminating variable	0	.0
	Total	9	7.8
Total		116	100.0

Table 3 Analysis Case Processing Summary

			Predicted Group Membership		
		ADHD	**No**	**Yes**	**Total**
Original	**Count**	No	84	2	86
		Yes	11	10	21
	%	No	97.7	2.3	100.0
		Yes	52.4	47.6	100.0

a. 87.9% of original grouped cases correctly classified.

Table 4 Classification Results[a]

A discriminant analysis was conducted to predict whether a child has symptoms of ADHD or not. The discriminate function revealed a significant association between groups and all predictors, accounting for 36.2% of between group variability; closer analysis of the structure matrix revealed three highly potential predictors, namely 'Number of clicks' (in the Making sandwiches mini game) (.493), 'Number of stars caught' (in the Magic land mini game) (.472), and 'Average reaction time' (in the Magic land mini game) (-.382). The classification results showed that overall 87.9% were correctly classified. The results showed that the children without ADHD were correctly classified as non-ADHD by 97.7%;

however, the children with ADHD were misclassified as non-ADHD (false negative) by 52.4%.

	t-test for Equality of Means						
						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Number of clicks in the 'Dress up mini game'	-1.981	116	.050	-10.754	5.428	-21.506	-.002
Number of clicks in the 'Making sandwiches mini game'	-2.211	20.869	.038	-128.848	58.263	-250.061	-7.635
Number of balloons that their estimated time were within acceptable range	-3.406	49.276	.001	-.625	.183	-.994	-.256
Average estimated time of balloons	2.645	87.274	.010	1.469	.555	.365	2.573
Average reaction time in the 'Magic land mini game'	5.428	86.870	.000	1.691	.311	1.072	2.311
Number of success caught stars in the 'Magic land mini game'	-6.512	77.226	.000	-12.604	1.935	-16.458	-8.750

Remark: The total number of children in each variable was slightly less than 118. They were excluded due to the missing values were found in those children

Table 5 Independent Samples Test

	ADHD	N	Mean	Std. Deviation	Std. Error Mean	Cohen's *d*	*r*
Number of clicks in the 'Dress up mini game'	No	97	21.721	21.591	2.19231	-0.442	-0.216
	Yes	21	32.476	26.695	5.82549		
Number of clicks in the 'Making sandwiches mini game'	No	97	97.866	83.312	8.45913	-0.657	-0.312
	Yes	21	226.714	264.169	57.64655		
Number of balloons that their estimated time were within acceptable range	No	97	2.041	1.126	.11438	-0.677	-0.321
	Yes	21	2.666	.658	.14365		
Average estimated time of balloons	No	97	11.053	4.276	.434200	0.455	0.222
	Yes	21	9.584	1.588	.346547		
Average reaction time in the 'Magic land mini game'	No	94	3.383	2.367	.244193	0.946	0.427
	Yes	21	1.691	.887	.193745		
Number of success caught stars in the 'Magic land mini game'	No	96	31.730	14.203	1.450	-1.159	-0.501
	Yes	21	44.330	5.877	1.282		

Remark: The total number of children in each variable was slightly less than 118. They were excluded due to the missing values were found in those children.

Table 6 Group Statistics

PART IV Reflection

Chapter 16. Conclusions and reflections

Psychological assessment tools by computers have not been used often. They are mostly paper and pencil tests. At this moment, health professionals could collect information about different forms of attention and executive functioning, and important data on time perception, which is an important problem in children with ADHD, using Timo's Adventure. To our knowledge "Timo's Adventure" is the first computer application that was designed for the diagnosis of ADHD by primarily targeting time perception. The game was developed furthermore to answer our main research question:

"How to design a game as a diagnosis supporting tool to collect data on time related aspects for children with ADHD?"

This research question could be answered with three different aspects that integrated together: the diagnostic capability, the design and the implementation of Timo's Adventure. Here, we reflect on the diagnosis, as well as on the game design and development. Furthermore, there are suggestions for future improvements of Timo's Adventure, and limitations reported of the research and the game.

16.1. Reflection on the diagnosis

Timo's Adventure satisfies its design purpose as a diagnostic tool since its classification results showed that 87.9% of children were correctly classified in overall (as children with or without ADHD)— it was not designed to be used exclusively to give the final judgment whether a child has ADHD or not. We tried comparing between the reliability of our findings with the NIMH Diagnostic Interview Schedule for Children Version IV (NIMH DISC-IV)(Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). Our reliability ($k = 0.54$) was found to be higher than DISC-IV's youth test-retest reliability in clinical samples for ADHD ($k= 0.42$). The reason could be that we used a computer game as the assessment, rather than interviewing the children. Playing a computer game may have reduced the awareness of children that they were being tested, which diminishes possible Hawthorne effects and removes observer expectancy effects. Moreover, our age group was four-to-seven years old while DISC-IV was nine-to-17 years old. As ADHD is more difficult to diagnose in younger children, this could indicate superiority of using Timo's Adventure over interviewing children with the DISC-IV method.

In our state of the art research (section 2.7.3), we found one other game that was designed to assist ADHD diagnosis: 'Groundskeeper', however the design of this game was not based on time perception problems. Researchers testing Groundskeeper reported a 75-78% classification accuracy (Srivastava et al., 2012), which would indicate that our approach in Timo's Adventure leading to an 87.9% classification accuracy is superior. In addition, that game required expensive additional hardware (Sifteo Cubes) to run the game on, that are currently difficult to obtain. Another game, 'Supermarket game' (Santos, Bastos, Andrade, Revoredo, & Mattos, 2011) was not designed to test ADHD specifically, but used for it retroactively, this game reached an agreement Cohen's kappa of 0.42, which is lower than Timo's Adventure (k = 0.54). Therefore, to our knowledge, Timo's Adventure improves the state of the art.

In addition, in section 2.5.3, slower and more variable reaction times have been found to be a characteristic of ADHD (Gooch et al., 2012; Karalunas et al., 2013) but we found the interesting opposite outcome in the magic land mini game, where participants in the non ADHD group had slower on average reaction times than the children with ADHD. This could be an interesting avenue for future research.

To design a computer game for diagnostic purposes, it should be designed aiming specifically to collect some variables that could be used in the diagnostic processes. Timo's Adventure was designed targeting time perception. Six of the time related aspects were formulated and designed into six mini games (see Table 7-9). This enables the game to test more than one time aspect. Those mini games were:

1. The dress up mini game, designed to test planning (as parts of executive functions).
2. The making sandwiches mini game, designed to test working memory (as parts of executive functions).
3. The cross the river mini game, designed to test time production (as parts of timing and executive functions).
4. The monkey mini game, designed to test response inhibition (as parts of executive functions).
5. The magic land mini game, designed to test reaction time (as parts of executive functions).

6. The rocket mini game, designed to test delay gratification (as parts of reward mechanisms).

Mini game	Description	Neuropsychological construct	Variables	Min/Max score	Pathway
Dress up	Choose garments that are necessary to get dressed	Planning	Total score: 1 point for completely dressed, 1 point for correct sequence	0-2	Executive Functions
			Number of clicks used in the task	minimum for a satisfying result is 4 clicks	Executive Functions
			Used time	minimum is 84 seconds	Executive Functions
Making Sandwiches	Remember the visually presented ingredients to make sandwiches	Working memory	Number of correct sandwiches	0-5	Executive Functions
			Number of clicks used in the task	minimum for 5 correct sandwiches is 22	Executive Functions
			Used time	minimum for 5 correct sandwiches is 88 seconds	Executive Functions

Table 7 An overview of all mini games and variables in Timo's Adventure (Peijnenborgh et. al, n.d.) [10]

[10]Peijnenborgh et. al, "The development of a diagnostic game for ADHD-symptoms in children: An exploratory study in 92 normally developing children and 24 children with ADHD" (manuscript submitted)

Mini game	Description	Neuropsychological construct	Variables	Min/Max score	Pathway
Cross the river	Inflate balloons by producing intervals of 10 seconds. A correct balloon has a produced interval between 9 and 11 seconds. The tasks ends after 3 correct balloons or after three minutes	Time production	Number of attempts	minimum is 3	Timing
			Average time used for each balloon	0-25 seconds	Timing
			Number of clicks used in the task	minimum for 3 correct balloons is 6 clicks	Executive Functions
			Used time	minimum for 3 correct balloons is 38 seconds	Executive Functions
Monkey	Remove the bananas, but only when the monkey is hidden behind the tree	Inhibition	Total number of inhibition mistakes. The closer to 0, the lesser mistakes.	0-15	Executive Functions
			Number of clicks used in the task	minimum to complete the task is 6 clicks	Executive Functions
			Used time	minimum is 11 seconds	Executive Functions

Table 8 An overview of all mini games and variables in Timo's Adventure (Peijnenborgh et. al, n.d.)[11] (Cont.)

[11]Peijnenborgh et. al, "The development of a diagnostic game for ADHD-symptoms in children: An exploratory study in 92 normally developing children and 24 children with ADHD" (manuscript submitted)

Mini game	Description	Neuropsychological construct	Variables	Min/Max score	Pathway
Magic land	Catch the stars as quickly as possible. Each star is preceded by a visual signal	Reaction time	Number of collected stars	0-50	Executive Functions
			Average reaction time for collected stars	1-4 seconds	Executive Functions
			Number of clicks used in the task	maximum to complete the task perfect is 50 clicks	Executive Functions
Rocket	Wait until the fueling of the rocket is finished to make a flight in the rocket (large reward), or end the task at any moment (small reward). The task ends after two minutes	Delay gratification	Small (=0) or large (=1) reward	0-1	Reward Mechanisms
			Time waited	0-120 seconds	Reward Mechanisms

Table 9 An overview of all mini games and variables in Timo's Adventure (Peijnenborgh et. al, n.d.)[12] (Cont.)

16.1.1. Discussion on Timo's Adventure

Timo's Adventure could be the first computer game designed specifically to test time related aspects for children with ADHD, but it was not the first computer game designed for children with ADHD. We already mentioned 'Groundskeeper', but this ran on specific hardware (tangible cubes). There were two fully screen-based computer games developed that could diagnose ADHD that we selected for the discussion of the novelty of Timo's Adventure.

The Supermarket Game

The Supermarket Game is an adaptive intelligent computer game for Attention Deficit/Hyperactivity Disorder Diagnosis (Andrade et al., 2006). This game was created targeting the detection of Dysexecutive Syndrome (DES) of children with, among others, ADHD. DES was

[12]Peijnenborgh et. al, "The development of a diagnostic game for ADHD-symptoms in children: An exploratory study in 92 normally developing children and 24 children with ADHD" (manuscript submitted)

introduced by Alan Baddeley (Baddeley & Wilson, 1988), the term was used to describe a common pattern of dysfunction in executive functions, such as planning, abstract thinking, flexibility and behavioural control. Children with ADHD who have DES could have a problem in planning.

Figure 77 Screenshot of The Supermarket Game (Andrade et al., 2006)

The game evaluated planning capability and the execution capability of the children with ADHD within a 2D labyrinthine supermarket, by letting children determine the best path to follow, in order to purchase all listed items in the shortest time. The game was played using arrow keys on the keyboard to navigate in the supermarket.

Braingame Brian

Braingame Brian is a cognitive training program (Prins et al., 2013), it was developed based on the assumption that, by repeatedly performing working memory tasks, participants themselves would elaborate on the different strategies that could improve their performance (Prins et al., 2013). Children with ADHD should be trained with Braingame Brian in a total of 25 sessions over a period of five weeks. It has a storyline about 'Brian' who is the main character of Braingame Brian. He could power up, and create inventions to help people in his village, resulting in happier village people. This storyline might be motivating to children with ADHD. Embedded in a game world (see Figure 78), it would train three executive functions in a fixed order: visuospatial working memory, inhibition, and cognitive flexibility (Prins, Dovis, Ponsioen, Brink, & van der Oord, 2011).

Figure 78 Screenshot of Braingame Brian (Prins et al., 2013)

Working memory training in Braingame Brian was a rectangles game. Rectangles would light up in a random sequence and children might reproduce the sequence by clicking the rectangles that had lit up in the requested sequence with the computer mouse. Inhibition training in Braingame Brian was using the Stop Signal Reaction Time in a lights up game. Children have to hit ‘Q’ or ‘P’ in a time between 700-1000 ms, depending on the side of light that was up, and stop hitting if the machine turned red. Cognitive flexibility training in Braingame Brian was a sorting game. Children had to sort various objects either by color or by shape according to the given instruction.

Timo’s Adventure

Timo’s Adventure and the Supermarket game: Timo’s Adventure was designed to support diagnosis, similar to the Supermarket game. Although our game was different than the Supermarket game because it displayed three dimensional graphics, one of the similar targets was that both of the games targeted planning, as part of our executive functions. Timo’s Adventure could not adapt to children performances as the Supermarket game could.

Timo’s Adventure and Braingame Brian: the purpose of Braingame Brian was to train three executive functions in children with ADHD, which differed from Timo’s Adventure. Both of the games were displayed in a 3D game world, but Braingame Brian switched its display between the first-person perspective and third-person perspective. Braingame Brian allowed children to walk around freely in the game world, but we could not allow that because we wanted to control the consistency of time spent both in each mini games and in the diagnostic session. For each child, Braingame Brian could be played a multiple number of times, but Timo's Adventure should be played only once.

Timo's Adventure was designed for the diagnosis of ADHD, with more diagnosis variables specifically aimed at ADHD than the Supermarket game. The storyline was more involved, possibly creating more immersion into the game's fantasy world, and subsequently decreasing the possibility of Hawthorne effects. Timo's Adventure was displayed in the 3D game world as Braingame Brian, both games also have their own storyline. The difficulty of Timo's Adventure mini games could not be adapted to the child performances, and the number of time the child could use Timo's Adventure was limited to a single play-through. This reflects the different purpose of the games; Timo's Adventure was a game designed to test ADHD, whereas Braingame Brian was designed to train coping with ADHD.

16.1.2. Benefits of Timo's Adventure

Assessment with fun

Games enable both clinicians and children simple and fun activities (Friedberg, Crosby, Friedberg, Rutter, & Knight, 1999). We turned tasks that could be quite dull for youngsters, into something more fun and playful. Timo's Adventure satisfies some advancements of the state of the art, that it could be especially useful to pretest children e.g. on school without the parents present. Detected children could then be earmarked for a real diagnosis for ADHD. In less than an hour, psychologists could set up and conduct the test, and gain information that may help the clinician in the diagnostic process while children would perceive those tasks as fun activities.

Children would not experience too much fatigue

The game would be used as a tool in the diagnostic process for children with ADHD, who are sensitive to the effects of fatigue. Therefore, it has been designed not to cause too much fatigue for children. No mini game lasts more than five minutes including the introduction and ending, and it will take no more than 30 minutes overall. We implemented a time-checking mechanism in each mini game that triggered an ending cutscene if time ran out.

User interactions were recorded

User interactions during game play were automatically recorded by the game. We designed and implemented this functionality before the start of the interactive prototype implementation. As a rule of thumb, we collected all possible variables we could collect, and what we thought would be useful for the diagnosis.

Psychologists can modify and try out other game parameters

We enabled the game to be customizable so that psychologists could modify game parameters without any technical expert intervention. Documentation about the detailed instruction and explanation to do so was communicated. Psychologists can change values in the specific property files using a plain text editor. The file could be modified once and reused.

Full of configurable distractors

Our game has many distractors that psychologists could configure. The effect of distractors in our computer game was another topic we were interested in. The distractors we designed were based on three rules:

1) They would not interfere with the gameplay of the child, they would not block the child's view or cause the gameplay to halt because of their appearance.
2) They would not act violently in the game.
3) No singular distractors could switch its role in the game; consistency of distractor categories must be preserved. To prevent confusions, the auditory distractors would not have an appearance, the visual distractors would not cause a sound for the entire session of the game.

16.2. Reflection on the game design

There is no pre-defined rule about how to design a computer game for diagnostic purposes. Using our work as a case study, this section describes our lessons learnt while designing Timo's Adventure, which could be adapted for designing computer games for children.

16.2.1. Design to be children friendly

The game we created was children friendly in four aspects:

1) It has a friendly look and feel because all the models in the game have been colored in cartoon style and a rounded look (with as minimum polygons needed as possible).

2) It is a violence-free computer game. Violence is the most common concern from parents when applying a gaming context for children (Dill & Dill, 1998; Walsh, 2001). There was no blood or gore, weapons, or animals hurt in the entire game.

3) It has a friendly graphical user interface and user interaction. The graphical user interface in the game was simple and consistent for all mini games. This consistency prevented the game from confusing the child. User interaction was limited to only click and touch—in case of using the game with a touch screen.

4) It has friendly sounds and background music, which the psychologists approved as suitable for children.

16.2.2. Design towards play

All mini games were designed aiming to induce play, and to convince children that they were playing instead of being tested. Interestingly, from the interactive prototype evaluation feedback, none of the children mentioned that our game was a test, but they seemed to believe that this was a game at first glance. The only thing we cannot design and control was to ensure that the child would have fun when playing our game. Individual differences play a major role here, where one child might like playing computer game but another might not. Therefore, if a child got bored during the play, he might think that this was a test for him.

16.2.3. Preservation of continuity and engagement

The continuity and engagement of children while changing between mini game scenes should be preserved. Therefore, we implemented a smooth transition between mini game scenes in a 3D environment for this specific purpose. The child engagement would not be disturbed or broken.

16.2.4. This game has no failure state

Different than most games, where a player may fail for not obtaining enough points or overcoming an obstacle, each of our mini game would always lead to success for the child, regardless of the child's performance. However, because this was a diagnostic game, the time that the child could spend in each mini game had to be restricted, and we did not allow the child to play the same mini game over again.

16.2.5. Dress up mini game

This mini game was designed around daily routines to test the planning skill of the child. We designed and implemented our game differently from the dress up game we found online. The games we found displayed the game environment in 2D. We designed the game to be displayed in 3D. One of the benefits of designing the game in 3D was 'depth'. We got a 'Z' dimension in addition to 'X', and 'Y' and we could utilize this added dimension. The games we found separately displayed the dress items and the avatar. On the other hand, we placed dress items to be part of the environment of the game (see Figure 79). Integrating dress items in the game's scene utilized the added value of the 'Z' dimension. This could in turn give a better user experience as more presence is usually experienced in a 3D environment (McMahan, 2003). This first mini game's view could lead player toward more engagement with the later mini games.

Figure 79 We utilized 3D environment for dress items placement

Consistency of user interaction had been preserved; a single click or touch on the dress item was the only user interaction in the dress up mini game. After the child selected a dress item in the bedroom, the item would fly downward to the bottom of the screen, and then the avatar in the mirror would get dress.

16.2.6. Making sandwiches mini game

Figure 80 Children should rely on their working memory in making sandwiches mini game

This mini game was again designed around daily routines in order to test the working memory of the child. Our making sandwiches mini game was different from cooking games found online not because it was displayed in a 3D environment, but other cooking games usually keep showing the list of ingredients for the player for all time. Our game on the other hand, hid the list of ingredients after five seconds in order to test working memory (see Figure 80).

The player had to rely on its working memory to remember the list of ingredients and subsequently make a correct selection of ingredients, both the ingredients themselves as their order.

Our mini game would not adapt its difficulty to match the performance of player. Every player would have the same level of difficulty. And the player could not undo the selection actions in case mistakes had been made.

16.2.7. Cross the river mini game

This mini game was designed to test time production of the child by requiring the child to estimate the duration of 10 seconds. The idea of this mini game was to test how well the child could count from one to ten. The easiest intervention could be that the child presses the space bar once and presses again when he thinks ten seconds passed. We used this simple idea and woven it into game story.

The remote did not intuitively link to the balloon maker however, so we implemented that the combined distractor would fetch the remote and give it to the child. The child might have no idea about the relationship between the remote and the balloon maker setting and formulate the questions 'what', 'why' and 'how' in his mind. Therefore, Timo would answer those questions on what, why and demonstrate how to use the balloon maker in an introduction of this mini game. The design of this mini game was the 'local maximum' solution we could find.

16.2.8. Monkey mini game

This mini game was designed to the test response inhibition of the child. The Go/No-Go in this mini game was mnemonically 'encoded' in the monkey. Mnemonic strategy is used to make a better relation between a new word and its meaning in learning (Lafayette, 1989; Scruggs, Mastropieri, Berkeley, & Marshak, 2010). We used mnemonic strategy by transforming 'Go' and 'No-Go' into visual sign represented by the monkey. Although our game was not designed for training or learning purposes, it would be possible to develop this game further for training. The mnemonic messages in this mini game were:

- Monkey might be perceived as naughty and less likely to stand still. It could be closely related to a child with hyperactivity.
- The monkey blocking the pathway represented the 'No-Go' signal (see Figure 81 A).
- The hidden monkey behind the banana tree represented the 'Go' signal (see Figure 81 B). We designed the monkey to hide behind the banana tree instead of running outside the view of children, because this reduced the time to switch between signals (see Figure 81 C).

Figure 81 Mnemonic of signal as the monkey
(A) 'No-Go' represented with 'blocking' by monkey
(B,C) 'Go' represented with monkey hidden behind banana tree

We found that the children liked the monkey, and they said that this mini game was the most fun game in Timo's Adventure.

16.2.9. Magic land mini game

Figure 82 Magic land mini game was a violence-free version of 'whack-a-mole'

This mini game was designed to the test the reaction time of the child. Our test of reaction time was not a simple reaction time, but was closely related to warned reaction time (Sinclair & Hammond, 2008). There was a visual signal shown at the geyser where the star would appear (see Figure 82).

Our making magic land mini game was different than other 'whack-a-mole' games because we designed to eradicate violence from our game. Violence within games crucially affects the acceptability of games in general (Anderson & Bushman, 2001; Gentile & Anderson, 2003; Walsh, 2001). Although the violent content in computer games was not the only factor that induced aggression in the computer game player, background hostility of player and time exposure to violence in computer game were correlated too (Gentile & Anderson, 2003), eliminating violence from the game could guarantee that the game was more child (and parent) friendly.

16.2.10. Rocket mini game

This mini game was designed to the test delay gratification of the child. We created a game version based on the study of delayed gratification of Stanford University in 1970s—also known as the marshmallow experiment (Mischel et al., 1972). We gave the child two choices, a small reward as Timo's brought the child home immediately and thanked the child, or a big reward as the child made a flight in the rocket over the game world before Timo brought the child home and thanked the child.

We found it was difficult to simulate the marshmallow experiment (MX) in our game. Because in MX a marshmallow was the real-world object given to the child. A real-world object has more influences than the intangible digital version. The experiment by Marx and colleagues (Marx et al., 2011) studied the influence of both reward and penalty on delayed decisions in children with ADHD. Marx used 'chips' as a real-world object in his experiment, children knew that they could exchange chips to watch a video (reward) or to write an essay (penalty).

Another difference of our game and MX was the time after which the small reward was given. In MX, a small reward was given upfront, also in Marx's experiment chips were given when the child successfully waited, and could be exchanged later. In our mini game, no 'tangible' reward was given.

It could be that the presented mini game story was not clear for the child. The child would not know what reward had been given. Digital rewards have only limited modalities, i.e. can only be seen and heard, not touched, smelled, or eaten. This may be too limited a reward for waiting two minutes. The child may also have had no clear idea of the reward he was waiting for. Lastly, this mini game may have been a social exclusion or a 'time out' for him (Wolf, McLaughlin, & Williams, 2006), and this could have led to his decision to end this mini game. The bottom line could be that our game was unsuccessful to resemble the marshmallow experiment.

16.3. Reflection on game development

To develop a computer game for diagnostic purposes, game development could be done taking many approaches. Using our work as a case study, this section describes our lessons learnt while creating Timo's Adventure, which could be adaptable for other game developers.

16.3.1. The power of participatory design

Participatory design was an approach where the designer involves users in the design process. This increases the chance for acceptance of the outcome by users, because the outcome is more usable and fulfills their needs and requirements.

In the early stage of this design process, skillful users might not have a concrete image of what would be the final 'product'. Therefore, it was the responsibility of the designer to explain and bring users into the design. This took several iterations, and in order to speed up, the designer used design methods such as paper prototype and rapid prototype to create a loosely imaginable outcome for the user. After the user perceived what is possible and what is impossible, the designer can expect higher quality input and more functional requirements from the users.

We involved users in the design process combined with a user-centered design; users are taken as centers to which the design must be adapted to, and this is done by heavily consulting with the users. Users are allowed to propose changes or have input on the design, while the more specialized person did the features and system implementation (Iivari, Isomäki, & Pekkola, 2010).

For example, after we designed the game story and its user interaction, a question arose whether the children between four to seven years old could easily understand our designs. The only way to answer this question was to ask children. Therefore, evaluations of the game with children with the paper prototype and the interactive prototype were conducted. We evaluated the game story and its interaction to increase our confidence that our game was easy to understand for the target age children. All the children we tested our prototype with liked our designs and most of them understood how to interact with the game.

16.3.2. Changes of users' requirements

It was sometimes difficult for the users to understand or be aware of what could be the problem in the development process when they changed their requirements. There is no way to prevent this from happening, but it is important to find a way to stabilize the user requirements. Many software development techniques could be applied to make requirements more stable such as 'Prototype', 'Rapid Application Development', and 'Joint Application Design' (Jones, 1996). Moreover, game designers could apply 'future analysis' techniques (Land, 1982), in that game (software) should be designed providing a 'vision' or 'prediction' of what the result would look like or that could be requested by the user in the future. However, it cannot guarantee that the designs would fit in the future needs. Therefore, the team needed to bring the former requirement into discussion before making a decision. Documentation was required for every iteration step and this was the first thing to look back into when the users changed their mind.

The reason that users change their former ideas and requirements could not be labeled as faulty. In fact, this means that the users can grasp the ideas of the current design, and that they are more engaged in the participatory design, and willing to offer help and suggestions on what was currently being implemented. It was a good sign that participatory design works. We listened to the reason why requirements should be changed as requested by the users— user centered design comes into this decision process. If the users suggested with a plausible explanation of reasons that the former design was not functional and changes were required, then the former design was mandatory to be changed.

The solution was not to change every single bit in the development process, but to change only what was needed. A modular object-oriented paradigm was used (Korson & McGregor, 1990). The game was integrated from smaller objects, each object should be able to stand on its own with little dependency to other objects. With this paradigm, we can introduce new user requirements while maintain the old. It was found to be easier to add new functionalities rather than re-design the old system and re-build. It was like creating a scaffolding of the building and adding more functionality into it.

16.3.3. Iterative development process

An incremental software development approach, which was an application of the cyclic software process, was used. Our approach was closely related to the SCRUM in Agile methodology (Martin, 2003; Rising & Janoff, 2000). This development process was robust for big changes during the development. Especially when the final product was still undefined and changed during development. The iterative software development model hastened the development of the game. However, we found some lessons learnt from the process:

- We sometimes lost focus of the goal of the game, because it was unclear on what would really be the ‘thing’ we wanted. In addition, there were frequent changes throughout the processes. Documentation was needed in every meeting with which we could refer to when there was anything seemingly going off track.

- Knowledge transfer to new group members might be another challenge. In the iterative process a team member was free to express ideas based on experience with the previous iterations, however a new member could have an unclear idea on what was the history and goal of the project.
- Because of the difficulty of creating a high quality game, the development process needs someone who is heavily experienced in software. Because that person should be able to make a decision, give a feasible time estimation for the development, and give advice on any possible limitations. Someone less experienced is at risk of saying yes to the users too eagerly.
- Evaluation must be done concurrently with the implementation in the early phase. We needed the feedback from the evaluation to validate the correctness of the game design, and to improve the game in case that some of the former design choices did not fulfill the requirements. And data analysis was recommended to be conducted as early as possible to give us feedback whether the data structure was in the right form to import into statistics software or not. This would give us more time to make changes if something was off-track. This however led to problems because the design changed over time and the children used for the usability test could no longer be used for the diagnosis evaluation.

16.4. Future improvements

There were many functionalities that could be added into the project. The game was found to be able to correctly predict whether the child has ADHD or not by 87.9%, but it could still be further improved.

16.4.1. Voice of Timo

We wanted every child to easily understand the game, therefore we implemented the introduction part in the beginning of each mini game. This introduction part came from the evaluation of the interactive prototype. At the time we evaluated the game using the interactive prototype, the psychologists served as the narrator and the instructor for the younger child. This could not be a feasible solution because we needed every child to have the same introduction. Therefore, the game should get instructions from Timo—the robot. Verbal communication was the only medium we could use in the game because the younger children are not yet fluent enough to read. Due to the economical reasons, we used a recording voice from free text-to-speech web-application we found on the internet. The clearness and correctness in the pronunciation and stress of the voices were usable, but far from perfect. However, Timo is indeed a robot so the voice from the text-to-speech conversion fitted into this context. Therefore, we agreed to use the voices from text-to-speech instead of real human voices in the game.

In case that we implement this game further as a training tool, a voice of a human would be more suitable. The clearness and correctness of a real human's voice is needed to convey messages to the child in the training tool.

16.4.2. Dress up mini game

The dress scores of the sample were calculated and tested using independent samples T-tests and the result showed that there was no significant difference between groups (ADHD or no ADHD) on the dress score. But the result of total number of clicks in this mini game showed a borderline significant effect of ADHD, with the total number of clicks in the mini-game being lower for the non ADHD group than for the ADHD group. Perhaps the child was trying to change the order of the selected dress items, but the game would not allow the child to do so.

The child could not change the order of dress items in the current version of this mini game. The child could not undo his selection if he wanted to. The next version should enable the undo functionality. We might have more correct data reflecting on the child selection order. In addition, this undo button itself could be a valuable ADHD predictor. The child who undid less could score better than the one who undid more.

The undo functionality could be implemented with a wrong dress appearing on the mirror. For example, if the child picked 'T-shirt' before 'Under shirt', the reflection in the mirror should be shown that the under shirt was placed above the T-shirt. This could make the child notice the wrong order selected and motivate him to change the order.

Another feature that could be implemented for this mini game is the ability to 'drag' a dress item. The child could click and drag the dress item to itself in two directions: 1) to itself by dragging downward, or 2) to the avatar by dragging to the left of the screen. We could compare the performance of children, e.g. information about the direction preferences, and user interaction preferences between click only and drag interaction in the future.

16.4.3. Making sandwiches mini game

The total number of sandwiches that were made with the correct sequence was tested using an independent samples T-test. The result showed that there was no significant difference between the groups. Again the result of total number of clicks in this mini game showed that there was a significant effect of ADHD, with participants in the non ADHD group clicking significantly fewer times in this mini game than the children with ADHD. Therefore, a similar improvement as the dress mini game can be applied.

In this version, the child could not change his decision. The child had only one chance to choose the ingredients when making a sandwich. If the child made a mistake, there was no option to undo. Therefore, the child must remember, organize and plan ahead of what were the ingredients and what was the order of them. The next version could have an option for psychologists to set, and enable the child to undo the previous selected ingredients. In this case, impulsive type ADHD children might be less inclined to plan ahead and make more mistakes.

The implementation could be that when the child clicks an ingredient that was placed on the bread, it would move back to the ingredient plate. However, we should limit the child from being able to undo an action after the top-bread was placed, at this was used to finish the sandwich.

16.4.4. Monkey mini game

We discovered that many children told the psychologist that they love this mini game because it was easy. We expected that this mini game could not be able to distinguish well between children with a good response inhibition and poor counterparts. Statistical test results showed us that we were correct. The total number of clicks in this mini game, the total number of bananas cleared during No-Go signals, and the time the child spent in this mini game were tested using an independent samples T-test. It showed that there was no significant difference between groups in any of them. Our finding conformed to that of Bioulac (Bioulac et al., 2014), that children with ADHD presented no difference in inhibitory performances compared with control children when playing a video game.

In this current version, the monkey went peek-a-boo every three and six seconds. The next version of the mini game could be designed to make the time of this peek-a-boo adjustable. This will enable the monkey to more frequently block the child's action with a No-Go signal and at the same time reduce the number of go signals and make the game more challenging.

A penalty system when the child makes a mistake in this mini game can be added. Therefore, when the child clears/sweeps the banana peels during the No-Go signal, instead of only one banana being replaced by the monkey, there could be two banana peels falling down. Without a penalty, the child could spam clearing banana peels during the go signal, and if the monkey detects it, there is nothing he has to worry about. The penalty system could make the child more careful. This will make the mini game more challenging and the child will not focus only on clearing the banana peels during the Go signal, but to also avoid making any mistake in No-Go signal.

16.4.5. Magic land mini game

We did an independent samples T-test on the average reaction time, and the total number of stars caught in this mini game. The result showed that participants in the non ADHD group were slower in average reaction time than the children with ADHD. It also showed that participants in the non ADHD group caught fewer stars in this mini game than the children with ADHD. The statistical outcome was significant, but we could further improve this mini game.

In this version of the mini game, every star was spawned after the corresponding geyser spawned a signal. We planned and designed for the next version of this mini game to have two alterations.

1. A star does not always spawn after a signal. Sometime a geyser can spawn a signal, but this time no star will be spawned after the signal. This false alarm could serve as a salient visual distractor that draws the child's attention. Since there is not always a star that comes after the signal, the child cannot just rely on the signal.

2. A star can be spawned from a geyser without a signal. This makes an unpredictable gameplay for the child when a star will be spawned.

Another possible improvement is to implement the sequences of stars to be configurable. This would empower psychologists to create different scenarios for the test.

16.4.6. Rocket mini game

In line with the considerations stated in 16.2.4, the story of this mini game could be changed so it could give upfront the small reward to the child and let the child decide to wait for big reward. The story could be *"the child could fly on the rocket for a short distance then land back at the same place. Timo could explain that he thought that the rocket was fully refueled. If the child could wait until it is fully refueled, he would fly home on the rocket."* This would give the child the idea of reward he could be given.

16.4.7. Combine the game with an eye tracker

The current version of the game was not yet integrated with the eye tracker. Using eye tracking might yield behavioral data of a child while playing the game, which we could analyze together with the game play data. It could answer us whether the distractors were able to influence the child's performance during game play or not.

Our game can be extended even further by integrating with an eye tracker for more validity in the diagnosis. Tobii X2-60 eye tracker was bought to do the experiment in this circumstance.

"The Tobii X2-60 Eye Tracker is a (…) 60 Hz eye tracking research system. (…) Participants can behave naturally thanks to uniquely large freedom of head movement. The Tobii X2-60 Eye Tracker makes it possible to integrate eye tracking into numerous varieties of human behavior studies in psychology, usability and market research."—Tobii AB (public company).

In order to integrate the eye tracker with our game, it is crucial to get x-y coordinates of the player's gaze position in real-time. The mechanism of how to get the data can be derived from the basic example of the eye tracker application provided with Tobii Analytics Software Development Kit (Tobii SDK). The application demonstrated how to connect and get eye coordination from the eye tracker without relying on Tobii Studio—its application suite. The developer can choose four programming languages to develop the application.

	Windows XP, Vista, Win7 (32- and -64-bit)	**Ubuntu 12.04 LTS (32- and -64-bit)**	**Mac OS X 10.7**
.NET (C#)	Yes	No	No
Python 2.7	Yes	Yes	Yes
C++	Yes	Yes	Yes
MATLAB	Yes	No	Yes

Table 10 Supported platforms and programming languages

In the time of experimenting we used Unity3D version 4.3x, which did not support multi-threading. We found out that multi-threading was required for the eye tacking to operate normally. Therefore the architecture of this integration has to be altered to some extents

There was another requirement from the psychologists that the eye tracking application should be able to run on Windows 7 on a separate computer. Although our game was able to run on Windows 8 and utilize touch interaction, the Tobii Studio that came with the eye tracker was not fully supported in Windows 8 at the time of experimenting. Therefore the architecture of the application should make it possible to run the eye tracker and the game from different machines.

Instead of implementing the eye tracker application inside the Unity game engine, we designed the eye tracking application to run concurrently in a background process. We could deliver the data from the eye tracking application to the game engine by implementing the communication between the Unity game engine and Tobii eye tracking application using the .NET socket over TCP/IP. The data from the eye tracking application was delivered to the game engine per request. The eye tracking application was able to run dedicatedly from the game engine. It managed its own multi-thread, collected user's eye position, and waited for data acquisition from the game engine.

The resolution of the data was 60 frames per second—60 Hz. Therefore, there were 60 records every second. We found that sometimes the eye tracker could not detect the user's eye. This caused some missing data in the recording. To prevent this and make every record more consistent, we calculated the relative position of a user's eyes using the average value of the previous five frames. The eye tracking application would keep only the last 30 frames in the memory to prevent memory leak.

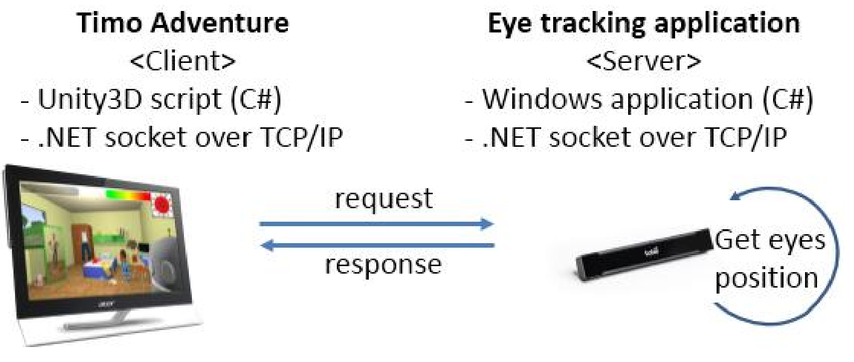


Figure 83 Communication architecture of the game and eye tracking application

In order to use the eye tracking with the next version of the game. The structure of logging data needs to be changed. Because in this game version, the logging data had been designed to write records *event-based*— it recorded only if something was triggered, or an event occurred in the game. When we are going to integrate with the data from the eye tracking application, it must be recorded *time-based*— that is all data collected and recorded on set intervals.

The integrated logging mechanism could be programmed to collect data at the maximum resolution of 60 records per second, or less resolution to save some disk space and processing time.

16.5. Limitations

16.5.1. Age of children

It was found that the age of the child plays a major role in his/her performance: the older the child, the better the performance. The age of the children with ADHD in our sample was slightly older than controls. A possible explanation for this is that attentional problems might be more pronounced and obstructive when academic demands are increasing. Therefore, the diagnosis of ADHD might occur more in older children, whereas in younger children an attitude of wait and see might be used.

16.5.2. Medication with ADHDs

Drugs are used to alleviate the symptoms of ADHD. They work by increasing the levels of brain chemicals called neurotransmitters which are messengers between nerve cells in the brain ("Managing Medication for Children and Adolescents with ADHD (WWK3)," 2004). With an effectiveness of about 70% to 80% for patients, these medicines help people with ADHD to focus their thoughts, ignore distractions, and be less hyperactive and impulsive. Medication is an integral part of the treatment (though not a cure) for ADHD, and it may only be prescribed by medical professional. Medication is used to suppress the symptoms of ADHD so the children with ADHD could function more effectively on a daily basis. Therefore, it is not something normal or non-diagnosed children would take.

Some of the children in our sample were using medication. In the next evaluation of the game, children who had already been diagnosed as having ADHD should be off-medication at least 24 hours before the test to eliminate the effect of medication. It should be done because of the following reasons: 1) We know that they have ADHD— so the reason was not to find whether they have ADHD or not, but 2) we involve them in the evaluation process just to check for our game's ability to discriminate between normal and children with ADHD. If the children with ADHD are on-medication, the medication they took will alleviate or diminish their symptoms and make them behave closely with the children without ADHD. As a result the game would not be able to clearly discriminate between children with ADHD and without ADHD because their performances would be similarly to those of the normal children.

Medications could increase the ability to focus and sustain their attention in children with ADHD, and sometimes make them out perform the controls (Parkin, 2015). This may have played a part in our classification results that the children without ADHD were correctly classified as non-

ADHD by 97.7%; however, the children with ADHD were miss classified as non-ADHD by 52.4%. In this case, our game could actually be better in classifying ADHD than current results indicate.

16.5.3. The unmet minimal requirements of the computer

We used timestamps in the log files to calculate the time used by children. The unusual timestamps in the log files caused strange times when calculated, resulting in outliers in the statistical analysis. We had to exclude nearly half of the sample as a consequence of this.

Since the game used in the testing process was the same, the difference would be the machine running the game. A possible cause of this problem was because some of the laptops used in the test had low clock speeds for their central processing unit (CPU) and they were lacking a discrete graphic processing unit. This made them unable to run every mechanism in our game as smooth as it should and caused unusual timestamps in the log files.

We did not know about this issue until we tested the game. Basically the game should be tested on as many other machines as possible[13]. Especially the low-end machines, because it's probably loaded with many software and other memory resident processes that will interfere with and slow down our game. Beta testing would be the optimum choice next time. The other future work could be the optimization on the current version of the game, and make it runnable in the machine with lower processing speed.

16.5.4. Were our distractors effective enough

Distractors could be set to be disabled or enabled in the game. However, all the tests enabled the displaying of distractors during gameplay. Therefore we did not have any data to compare for the differences whether our distractors had any effect on the children's performances while playing the game or not. And in which group of children were

[13] http://answers.unity3d.com/questions/711400/how-to-determine-hardware-requirements-for-game-ma.html
AND http://gamedev.stackexchange.com/questions/437/how-do-i-determine-my-games-minimum-hardware-software-requirements

affected more among children with and without ADHD, in case there was any effect.

Unfortunately we did not have enough time. Otherwise we could have more test samples of children playing the game with minimal distractors, such as only the friends of Timo, serving as a control. Future tests should be done to display distractors in only one category: visual only, sound only, and the combination of both. This could provide better insight into the effect of our distractors, and if there are any differences for each category.

16.5.5. Some distractors did not have a chance to be shown

Distractors in each mini game could be set for their time to be played by the psychologist. The child should see the distractor when the time reached that point. However, in case that the child did so well in the mini game he could finish the mini game before reaching the moment the distractors were set to play. As a result, the distractors would not be played because their time could not be reached. This could have factored into the results, e.g. that the children who had good performances at the mini games actually saw less distractors than the poor counterparts.

16.5.6. The game was not serious enough

Another limitation for the generalizability of the results from this game was that it neither has knowledge transfer, nor clear learning goals. Therefore, if a serious game needs to be educational related, this game will not fit at the moment. Implementing knowledge transfer mechanisms and rehabilitation would be a further improvement in this game, but at this moment this game is primarily intended for data acquisition. We applied gaming in the context of being used as a diagnostic tool, acting as an interactive medium from which a player receives immediate stimuli while playing, while a psychiatrist receives the data of the player's selected actions logged to text files. It is designed specifically for diagnostic purposes with multimodal interaction.

16.6. Conclusion

Timo’s Adventure was a computer game that has been designed to detect the symptoms of time perception problems especially in ADHD children. With merely an hour—including the post processing of log files, psychologists could have preliminary data of children for the ADHD diagnosis. Moreover, Timo's Adventure was easily distributable because the game was a single-player game, operated on a PC, and supported both mouse and touch screen. Furthermore, it strengthened children's engagement because, thanks to its looks and feel, it is perceived as a game rather than a test. More importantly, psychologists could have more accurate data due to the reduced Hawthorne effect and less experimenter bias.

Many challenges were confronted during the research through design and implementation and when the project was started, there were many options we could select. Designing and creating a computer game as a diagnosis supporting tool to measure time related aspects for children with mental disabilities required not only a passion but also a good collaboration between experts in different disciplines. With a collaborative and multi-disciplinary team of computer scientists and designers from Eindhoven University of Technology, as well as psychologists from Kempenhaeghe, center for neurological learning disabilities, we shared a common interest and drive to get the project done.

The classification results from the discriminant analysis showed that overall 87.9% of children were correctly classified as ADHD or non ADHD with our game, but there are still opportunities to improve the diagnostic validity. With a three year span of my PhD journey, it was a challenging but rewarding responsibility to be both coordinator and driver so that this project could reach its goal.

"Time is the greatest force that drives our life. We mortals are its prisoner; it alters our age little by little, grows us stronger, but takes all of our strength at last. Every second gets counted and no one could ever successfully escape."

—Pongpanote Gongsook

Appendix I: Game Engines Comparison

Comparison of free game development kits

	Cry ENGINE 3	**Source SDK**	**UDK**	**Unity3D**	**jMonkeyEngine 3**
Licensing					
Non-commercial use	Free of charge	Free of charge	Free of charge	Free of charge[1]	Free software (BSD)
Commercial use	20% royalty	Discussed under NDA	\$99 upfront + 25% royalty after \$50,000 sales	Free of charge[1]	Free - see above
Engine					
Platforms	Windows, PlayStation 3*, Xbox 360*	Windows, Xbox 360*	Windows, Mac OS X, iOS*	Windows, Mac OS X, Web, PlayStation 3*, Xbox 360*, iOS*, Android*	Windows, Mac OS X, Linux, Solaris
Primary programming language	C++, Lua	C++	UnrealScript	JavaScript, C#, Boo	Java
Graphics	DirectX 11	DirectX 9	DirectX 11	DirectX 9, OpenGL	OpenGL
Audio	FMOD	Miles	XAudio2	FMOD	OpenAL
Physics	CryENGINE 3 physics	VPhysics	PhysX	PhysX	jBullet, Native Bullet
Networking	CryNetwork,CryLobby	Source networking	Unreal networking	Unity networking	SpiderMonkey
User interface	Scaleform GFx	VGUI	Canvas,Scaleform GFx	UnityGUI	Nifty GUI

	Cry ENGINE 3	Source SDK	UDK	Unity3D	jMonkeyEngine 3
Model format	COLLADA	SMD, DMX	FBX	COLLADA, FBX, more...	OgreXML, .blend
Tools					
Level editor	Sandbox	Hammer	UnrealEd	Unity Editor	jMonkeyPlatform
Terrain editor	Terrain editor	Displacements	Terrain editor	Terrain engine	Terrain editor
Material editor	Material editor	VTFEdit	Material editor	Materials inspector	Material editor
Particle editor	Particle editor	Particle editor	Cascade	Particle systems	Scene composer
Audio editor	Audio system	API only	SoundCue	Audio source	API only
Vehicle editor	Vehicle editor	API only	Animation system	Animation system	Vehicle creator
Scene animation	Track view	API only	Matinee	Animation view	API only
Character animation	Character editor	Faceposer	Animation system	Animation system	API only
Visual scripting	Flow Graph	Entity I/O	Kismet	third-party extensions	none
Links					
Reddit	/r/cryengine	/r/sourceengine	/r/udk	/r/unity3d	/r/jme

Credit: http://www.reddit.com/user/Jephir

Notes

* Requires additional license.

1. Free version is feature limited.

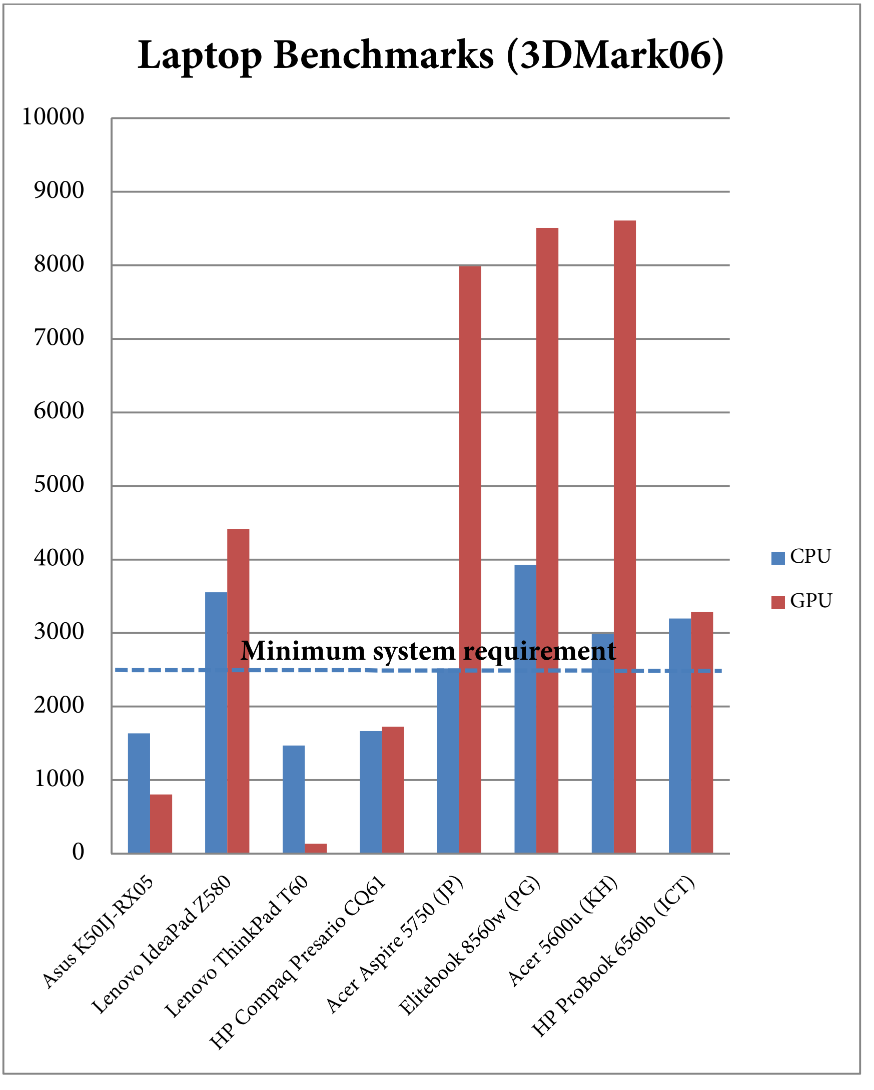
Computer specifications

Asus K50IJ-RX05	Lenovo IdeaPad Z580	Lenovo ThinkPad T60	HP Compaq Presario CQ61
GENERAL	**GENERAL**	**GENERAL**	**GENERAL**
System Type	System Type	System Type	System Type
Notebook	Notebook	Notebook	Notebook
Notebook type	Notebook type	Notebook type	Notebook type
Midsize, Budget, HD display	HD display, Budget, Midsize	Thin-and-light (4-6 lbs.)	Midsize, Budget, HD display
Manufacturer	Manufacturer	Manufacturer	Manufacturer
Asus	Lenovo	Lenovo	HP
PROCESSOR / CHIPSET	**PROCESSOR / CHIPSET**	**PROCESSOR / CHIPSET**	**PROCESSOR / CHIPSET**
CPU	CPU	CPU	CPU
Intel Pentium T4200 / 2 GHz	Intel Core i5 (3rd Gen) 3210M / 2.5 GHz	Intel Core Duo T2300	AMD Athlon II M320, Intel Celeron M 900
Number of Cores	Number of Cores	Number of Cores	Number of Cores
Dual-Core	Dual-Core	Dual-Core	Single-Core
Cache	Cache	Cache	Cache
L2 - 1 MB	3 MB	L2 - 2 MB	L2 - 512 KB
MEMORY	**MEMORY**	**MEMORY**	**MEMORY**
Max RAM Supported	Max RAM Supported	Max RAM Supported	Max RAM Supported
4 GB	8 GB	4 GB	4 GB
Technology	Technology	Technology	Technology
DDR2 SDRAM	DDR3 SDRAM	DDR2 SDRAM	DDR2 SDRAM
STORAGE	**STORAGE**	**STORAGE**	**STORAGE**
Hard Drive	Interface	Interface	Interface
320 GB HDD / 5400 rpm	Serial ATA-300	Serial ATA-150	Serial ATA-150
DISPLAY	**DISPLAY**	**DISPLAY**	**DISPLAY**
Widescreen	Widescreen	Widescreen	Widescreen
Yes	Yes	No	Yes
VIDEO	**VIDEO**	**VIDEO**	**VIDEO**
Graphics Processor	Graphics Processor	Graphics Processor	Graphics Processor
Intel GMA 4500	Intel HD Graphics 4000	Intel GMA 950	ATI Mobility Radeon HD 4200 - 128 MB

CPU Benchmark (3DMark06 CPU)	CPU Benchmark (3DMark06 CPU)	CPU Benchmark (3DMark06 CPU)	CPU Benchmark (3DMark06 CPU)
1636	3553	1470	1667.5
GPU Benchmark	**GPU Benchmark**	**GPU Benchmark**	**GPU Benchmark**
803	4415	132.4	1726
		Ati Radeon X1400 M54 1064	
Sources:	**CPU Benchmarks** http://www.notebookcheck.net/Mobile-Processors-Benchmarklist.2436.0.html **GPU Benchmarks** http://www.notebookcheck.net/Mobile-Graphics-Cards-Benchmark-List.844.0.html		

Computer specifications (Cont.)

Acer Aspire 5750 (JP)	Elitebook 8560w (PG)	Acer 5600u (KH)	HP ProBook 6560b (ICT)
GENERAL	**GENERAL**	**GENERAL**	**GENERAL**
System Type	System Type	System Type	System Type
Notebook	Notebook	AOI	Notebook
Manufacturer	Manufacturer	Manufacturer	Manufacturer
Acer	HP	Acer	HP
PROCESSOR / CHIPSET	**PROCESSOR / CHIPSET**	**PROCESSOR / CHIPSET**	**PROCESSOR / CHIPSET**
CPU	CPU	CPU	CPU
Intel Core i3-2310M	Intel Core i7-2640M @ 2.80GHz	Intel Core i3-3110M @ 2.40GHz	Intel Core i5 (2nd Gen) 2410M / 2.3 GHz
DISPLAY	**DISPLAY**	**DISPLAY**	**DISPLAY**
Widescreen	Widescreen	Widescreen	Widescreen
Yes	Yes	Yes	Yes
VIDEO	**VIDEO**	**VIDEO**	**VIDEO**
Graphics Processor	Graphics Processor	Graphics Processor	Graphics Processor
Nvidia GeForce GT 540M	Quadro 1000M	nVidia GeForce GT 630M with 1GB VRAM	Intel HD Graphics 3000
CPU Benchmark (3DMark06 CPU)	**CPU Benchmark (3DMark06 CPU)**	**CPU Benchmark (3DMark06 CPU)**	**CPU Benchmark (3DMark06 CPU)**
2517	3927	2988	3198
GPU Benchmark	**GPU Benchmark**	**GPU Benchmark**	**GPU Benchmark**
7986	8509	8610	3286.5
Sources:	**CPU Benchmarks** http://www.notebookcheck.net/Mobile-Processors-Benchmarklist.2436.0.html		


Laptop Benchmarks (3DMark06)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Minimum system requirement
CPU
GPU
Asus K50IJ-RX05
Lenovo IdeaPad Z580
Lenovo ThinkPad T60
HP Compaq Presario CQ61
Acer Aspire 5750 (JP)
Elitebook 8560w (PG)
Acer 5600u (KH)
HP ProBook 6560b (ICT)

Appendix II: Game-relates information

Table 11 Stars spawning sequences

Geyser No.➢ Time⮟	1	2	3	4	5
6		✓			
12			✓		
13				✓	
21					✓
27				✓	
31	✓				
33		✓			
41					✓
42				✓	
43				✓	
45		✓			
51					✓
59	✓				
63			✓		
67	✓		✓		✓
69		✓		✓	
73	✓		✓		✓
75		✓		✓	
79	✓				
83			✓		
80					✓
81		✓			
82				✓	
89	✓	✓		✓	✓
90			✓		
94		✓	✓	✓	
96	✓				✓
100	✓				✓
102		✓	✓	✓	
108	✓	✓	✓	✓	✓

The stars spawning sequences were recorded in the database. They would be fetched and set into the game variable waiting to be played in the magic land mini game. There were five geysers which place evenly on the ground in the magic land mini game. They emit white vapor and star, which the child could try catching as fast as he could before the star disappeared in the air.

In the Table 11 Stars spawning sequences, the top row presents the geyser number from 1 to 5. And the leftmost column presents the time, which white vapor would be emitted. After the white vapor was emitted, the star would be spawned 1.5 seconds later. Each star has its lift time of 3 seconds before it would disappear in the air.

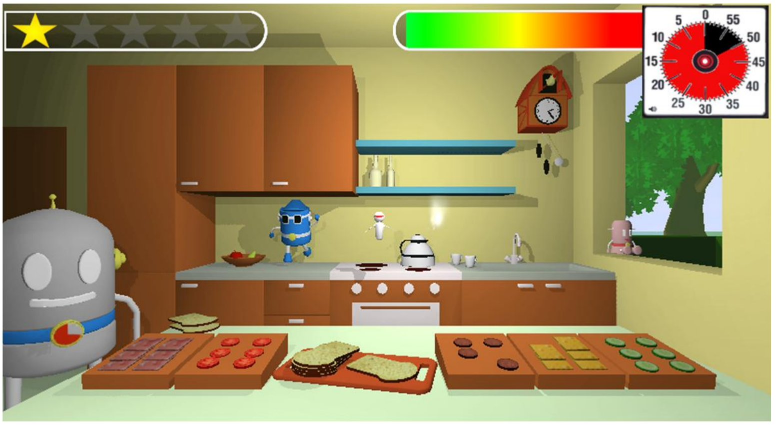
Example GameProperties file

```
[PROPERTY_NAME]                 [VALUE]
TIME_BEFORE_INACTIVE            20
SANDWICH_TRIAL_TIMEOUT          60
CHECK_FOR_CORRECT_ORDERING      0
CHECK_FOR_CORRECT_INGREDIENTS   1
FIRST_TRIAL_GIVES_FEEDBACK      1
ENABLE_TOGO_WITHOUT_UFO         0
AVERAGE_BALLOON_TIME            10
BALLOON_THRESHOLD               0.5
BALLOON_END_TIME                210
LASTCHANCE_BALLOON_TIME         20
TIME_FOR_WAITING                120
REWARD_PATH_01_TIME             30
REWARD_PATH_02_TIME             25
SHOW_RERUN_BUTTON               1
SHOW_SCENE_TRANSITION           0
SHOW_DEBUG_LOG                  0
SHOW_HIGHLIGHT                  0
```

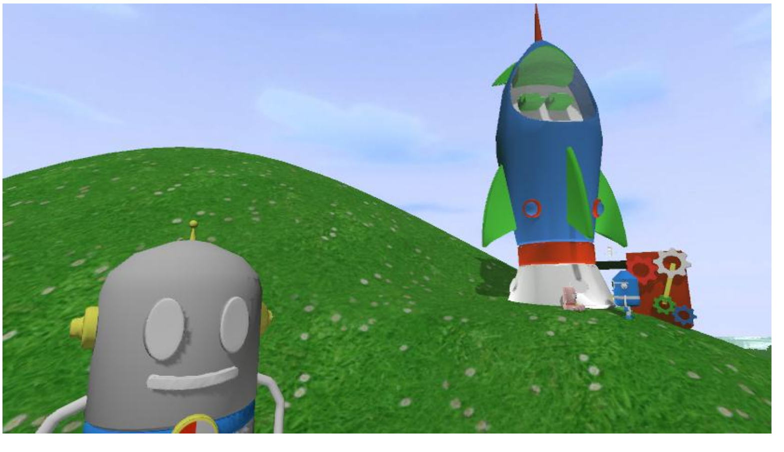
Example DistractorProperties file

```
[PROPERTY_NAME][VALUE1,VALUE2,...]
DIST_DRESS_DOORBELL          10
DIST_DRESS_COMPUTER          30
DIST_DRESS_RADIO             10,25,40
DIST_DRESS_SOUND             5,15,25
DIST_DRESS_VISUAL            10,20,30
DIST_DRESS_MIXED             15,25
DIST_KITCHEN_OVEN            10,25,40
DIST_KITCHEN_KETTLE          30,50
DIST_KITCHEN_CUCKOO          10,20,30
DIST_KITCHEN_SOUND           10,20,30
DIST_KITCHEN_VISUAL          10,20,30
DIST_KITCHEN_MIXED           10,20,30
DIST_BALLOON_FISH            5,15,25,35
DIST_BALLOON_BOAT            30,40,50
DIST_BALLOON_BIRDSND         50,65,80
DIST_BALLOON_BIRDGULL        5,15,25
DIST_BALLOON_WHALE           5,25,45,65,85,105
DIST_BALLOON_SOUND           5,15,25,35
DIST_BALLOON_VISUAL          5,15,25,35
DIST_BALLOON_MIXED 5,15,25,35,45,55,65,75
DIST_MONKEY_BIRD             10,25
DIST_MONKEY_LADYBIRD5,20,35,50,65,80
DIST_MONKEY_WIND             50,65
DIST_MONKEY_MOUSE            5,15,25
DIST_MONKEY_SQUIRREL         5,10,15,20,25,30,35
DIST_MONKEY_SOUND            5,15,25,35
DIST_MONKEY_VISUAL           5,15,25,35
DIST_MONKEY_MIXED            5,20,35,50,65,80,95
DIST_MAGICLAND_BIRD          30,45
DIST_MAGICLAND_WIND          50,65
DIST_MAGICLAND_OWL           15,25
DIST_MAGICLAND_BUTTERFLY     10,20
DIST_MAGICLAND_LEAVES_L      5,20,35
DIST_MAGICLAND_LEAVES_R      5,20,35
DIST_MAGICLAND_SQUIRREL      5,15,25,35,45
DIST_MAGICLAND_SOUND 10,20,30
DIST_MAGICLAND_VISUAL 10,20,30
DIST_MAGICLAND_MIXED 10,20,30
[Unrepeatable                Distractor]
DIST_MAGICLAND_APPLE         10
DIST_DRESS_BOOK              10
```

Distractor in each mini game




0
5
55
10
50
15
45
20
40
25
30
35



Appendix III: Data logging mechanism

1. Data logging mechanism

The game log mechanism was a dedicate GameObject that attached a code to handle writing logging events to log files. It had four ArrayList to store game events. They were arrayListFileAllTouch, arrayListFileAllTouchLocal, arrayListFileGamePlayTouch, and arrayListFileObjectTouch. These ArrayLists were acting as a container for events from the game. It was public access for registering events from all other GameObject.

1.1. ArrayListFileAllTouchLocal

ArrayListFileAllTouchLocal kept all mouse clicks/touch event occurring inside the game. It would record in a log file and append 'AllTouches' in its name. The tab-separate value data format was:

(X,Y) <tab> Position of X in screen resolution ratio <tab> Position of Y in screen resolution ratio <tab> Time of event from the game start <tab> Local timestamps in HH:mm:ss:ffff format

Example: (X,Y) <tab> 0.511875 <tab> 0.3452915 <tab> 2.274583 <tab> 11:34:34:8436

- Note: The white spaces surrounding <tab> were for readability only.
- arrayListFileAllTouch was a container of every touches of all participants who play the game. We use logs data in this container for calculating of clicks per mini games.

1.2. ArrayListFileGamePlayTouch

ArrayListFileGamePlayTouch kept all mouse clicks/touch event related to game play. It would record in a log file with 'GamePlay' in its name. The tab-separate value data format was:

Event <tab> what kind of event <tab> Time of event from the game start <tab> Local timestamps in HH:mm:ss:ffff format

Example: BOY BUTTON <tab> CLICKED AT <tab> 6.107882 <tab> 11:34:39:2498

- Note: The white spaces surrounding <tab> were for readability only.

1.3. ArrayListFileObjectTouch

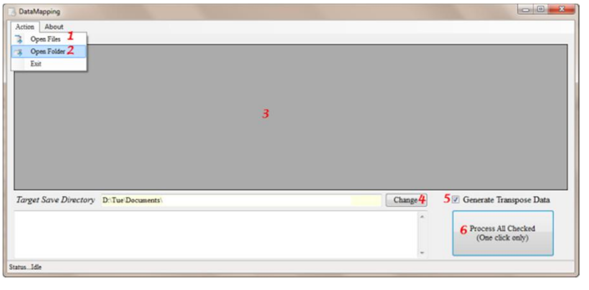
ArrayListFileObjectTouch kept all mouse clicks/touch event that interacted with game objects and distractors in the game. It would record in a log file with 'SpecificObjects' in its name. The tab-separate value data format was:

Object <tab> what kind of event <tab> Time of event from the game start <tab> Local timestamps in HH:mm:ss:ffff format

Example: SOUND DISTRACTOR <tab> WAS TOUCHED AT <tab> 135.4436 <tab> 10:45:40:9946

- Note: The white spaces surrounding <tab> were for readability only.

2. Semi-automated data mining application



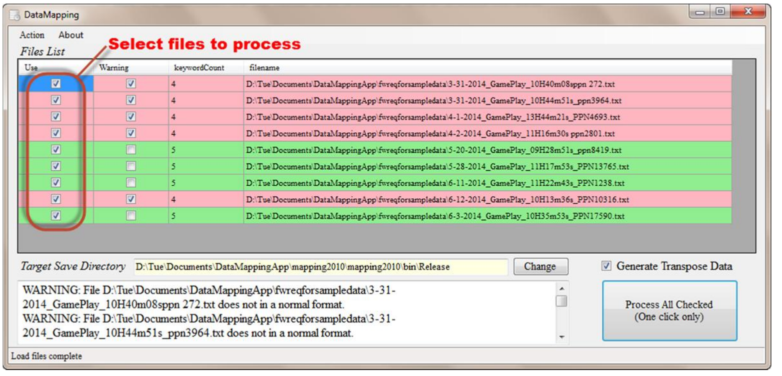
User interface

1. Drop down for selecting raw data file(s) manually.
2. Drop down for selecting folder contains raw data file(s).
3. This was the files display area.
4. Button for changing output directory. *(Optional)*
5. Checkbox for generating transpose data for SPSS. *(Optional)*
6. Button to process raw data.

Generally, this application could be used with only 2 steps:
1) give the application the file needed to be processed and 2) process the data.

Step 1: Select file(s)

Please select raw data file(s) manually* or select the folder contains multiple files**.
* - Log files must be a text file (.txt).
** - Program would read <u>all files</u> having 'GamePlay' in their name, in the selected folder.



Step 2: Select unwanted file(s)

After selecting files, the files-display area would be shown.

In this area there were 2 distinctive colors;

Light Pink was a file that was missing some information, which could be resulted from a previous game version (v.1.4), or incomplete mini games keywords.

Light Green was a normal file having complete mini games keywords, files version 1.5 or later.

The program would process only the file that checked in 'Use' column. The unwanted file could be checked off.

Step 3: Change output directory (optional)

The program would write the processed result to an Excel file (.xls) in the program executing folder by default. However, if the system does not allowed to write into the selected location, the user could change the output directory by click on 'Change' button.

Step 4: Process the data

Press the 'Process all checked' to process and write the data into Excel file **'Gamelogs.xls'** in the selected destination.

Example:

Dress up sheet

	A	B	C	D	E
1	ID	ITEM_NAME	CLICK_AT	TIME_FROM_START	ITEM_ORDER
2	5-20-2014_GamePlay_09H28m51s_ppn8419.txt	Jeans	51.20109	32.83204	1
3	5-20-2014_GamePlay_09H28m51s_ppn8419.txt	UnderShirt	57.92668	39.55763	2
4	5-20-2014_GamePlay_09H28m51s_ppn8419.txt	PullOver	67.85753	49.48848	3
5	5-28-2014_GamePlay_11H17m53s_PPN13765.txt	Pants	40.57854	32.607728	1
6	6-11-2014_GamePlay_11H22m43s_PPN1238.txt	TShirt	41.77708	34.568213	1
7	6-11-2014_GamePlay_11H22m43s_PPN1238.txt	Pants	53.23169	46.022823	2
8	6-11-2014_GamePlay_11H22m43s_PPN1238.txt	Shoes	67.04019	59.831323	3

Dress up Transpose

	A	B	C	D	E	F	G	H
1	ID	ITEM_1	ITEM_2	ITEM_3	ITEM_4	ITEM_5	ITEM_6	ITEM_7
2	3-31-2014_GamePlay_10H40m08sppn 272.txt	Socks	Pants	TShirt	Shoes	PullOver		
3	3-31-2014_GamePlay_10H44m51s_ppn3964.txt	Skirt	UnderShir	Socks	Shoes			
4	4-1-2014_GamePlay_13H44m21s_PPN4693.txt	Skirt	UnderShir	TShirt	PullOver			
5	4-2-2014_GamePlay_11H16m30s ppn2801.txt	UnderShir	Skirt	Shoes	Socks			
6	5-20-2014_GamePlay_09H28m51s_ppn8419.txt	Jeans	UnderShir	PullOver				
7	5-28-2014_GamePlay_11H17m53s_PPN13765.txt	Pants						
8	6-11-2014_GamePlay_11H22m43s_PPN1238.txt	TShirt	Pants	Shoes				
9	6-12-2014_GamePlay_10H13m36s_PPN10316.txt	Pants	TShirt	PullOver	UnderShir	Shoes	Socks	
10	6-3-2014_GamePlay_10H35m53s_PPN17590.txt	Jeans	UnderShir	TShirt	PullOver	Socks		

After transposition, data in excel could directly be import to SPSS for statistical analysis.

3. Example of game logs

Dress up mini game's logs

MinigameDressup_G	START AT	7.208867	11:22:51:9761		
TShirt	CLICKED AT	41.77708	11:23:26:8701		first
DOORBELL IN DRESSUP	PLAYED AT	49.21155	11:23:34:3026		
Pants	CLICKED AT	53.23169	11:23:38:3238		second
Shoes	CLICKED AT	67.04019	11:23:52:1326		third
COMPUTER_SCREEN IN DRESSUP	PLAYED AT	69.2166	11:23:54:3087		
BOOK_FALL IN DRESSUP	PLAYED AT	79.21039	11:24:04:3023		
MAKING SANDWICH START AT	153.5423	11:25:19:3496			

Figure 84 Logs from the Dress up mini game

This example logs data shown us that:

1) We could see that this child was a girl; from the suffix of *Mini gameDressup_G* (would be changed to *Mini gameDressup_B* in case the child was a boy).

2) The child selected 3 items for dress up; T-shirt, Pants, and Shoes.

3) The time the child made selections were at 41.77708, 53.23169, and 67.04019 sequentially from the game started. We could calculate the time that the child selected item from starting time of this mini game by simply minus them with the *Mini gameDressup_G* time (7.208867).

4) Three distractors were played; DOORBELL, COMPUTER_SCREEN, and BOOK_FALL.

The dress up mini game's score calculation

The order of dress items selected by the child makes a difference when we consider about how good they were when given scores. At least one item must be selected in order to proceed to the next mini game. There were two parts for dress items: the upper part, and the lower part.

On the upper part of the body, the child could select these items: Undershirt, T-Shirt, and Pullover. And on the lower part of the body, the child could select these items: Skirt or Pants or Jeans, Socks, and Shoes as the perfect order.

The total selected items would be categorized into two parts and given a score. Undershirt, Skirt, Pants, and Jeans have the same value of 1. They should be selected as the first order, and they were having the same value because their order of selection could interchangeable without any differences. Undershirt would categorize to the upper part of the child's body. However, the child could select only one item for his lower part by either Skirt, or Pants, or Jeans. T-Shirt and Socks have the value of 2. They were second ordered item which should be selected after the items in first order. Lastly, the items which should be selected in the third order by the child were Pullover and Shoes which having a value of 3.

Regarding the order of dress items selected in the log file, we pairwise comparison with the values of the selected items and calculate cumulative scores. Given the example of dress items selected as follows: UnderShirt, Skirt, TShirt, Socks, Shoes, Pullover

1. The first step was to categorize those items into two parts:

Upper part: UnderShirt, TShirt, Pullover

Lower part: Skirt, Socks, Shoes

2. The second step was to give each item score and did the pairwise comparisons:

Upper part: UnderShirt(1), TShirt(2), Pullover(3)

UnderShirt(1), **TShirt(2),** Pullover(3) = 1
UnderShirt(1), TShirt(2), **Pullover(3)** = 2
UnderShirt(1), **TShirt(2), Pullover(3)** = 1

Lower part: Skirt(1), Socks(2), Shoes(3)

Skirt(1), Socks(2), Shoes(3) = 1
Skirt(1), Socks(2), **Shoes(3)** = 2

Skirt(1), **Socks(2), Shoes(3)** = 1

3. The third step was to accumulate all scores: 1+2+1+1+2+1 = 8

The score would be two times negative in case that the child selected with wrong order. Given the example of dress items selected as follows: Pullover, Shoes, Socks, TShirt, Skirt, UnderShirt

1. The first step was to categorize those selected items
Upper part: Pullover, TShirt, UnderShirt
Lower part: Shoes, Socks, Skirt
2. The second step was to give each item score and did the pairwise comparisons:
Upper part: Pullover(3), TShirt(2), UnderShirt(1)

Pullover(3), TShirt(2), UnderShirt(1) = -2
Pullover(3), TShirt(2), **UnderShirt(1)** = -4
Pullover(3), **TShirt(2), UnderShirt(1)** = -2

Lower part: Shoes(3), Socks(2), Skirt(1)

Shoes(3), Socks(2), Skirt(1)= -2
Shoes(3), Socks(2), **Skirt(1)** = -4
Shoes(3)**, Socks(2), Skirt(1)** = -2

3. The third step was to accumulate all scores: -2-4-2-2-4-2 = -16

Making sandwiches mini game's logs

MAKING SANDWICH START AT	153.5423	11:25:19:3496			
Cheese	CLICKED AT	167.918	11:25:33:7254		
Cheese	IS THE INGREDIENT	1	OF SANDWICH	0	11:25:33:7254
Salami	CLICKED AT	172.3532	11:25:38:1616		
Salami	IS THE INGREDIENT	2	OF SANDWICH	0	11:25:38:1616
Bread_Top	CLICKED AT	178.7632	11:25:44:5710		
CURRENT FINISHED SANDWICH IS	1	11:25:44:5710			
CURRENT FINISHED SANDWICH(4) [	Cheese Salami]	MATCH?=False	CORRECT INGREDIENTS?=True	11:25:46:6421	
OVEN_SOUND IN KITCHEN	PLAYED AT	201.8012	11:26:07:6073		
Cheese	CLICKED AT	211.2262	11:26:17:0339		
Cheese	IS THE INGREDIENT	1	OF SANDWICH	1	11:26:17:0339
Tomato	CLICKED AT	217.0658	11:26:22:8732		
Tomato	IS THE INGREDIENT	2	OF SANDWICH	1	11:26:22:8732
KETTLE IN KITCHEN	PLAYED AT	221.8161	11:26:27:6235		
Bread_Top	CLICKED AT	225.3286	11:26:31:1367		
CURRENT FINISHED SANDWICH IS	2	11:26:31:1367			
CURRENT FINISHED SANDWICH(4) [	Cheese Tomato]	MATCH?=False	CORRECT INGREDIENTS?=True	11:26:33:2348	

Figure 85 Logs from the Making sandwiches mini game

This example logs data shown us that:

1) The child selected Cheese and Salami for sandwich number 1.
2) The child selected Cheese and Tomato for sandwich number 2.

The making sandwiches mini game's score calculation

Each sandwich made by the child would be checked for the correctness of the order and the correctness of ingredients regarding the model in Figure 51 *Ingredients design layout* on page 117. The first sandwich that the child could make was '*a trial*'. This sandwich did not have time pressure, but the child has 60 seconds to finish this trial sandwich. This was because we want the child to get familiar with how to make the sandwich in this mini game. Within 240 seconds the child could make the four remaining sandwiches with correct ingredients as shown on its recipe and with correct order from left to right.

1) The first trial sandwich needed only one Cheese.
2) The second sandwich needed Tomato, and Cheese.
3) The third sandwich needed Ham, Cucumber, and Tomato.
4) The forth sandwich needed Salami, Ham, Cucumber, and Tomato.
5) The fifth sandwich needed Salami, Ham, Cucumber, Tomato, and Cheese.

If the child made sandwich with correct ingredients regardless of order, there would be 1 point for 'Ingredient correctness'. Furthermore, if all those ingredients were placed in the correct order as shown on the recipe, there would be another point for 'Order correctness'.

After the child finished the making sandwiches mini game, all sandwiches that the child made would be counted, and scored. We could later calculate for the percentage of correctness of the order and ingredients selected.

Cross the river mini game's logs

BALLOON MINIGAME START AT	513.1195	11:31:19:2972	
BALLOON	FINISHED TO CLICK AT	520.628	11:31:26:8046
BALLOON	TOTAL TIME CLICKED IS	3.037354	11:31:26:8046
BALLOON	TIME IS TOO SMALL	520.628	11:31:26:8056
FISH IN BALLOON	PLAYED AT	523.1215	11:31:29:2967
BOAT_SOUND IN BALLOON	PLAYED AT	543.139	11:31:49:3159
BALLOON	FINISHED TO CLICK AT	547.1517	11:31:53:3291
BALLOON	TOTAL TIME CLICKED IS	19.04059	11:31:53:3291
BALLOON	TIME IS TOO MUCH	547.1517	11:31:53:3291
BIRD IN BALLOON	PLAYED AT	563.1198	11:32:09:2970
BALLOON	FINISHED TO CLICK AT	567.2727	11:32:13:4502
BALLOON	TOTAL TIME CLICKED IS	12.74597	11:32:13:4502
BALLOON	TIME IS TOO MUCH	567.2727	11:32:13:4502
BALLOON	FINISHED TO CLICK AT	575.9105	11:32:22:0877
BALLOON	TOTAL TIME CLICKED IS	3.921692	11:32:22:0877
BALLOON	TIME IS TOO SMALL	575.9105	11:32:22:0877
BALLOON	FINISHED TO CLICK AT	597.0995	11:32:43:2770
BALLOON	TOTAL TIME CLICKED IS	14.62177	11:32:43:2770
BALLOON	TIME IS TOO MUCH	597.0995	11:32:43:2770
BALLOON	FINISHED TO CLICK AT	608.158	11:32:54:3356
BALLOON	TOTAL TIME CLICKED IS	8.063538	11:32:54:3356
BALLOON	TIME IS TOO SMALL	608.158	11:32:54:3356
BALLOON	FINISHED TO CLICK AT	638.8105	11:33:24:9893
BALLOON	TOTAL TIME CLICKED IS	12.78503	11:33:24:9893
BALLOON	TIME IS TOO MUCH	638.8105	11:33:24:9893
BALLOON	FINISHED TO CLICK AT	644.2263	11:33:30:4056
BALLOON	TOTAL TIME CLICKED IS	0.6251221	11:33:30:4056
BALLOON	TIME IS TOO SMALL	644.2263	11:33:30:4056
BALLOON	FINISHED TO CLICK AT	655.3283	11:33:41:5083
BALLOON	TOTAL TIME CLICKED IS	9.025024	11:33:41:5083
SUCCESS BALLOON IS	1	655.3283	11:33:41:5083
BALLOON	FINISHED TO CLICK AT	669.4178	11:33:55:5971
BALLOON	TOTAL TIME CLICKED IS	5.467041	11:33:55:5971
BALLOON	TIME IS TOO SMALL	669.4178	11:33:55:5971
BALLOON	FINISHED TO CLICK AT	686.4471	11:34:12:6261
BALLOON	TOTAL TIME CLICKED IS	10.58075	11:34:12:6261
SUCCESS BALLOON IS	2	686.4471	11:34:12:6271
BALLOON	FINISHED TO CLICK AT	701.7469	11:34:27:9269
BALLOON	TOTAL TIME CLICKED IS	5.106873	11:34:27:9269
IT IS NEARLY TIME OUT	SO THIS BALLOON IS ALWAYS SUCCESS, AT	701.7469	11:34:27:9269
BALLOON MINIGAME IS ENDED	AT	701.7469	11:34:27:9269
BALLOON TIME OUT!	AT	741.2751	11:35:07:4552
BALLOON MINIGAME LASTCHANCE BE(	741.2751	11:35:07:4572	

Figure 86 Logs from the Cross the river mini game

This example logs data shown us that:

1) The child tried to estimate 12 balloons (blue stripe).
2) The child succeeds in estimate 2 balloons in the acceptable range of time (10 +- 1 second). The estimated time were 9.025024 and 10.58075
3) We could calculate average/mean time, which the child did by (the sum of 12 times)/12.

The cross the river mini game's score calculation

This mini game needs three balloons, as the perfect number in order to cross the river. However, the number of balloon tried by the child could be varied. The obvious reason was because of the estimated time by the child did not fall within 10 seconds plus threshold of 0.5 seconds was counted. Therefore, we could not use the total number of estimated balloon as a mini game score, but the number of balloons that the child successful at estimated time of 10 seconds.

Moreover, the child could try to make as many balloons as he could within 210 seconds, which we calculated the average estimation time as another mini game score.

Monkey mini game's logs

MONKEY MINIGAME START AT	800.6597	11:36:07:2976		
MONKEY MINIGAME CURRENT SIGNAL	TRUE	801.5897	11:36:08:2257	
CLEAR BANANA PEEL	(SUCESSFUL) AT	803.5761	11:36:10:2128	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	804.5881	11:36:11:2228	
CLEAR BANANA PEEL	(FAILURE) AT	807.5868	11:36:14:2220	
MONKEY MINIGAME CURRENT SIGNAL	FALSE	810.5674	11:36:17:2022	
BIRD IN MONKEY_GAME	PLAYED AT	810.6875	11:36:17:3232	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	813.5608	11:36:20:1954	
CLEAR BANANA PEEL	(FAILURE) AT	813.8555	11:36:20:4904	
MONKEY MINIGAME CURRENT SIGNAL	FALSE	819.5661	11:36:26:2007	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	822.574	11:36:29:2089	
MONKEY MINIGAME CURRENT SIGNAL	FALSE	828.5795	11:36:35:2142	
CLEAR BANANA PEEL	(SUCESSFUL) AT	830.6716	11:36:37:3073	
LADYBIRD_SOUND IN MONKEY_GAME	PLAYED AT	830.6716	11:36:37:3073	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	831.5629	11:36:38:1984	
MONKEY MINIGAME CURRENT SIGNAL	FALSE	837.5649	11:36:44:1997	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	840.5604	11:36:47:1959	
MONKEY MINIGAME CURRENT SIGNAL	FALSE	846.5843	11:36:53:2192	
CLEAR BANANA PEEL	(SUCESSFUL) AT	847.7159	11:36:54:3523	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	849.5864	11:36:56:2224	
WIND_SOUND IN MONKEY_GAME	PLAYED AT	850.6774	11:36:57:3135	
MONKEY MINIGAME CURRENT SIGNAL	FALSE	855.5707	11:37:02:2058	
CLEAR BANANA PEEL	(SUCESSFUL) AT	857.1126	11:37:03:7489	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	858.5734	11:37:05:2089	
MONKEY MINIGAME CURRENT SIGNAL	FALSE	864.5964	11:37:11:2323	
CLEAR BANANA PEEL	(SUCESSFUL) AT	865.829	11:37:12:4654	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	867.5787	11:37:14:2145	
MONKEY MINIGAME CURRENT SIGNAL	FALSE	873.565	11:37:20:2008	
CLEAR BANANA PEEL	(SUCESSFUL) AT	873.6452	11:37:20:2818	
SUCCESSFULLY CLEAR ALL BANANA PEI	AT	873.6452	11:37:20:2818	

Figure 87 Logs from the Monkey mini game (1)

This example logs data shown us that the child succeeds in clear all the banana peels (six times). All the banana peels were cleared in 7.9855 seconds (873.6452 - 800.6597).

MONKEY MINIGAME START AT	800.6597	11:36:07:2976	
MONKEY MINIGAME CURRENT SIGNAL	TRUE	801.5897	11:36:08:2257
CLEAR BANANA PEEL	(SUCESSFUL) AT	803.5761	11:36:10:2128
MONKEY MINIGAME CURRENT SIGNAL	TRUE	804.5881	11:36:11:2228
CLEAR BANANA PEEL	(FAILURE) AT	807.5868	11:36:14:2220
MONKEY MINIGAME CURRENT SIGNAL	FALSE	810.5674	11:36:17:2022
BIRD IN MONKEY_GAME	PLAYED AT	810.6875	11:36:17:3232
MONKEY MINIGAME CURRENT SIGNAL	TRUE	813.5608	11:36:20:1954
CLEAR BANANA PEEL	(FAILURE) AT	813.8555	11:36:20:4904
MONKEY MINIGAME CURRENT SIGNAL	FALSE	819.5661	11:36:26:2007
MONKEY MINIGAME CURRENT SIGNAL	TRUE	822.574	11:36:29:2089
MONKEY MINIGAME CURRENT SIGNAL	FALSE	828.5795	11:36:35:2142
CLEAR BANANA PEEL	(SUCESSFUL) AT	830.6716	11:36:37:3073
LADYBIRD_SOUND IN MONKEY_GAME	PLAYED AT	830.6716	11:36:37:3073
MONKEY MINIGAME CURRENT SIGNAL	TRUE	831.5629	11:36:38:1984
MONKEY MINIGAME CURRENT SIGNAL	FALSE	837.5649	11:36:44:1997
MONKEY MINIGAME CURRENT SIGNAL	TRUE	840.5604	11:36:47:1959
MONKEY MINIGAME CURRENT SIGNAL	FALSE	846.5843	11:36:53:2192
CLEAR BANANA PEEL	(SUCESSFUL) AT	847.7159	11:36:54:3523
MONKEY MINIGAME CURRENT SIGNAL	TRUE	849.5864	11:36:56:2224
WIND_SOUND IN MONKEY_GAME	PLAYED AT	850.6774	11:36:57:3135
MONKEY MINIGAME CURRENT SIGNAL	FALSE	855.5707	11:37:02:2058
CLEAR BANANA PEEL	(SUCESSFUL) AT	857.1126	11:37:03:7489
MONKEY MINIGAME CURRENT SIGNAL	TRUE	858.5734	11:37:05:2089
MONKEY MINIGAME CURRENT SIGNAL	FALSE	864.5964	11:37:11:2323
CLEAR BANANA PEEL	(SUCESSFUL) AT	865.829	11:37:12:4654
MONKEY MINIGAME CURRENT SIGNAL	TRUE	867.5787	11:37:14:2145
MONKEY MINIGAME CURRENT SIGNAL	FALSE	873.565	11:37:20:2008
CLEAR BANANA PEEL	(SUCESSFUL) AT	873.6452	11:37:20:2818
SUCCESSFULLY CLEAR ALL BANANA PEI	AT	873.6452	11:37:20:2818

Figure 88 Logs from the Monkey mini game (2)

However the child failed in clear the banana peels two times.

The monkey mini game's score calculation

Six banana peels were needed to be clear from the pathway. If the child succeeds cleared all six banana peels in '*Go*' signal before time up then the child can proceed to the next mini game. However, if the child cleared banana peel in '*No-Go*' signal, one substitute banana would be added.

The number of successfully cleared banana peels and failure cleared would be counted. Moreover, the average time used to clear each banana peel was calculated.

Magic land mini game's logs

MAGICLAND MINIGAME STARTED AT		974.0031	11:39:01:1186		
SIGNAL 1	SPAWNED AT		977.9063	11:39:05:0208	
STAR 1(979)	SPAWNED AT		979.4171	11:39:06:5309	
SIGNAL 2	SPAWNED AT		979.9329	11:39:07:0469	
STAR 2(981)	SPAWNED AT		981.4448	11:39:08:5590	
STAR 1(979) CLICKED AT		982.3417	11:39:09:4560		
APPLE IN MAGIC_LAND	PLAYED AT		984.0323	11:39:11:1461	
STAR 2(981) CLICKED AT		984.6946	11:39:11:8102		
SIGNAL 3	SPAWNED AT		985.9322	11:39:13:0462	
SIGNAL 4	SPAWNED AT		986.9166	11:39:14:0303	
STAR 3(987)	SPAWNED AT		987.4444	11:39:14:5583	
STAR 4(988)	SPAWNED AT		988.4255	11:39:15:5404	
SIGNAL 5	SPAWNED AT		994.9031	11:39:22:0168	
STAR 5(996)	SPAWNED AT		996.4183	11:39:23:5328	
STAR 5(996) CLICKED AT		998.6843	11:39:25:7990		
SIGNAL 4	SPAWNED AT		1000.93	11:39:28:0441	
STAR 4(1002)	SPAWNED AT		1002.467	11:39:29:5812	
BIRD_SOUND IN MAGIC_LAND	PLAYED AT		1004.035	11:39:31:1503	
SIGNAL 1	SPAWNED AT		1004.915	11:39:32:0293	
STAR 1(1006)	SPAWNED AT		1006.418	11:39:33:5334	
SIGNAL 2	SPAWNED AT		1006.932	11:39:34:0464	
STAR 1(1006) CLICKED AT		1008.475	11:39:35:5895		
STAR 2(1008)	SPAWNED AT		1008.475	11:39:35:5895	
STAR 2(1008) CLICKED AT		1010.08	11:39:37:1956		
SIGNAL 5	SPAWNED AT		1014.913	11:39:42:0279	
SIGNAL 3	SPAWNED AT		1015.948	11:39:43:0630	
STAR 5(1016)	SPAWNED AT		1016.422	11:39:43:5370	
SIGNAL 4	SPAWNED AT		1016.944	11:39:44:0580	
STAR 5(1016) CLICKED AT		1017.411	11:39:44:5270		

Figure 89 Logs from the Magic land mini game (1)

This example logs data shown us that the child clicked five stars. However, in the full magic land log there are 50 stars in total.

MAGICLAND MINIGAME STARTED AT	974.0031	11:39:01:1186	
SIGNAL 1	SPAWNED AT	977.9063	11:39:05:0208
STAR 1(979)	SPAWNED AT	979.4171	11:39:06:5309
SIGNAL 2	SPAWNED AT	979.9329	11:39:07:0469
STAR 2(981)	SPAWNED AT	981.4448	11:39:08:5590
STAR 1(979) CLICKED AT	982.3417	11:39:09:4560	
APPLE IN MAGIC_LAND	PLAYED AT	984.0323	11:39:11:1461
STAR 2(981) CLICKED AT	984.6946	11:39:11:8102	
SIGNAL 3	SPAWNED AT	985.9322	11:39:13:0462
SIGNAL 4	SPAWNED AT	986.9166	11:39:14:0303
STAR 3(987) ✕	SPAWNED AT	987.4444	11:39:14:5583
STAR 4(988) ✕	SPAWNED AT	988.4255	11:39:15:5404
SIGNAL 5	SPAWNED AT	994.9031	11:39:22:0168
STAR 5(996)	SPAWNED AT	996.4183	11:39:23:5328
STAR 5(996) CLICKED AT	998.6843	11:39:25:7990	
SIGNAL 4	SPAWNED AT	1000.93	11:39:28:0441
STAR 4(1002) ✕	SPAWNED AT	1002.467	11:39:29:5812
BIRD_SOUND IN MAGIC_LAND	PLAYED AT	1004.035	11:39:31:1503
SIGNAL 1	SPAWNED AT	1004.915	11:39:32:0293
STAR 1(1006)	SPAWNED AT	1006.418	11:39:33:5334
SIGNAL 2	SPAWNED AT	1006.932	11:39:34:0464
STAR 1(1006) CLICKED AT	1008.475	11:39:35:5895	
STAR 2(1008)	SPAWNED AT	1008.475	11:39:35:5895
STAR 2(1008) CLICKED AT	1010.08	11:39:37:1956	
SIGNAL 5	SPAWNED AT	1014.913	11:39:42:0279
SIGNAL 3	SPAWNED AT	1015.948	11:39:43:0630
STAR 5(1016)	SPAWNED AT	1016.422	11:39:43:5370
SIGNAL 4	SPAWNED AT	1016.944	11:39:44:0580
STAR 5(1016) CLICKED AT	1017.411	11:39:44:5270	

Figure 90 Logs from the Magic land mini game (2)

There was a mechanism to see which stars were clicked in time or missed by tracing the log file. From the example logs, stars follow by their spawned geyser number and the time they spawned, for example, STAR 1(979) was spawned from geyser number 1 at 979 seconds from the beginning of the game. In the tested game version, every star was spawned 1.5 seconds after its signal.

This example logs data shown us that STAR 1(979), STAR 2(981), STAR 5(996), STAR 1(1002), STAR 2(1008), and STAR 5 (1016) were clicked. But STAR 3(987), STAR 4(988) and STAR 4(1002) were not clicked in time.

The magic land mini game's score calculation

The child could try catching the jumping stars as much as he could. The child would be able to proceed to the next mini game after 120 seconds. The number of total star spawned in this mini game was fixed at 50. Therefore, the number of stars that the child succeeds caught were counted and calculated into percentage of success. We also do the calculation for the average time that the child used to catch stars. The missed to catch stars were happening when the reaction time of the child was more than 4 seconds. We could bring number that the child missed into overall reaction time as this mini game score.

Rocket mini game's logs

WAITING MINIGAME STARTED AT		1187.057	11:42:34:3448		
WAITING MINIGAME STARTED RECEIVI		1218.294	11:43:05:7726		
WAITING GAME SMALL REWARD	AT		1219.332	11:43:06:8116	

Figure 91 Logs from the Rocket mini game

This example logs data shown us that the mini game started at 1187.057 seconds from the beginning. The mini game went with introduction and started receiving input and count down the child waiting time at 1218.294 seconds. However the child waited for 1.038 seconds (1219.332 – 1218.294), therefore the child received a small reward.

The rocket mini game's score calculation

The objective of this mini game was to let the child wait for 120 seconds. The child would be automatically receiving a big reward which was a longer version of the ending after 120 seconds passed. On the other hand, the child would receive a small version of the ending as a small reward if the child did any action during 120 seconds.

The score in this mini game was given as 1 for the small reward, and 2 for the big reward. These could discriminate between the child whom could hold his action during 120 seconds, and whom who could not.

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Summary of: Interactive Diagnostic Game for Time Perception

Time is a shared conceptual understanding that we experience and construct while we grow up from a child to an adult. We are aware of changes within the surrounding environment and are capable of causal reasoning into the past and mentally predict on what will follow in the near future by this concept. Not all the children perceive time normally however. Children with developmental disorders such as Attention Deficit Hyperactivity Disorder (ADHD) may have problems in time perception. We examined whether there were any tools we could use to diagnose symptoms related to problems in time perception. The use of computer games for children with developmental disorders receives growing interest in the current literature. Therefore, we created an interactive computer game for a diagnostic purpose. This doctoral dissertation subsequently examines the main research question: "How to design a game as a diagnosis supporting tool to collect data on time related aspects for children with ADHD?"

ADHD is one of the most common childhood developmental disorders that may affect children's school achievements. Unlike other symptoms such as hyperactivity or impulsivity, time perception problems remain present even when the child becomes an adult, which is different from other symptoms which may diminish as children with ADHD grow up. We believe that time perception is an important factor in diagnosing ADHD.

Although ADHD is a clinical diagnosis with several approaches, no diagnostic game has been designed to detect the symptoms of time perception problems in ADHD children. Psychologists diagnose a child for ADHD by referring to the ADHD diagnostic guidelines in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV). However, it is still difficult for psychologists to diagnose ADHD since this developmental disability is only revealed prominently when the child is exposed to classroom learning of academic tasks, which usually happens when the child reaches six years of age. In order to potentially improve the diagnosis of ADHD, a computer game was created, together with psychologists from Kempenhaeghe, center for neurological learning disabilities, which can be used as part of the psychological assessment.

We employed a combination of research through design, agile methodology, participatory design, and the user-centered design process in iterative stages. We designed the game to test various psychological aspects by creating smaller mini games, which were linked together with a single coherent story. Our six mini games were: 1) the Dress up mini game, which was designed for testing some parts of the executive functions; 2) the Making sandwiches mini game, which was designed for testing the working memory; 3) the Cross the river mini game, which was designed for testing time estimation; 4) the Monkey mini game, which was designed for testing response inhibition; 5) the Magic land mini game, which was designed for testing reaction time; and 6) the Rocket mini game, which was designed for testing waiting behavior.

The game was evaluated with 118 children. 97 normal children and 21 children with ADHD were analyzed with a discriminant analysis to determine whether the variables collected by the game could predict whether a child has symptoms of ADHD or not. Classification results showed that 87.9% of children were correctly classified in overall by Timo's Adventure. Our reliability was found to be higher than DISC-IV's youth test-retest reliability in clinical samples for ADHD. This could indicate that using Timo's Adventure is a valuable addition to the diagnostic process.

Chapter 1, the introduction of Timo's Adventure, describes the preliminary reasons for creating this game, its storyline, and how to use Timo's Adventure. In chapter 2 the insights from systematic literature reviews provide a state of the art and theoretical background for this dissertation. This forms the basis that drove us to create the interactive computer game to fulfill psychological requirements and answer our research question. Chapter 3 to 14 shows the design, implementation, and evaluation of each mini game. They show how each mini game was designed specifically to fulfill the psychological assessment requirements, but in different aspects of time perception. Chapter 15 summarizes our main finding. Chapter 16 reflects back and provides a general conclusion regarding the given research question of this thesis. Finally the technical aspects of this dissertation can be found in the appendix.

Curriculum Vitae

Pongpanote Gongsook was born on October 01, 1979 in Nakhon Pranom, Thailand. He has achieved his Bachelors and Masters in Computer Science from Ubon Ratchathani University and Thammasat University in 2002 and 2006 respectively. He is interested in utilizing computers for entertainment and educational purposes. His Master thesis contains the study of attention techniques in multimedia learning. In January 2012, he has been granted the Erasmus Mundus Doctorate Scholarship from EACEA, and got admitted to the Eindhoven University of Technology (TU/e), the Netherlands, and the University of Genoa (UNIGE), Italy.

Pongpanote worked as a PhD candidate at the faculty of Industrial Design and investigated the design of a serious game as a diagnosis supporting tool to measure time related aspects for children with mental disabilities, which has resulted in this thesis.

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