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COGNITIVE GAME BATTERY: ASSESSING AND IDENTIFYING DEFICITS IN MEMORY, ATTENTION, PROBLEM-SOLVING, AND DECISION-MAKING SKILLS

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BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

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Bachelor's Thesis Assignment

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Institut: Department of Computer Systems (DCSY)
Student: **Češka Ondřej**
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Title: **Cognitive Game Battery: Assessing and Identifying Deficits in Memory, Attention, Problem-Solving, and Decision-Making Skills**
Category: Computer vision
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Assignment:

1. Identify and define cognitive domains to be assessed by the games.
2. Identify challenges and limitations of existing games and methods that assess the impairment in cognitive skills through a literature review.
3. Design a single game or a set of digital games that target each cognitive domain.
4. Implement the game(s) on the Android platform with cloud accessibility.
5. Collect data on participants' performance while playing the games.
6. Analyze the data to assess cognitive skills and identify deficits.
7. Conduct critical analysis and discuss achieved results and their contribution.

Literature:

- Based on the supervisor's recommendation.

Requirements for the semestral defence:

- Fulfillment of items 1 to 3.

Detailed formal requirements can be found at https://www.fit.vut.cz/study/theses/

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Abstract

The goal of this work is the non-invasive assessment of selected cognitive domains (attention, memory, decision-making) using a new mobile application developed for this purpose. Assessment of cognitive deficits is important for the prevention of neurocognitive disorders. Existing assessment tasks were analyzed and based on them a cognitive game battery consisting of 3 mobile games was successfully designed and implemented. The application is made for the Android platform and was developed in the Unity engine. A system for collecting and storing game data and their subsequent evaluation with the help of cloud availability was created and evaluated using data collection and findings of existing studies. The presented application brings a different perspective to the assessment of cognitive deficits, compares the user's achieved score with other players, and provides them with detailed feedback.

Abstrakt

Cílem této práce je neinvazivní posouzení vybraných kognitivních domén (pozornost, paměť, rozhodování) pomocí nové mobilní aplikace vyvinuté za tímto účelem. Posuzování kognitivních nedostatků je důležité pro prevenci neurokognitivních poruch. Byly analyzovány existující posuzovací úlohy a na jejich základě byla navržena a úspěšně implementována kognitivní herní baterii sestávající ze 3 mobilních her. Aplikace je určena pro platformu Android a byla vyvinuta v Unity engine. Byl vytvořen systém pro sběr a uchovávání herních dat a jejich následné zhodnocení za pomoci cloudové dostupnosti. Jeho spolehlivost byla posouzena na základě vlastního sběru dat a poznatků existujících studií. Vyvinutá aplikace přináší jiný pohled na posuzování kognitivních nedostatků, porovnává uživatelem dosažené skóre s ostatními hráči a poskytuje mu detailní zpětnou vazbu.

Keywords

cognitive domains, cognitive games, memory, attention, problem-solving, decision-making, brain, Android, Unity, battery, cloud, identifying deficits

Klíčová slova

kognitivní domény, kognitivní hry, paměť, pozornost, řešení problémů, rozhodování, mozek, Android, Unity, baterie, cloud, identifikace nedostatků

Reference

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Rozšířený abstrakt

Tato práce je zaměřena na neinvazivní posuzování vybraných kognitivních domén pomocí sady mobilních videoher. Posuzované domény jsou pozornost, paměť, rozhodovací schopnosti a řešení problémů. Identifikace nedostatků v oblasti kognitivních dovedností je důležitá pro včasné odchycení a prevenci vzniku neurokognitivních poruch jako je např. Alzheimerova choroba.

Identifikoval a definoval jsem domény určené k posuzování a jejich existující metody evaluace. Zaměřil jsem se na existující kognitivní herní baterie[1] a zhodnotil jejich přínosy a nedostatky.

Většina evaluačních herních metod je zaměřená na konkrétní skupinu obyvatelstva jako jsou důchodci nebo děti a při hodnocení spoléhá na normativní data nasbíraná právě na určitém vzorku populace. Posuzování kognitivních dovedností je obecně složitý problém. Každý člověk žije s různě rozvinutými kognitivními dovednostmi a neexistuje nic takového jako zdravá norma kognice.

V mém návrhu jsem se rozhodl představit jiný pohled na posuzování. Při navrhování herní baterie jsem se rozhodl maximálně vytěžit možnosti cílové platformy a využít neklesající oblíbenosti mobilních zařízení pro vytvoření posuzovací metody založené na vzájemné evaluaci mezi uživateli pomocí dynamicky se rozšiřující databáze shromážděných dat.

Na principu odzkoušených klasických metod posuzování kognitivních dovedností jsem navrhl a úspěšně implementoval kognitivní herní baterii sestávající ze 3 her pro dotyková zařízení. První z her se zaměřuje na posuzování pozornosti, druhá na paměť a ve třetí hře se posuzují schopnosti rozhodovací a řešení problémů. Aplikace je určena pro operační systém Android a byla vyvinuta v Unity engine. V průběhu hraní jsou sbírána a odesílána podrobná herní data do cloudové databáze. Za účelem vytvoření základního datového fondu byl na 22 dobrovolnících proveden sběr dat formou hraní her. Následovala implementace evaluačních výpočetních metod pro stanovení jednotného skóre uživatele pro každou hru. Po dosazení všech zkoumaných metrik jednotlivých her do navržených vzorců je uživatel seznámen s jeho komplexním výsledkem pro danou hru a kromě číselného zhodnocení si může zobrazit vizualizaci svého výkonu v porovnání s ostatními uživateli ve formě grafu.

Aplikace byla testována na celkem 46 dobrovolnících ze dvou demografických skupin a průzkum ukázal, že uživatelé ocenili systém evaluace založený na vzájemném porovnání. Pro zvýšení důvěryhodnosti evaluační metody byly získané výsledky obou věkových skupin porovnány a jejich rozdíly zanalyzovány a zhodnoceny podle dostupných zdrojů. Vybrané kognitivní domény byly pomocí nově vytvořené kognitivní herní baterie úspěšně posouzeny.

[1] Sada úloh nebo testů určených pro posuzování kognice ve formě videohry

Cognitive Game Battery: Assessing and Identifying Deficits in Memory, Attention, Problem-Solving, and Decision-Making Skills

Declaration

I hereby declare that this Bachelor's thesis was prepared as an original work by the author under the supervision of Mr. Hussain. I have listed all the literary sources, publications and other sources, which were used during the preparation of this thesis.

....
Ondřej Češka
May 8, 2024

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I would like to express my profound gratitude to Mr. Yasir Hussain for his help, cooperation and guideship throughout the process of my work. I would also like to thank all of the volunteers for their willingness to participate in the user testing.

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Chapter 1

Introduction

Neurocognitive disorders such as the Alzheimer's disease affect millions of people worldwide every day. Treatment of these disorders is very hard and limited, in some cases non-existent. To prevent these disorders from fully developing, it is important to preventively assess and evaluate deficits in what we call cognition.

Cognitive function, a process in our brain responsible for acquiring and manipulating information, has been studied for centuries together with methods of it's assessment. The assessment methods evolved over time and are still being pushed forward. Brief introduction to the world of cognitive function and modern approaches to their assessment can be found in chapter 2.

The goal of this work is the assessment of selected cognitive domains (attention, memory, decision-making/problem-solving) using an assessment method in form of a set of touchscreen games. These games based on well-established evaluation tasks were created in Unity, a game engine suitable for this kind of task, as it is both powerful and user-friendly. For better understanding of the creation process of a Unity game, basic terminology is presented in chapter 3.

After analyzing availabile sources concerning this problematics, I decided to present a different approach to the evaluation of the collected game data by utilizing a large set of data and comparing the user scores with each other. The whole draft of the solution can be found in chapter 4.

The presented solution was then implemented for the Android operating system, as an application consisting of 3 games, each of them to assess a different cognitive domain. Details of the implementation are in chapter 5.

Data collected from the volunteers were used to create an extensive database and an evaluation system that allows the assessment of user's results by comparing them to the cumulative data. The collected data was split into two sets based on the age of the participants (<20 & 20+). Comparison between the two groups was conducted together with validation of it's results in order to add transparency to the evaluation method. More information on data collection, user testing, and critical analysis of achieved results is available in chapter 6.

Chapter 2

Theoretical introduction to cognitive function

In order to understand this thesis, it is necessary to understand the basic concept of cognitive function, how it is classified and which domains will be assessed in this work.

Cognitive function is a term referring to brain-based skills needed for acquiring knowledge, manipulating information, and reasoning[23]. Cognitive abilities play a crucial role in everyday functioning. They are skills we use on daily basis, usually without directly noticing it. Impairment of these skills has an impact on a person's life even if he doesn't realize that. To understand how these skills are classified and what role they play in our lives, let's have a closer look at each cognitive domain and how they overlap and interact with each other.

2.1 Cognitive abilities

The 6 universally accepted cognitive abilities include complex attention, executive function, learning and memory, language, perceptual-motor control, and social cognition.[5] These cognitive functions are closely interrelated and mostly work together to support various aspects of human behavior. Some cognitive domains are higher in the hierarchy, meaning that more basic sensory processes are being utilized by higher-level functions such as executive function. [19] Cognitive abilities are essential for „normal" physical life but also for the social part of functioning in a human civilization. People vary and not every cognitive skill is at the same level in each person's brain, some are gifted in different cognitive areas than others. That's why a less developed cognitive skill doesn't necessarily mean an impairment or present a serious issue.

Complex attention

Attention is a cognitive function that allows individuals to focus on a specific subject or stimuli whilst not getting distracted by other things. It plays a critical role in our ability to concentrate, be aware of our surroundings, and switch between different tasks. Complex attention consists of different types of attention, including divided attention (juggling between multiple tasks at the same time), selective attention (focusing on one single task and ignoring others) and sustained attention (maintaining focus over time).

Executive function

Executive function refers to a set of cognitive processes that helps individuals plan, organize, process, initiate, and carry out tasks. It involves skills such as decision-making, goal-setting, error correction, and problem-solving. These skills are closely intervened. To solve a problem or set a goal, a person needs to make good and quick decisions. So from executive function, decision-making is the point of focus for this thesis's assignment. Decision-making is a process of gathering information, evaluating it, visualizing possible outcomes, and choosing the most desirable one, it is an important part of one's problem solving abilities. Decision-making is crucial not only for everyday tasks but for long-term quality of life too.

Learning and memory

Learning is the process of acquiring new knowledge and skills, while memory involves the retention and retrieval of that information. These two functions are closely related and play a significant role in how individuals adapt to their environment and learn from past experiences. For something to be memorized, it first has to be learned, so assessing learning skills is usually done by assessing memory. That's why this work assesses memory directly. Memory can be divided into various types, such as working memory (temporary storage of information), episodic memory (recall of specific events), and semantic memory (general knowledge).

Language

Language is a complex cognitive function that enables individuals to communicate and convey thoughts, ideas, and emotions. It involves processes like understanding and generating spoken or written words, as well as the rules of grammar, syntax, and semantics. Language plays an important role in social interaction, education, and most aspects of human life. It is the only cognitive domain unique to humankind.[28]

Perceptual-motor control

Perceptual-motor control refers to the ability to perceive sensory information from the environment and use it to guide motor actions - moving our body. This function encompasses skills such as hand-eye coordination, spatial awareness, motor planning, and the integration of sensory input to perform physical activities. It's essential for activities like driving, sports, and fine motor skills like writing or drawing.

Social cognition

Social cognition involves the ability to perceive, interpret, and respond to social information and cues from others. This function encompasses skills such as understanding the emotions of other people (and yourself), recognizing social norms, empathy, theory of mind[1], and interpersonal communication. Social cognition is vital for forming and maintaining relationships and navigating social situations. Since socializing is something humans have developed to a point where it is critical for everyday life, having a good social cognition is indisputably important.

[1] the ability to understand the mental states of others

2.2 Abilities to be assessed

From the six cognitive abilities, this project focuses on assessing the following 3. They are most suitable for their assessment using the chosen method of touchscreen gaming.

- Complex attention
- Executive function (decision-making, problem-solving)
- Learning and memory (memory)

Decision-making and problem solving are both classified as part of the executive function. They are dependent on each other and their effective areas overlap. Problems cannot be solved without making decisions and decisions are often a problem themselves. That's why problem-solving and decision-making will be assessed together.

From the left out ones, social cognition and language aren't such great candidates as the evaluation of tasks including these skills is often subjective and hard to analyze for a computer lacking critical human thinking. Perceptual-motor control is needed, as using a touchscreen device is a predisposition for playing the game, and perceptual-motor control is responsible for this very activity. However, no measures for assessing perceptual-motor control skills will be in place as the utilization of perception and physical movement while playing a mobile game is very little and instead this work will focus solely on the three chosen domains.

Complex attention

Complex attention is a term used by the Diagnostic and Statistical Manual of Mental Disorders: Fifth Edition (further referred to as DSM-5)[5] because as mentioned before, attention consists of different types of attention. These variants are:

- divided attention
- selective attention
- sustained attention

Just like most of the higher-level cognitive functions, the neural circuitry in the prefrontal cortex (PFC) of the brain is responsible for proper function of attention.[29] The location of the prefrontal cortex can be seen in figure 2.1.

Divided attention

This type of attention provides us with the capability of switching our focus between multiple tasks and so seems like it is allowing us to do more in less time. Unlike common belief, multitasking, narrowly defined (in the sense of focusing on more activities at the same time), is not something a human mind can fully do. Divided attention is what gives us the feeling of focusing on multiple targets at once, whilst we actually just switch between them really fast (broadly defined multitasking).[43] The finding that task switching can reduce productivity[35] is supported by the channel theory, suggesting that the ability to perform more mental operations at the same time is limited by the capacity of a „central mechanism".[43] The idea of a central mechanism of the human brain is further discussed and compared to the von Neumann model of computer architecture[50] in Schweickert &

Boggs, 1984[38], but some papers dare to differ - e.g. Spelke, 1976.[42]. Whilst possible reduced productivity is one of the downsides, divided attention helps humans deal with the complex environment in which they live nowadays.[43]

Selective attention

Selective attention enables people to focus on 1 stimulus. A selection of the desirable target of attention has to be made every time a person changes their attention to a new subject. It might seem that fully focused on the target, the person ignores other distracting stimuli around him. But here comes the „cocktail party problem“ first defined and named in 1953 by Colin Cherry[9]. This problem lifts the fact that a person can listen to a particular conversation, (say, during a cocktail party) and be apparently ignorant to the other conversations happening around him. Nevertheless, this person is sometimes able to hear a familiar or important word (e.g. one's own name) in one of the ongoing unfocused conversations.[9] This phenomenon addresses both selective and divided attention and shows how selective attention helps to „filter“ out unnecessary stimuli and focus on one subject but also that even when fully focused, the human mind is not indifferent to other, apparently unimportant stimuli around. The ability to filter out other unimportant sources that overwhelm our sensory system is even more important in this modern age, where distracting stimuli are one every corner.

Sustained attention

Even more relevant to the modern age of advertisement-driven business and social media is sustained attention. This type of attention enables a person to maintain a long-lasting focus on a specific subject without losing focus or shifting his attention to other stimuli. Those disturbing factors don't have to be external, frequently internal thought processes are the cause of loosing concentration on a target. Being able to focus for a long time is a key skill for lots of everyday tasks. Learning, reading a book, listening to a complicated speech, even recreational activities such as watching a movie require long-term attention. The rising popularity of short videos and an increasing average number of hours of smartphone usage among young adults and kids can have negative impact on the ability to sustain attention. And so training sustained attention and identifying impairments in this cognitive subdomain is especially these days an important task.[41] [15]

Decision-making/Problem-solving

Decision-making is the process of choosing between options. It is a fundamental human behavior involving the synthesis of a variety of kinds of information and a key feature of problem-solving ability. Sensory inputs, autonomic and emotional responses, past associations, and future goals must be integrated with other known information, such as uncertainty, timing, cost-benefit, and risk, and then applied to select the most appropriate actions for one's benefit. This processing must be completed rapidly and must be flexible to some degree for it to be useful in a changing environment.[12] Lets's provide an example:

A child with a dollar bill in his hand seeing a line in front of a soda machine has two options. Either he gets to keep his dollar and has no soda or he chooses to stand in the line, and after 2 minutes, he has no dollar but has acquired a fresh soda can. Now, let's consider that the child has to be home for dinner in 5 minutes. Now, he has to decide fast, does he have enough time to stand in the line until it's his turn and then make it home in time? What if there's no dinner at home, does he keep the money for some food?

These are all variables the human brain has to account for when making decisions.

Decision-making is done in the brain by an interaction between the hippocampus, which stores the knowledge, and the prefrontal cortex, which approximates the goals.[30] There is a consensus in the field of cognitive science that damage to the frontal lobe, containing the prefrontal cortex, can lead to the impairment of decision-making[39], as well as other cognitive skills.[29]

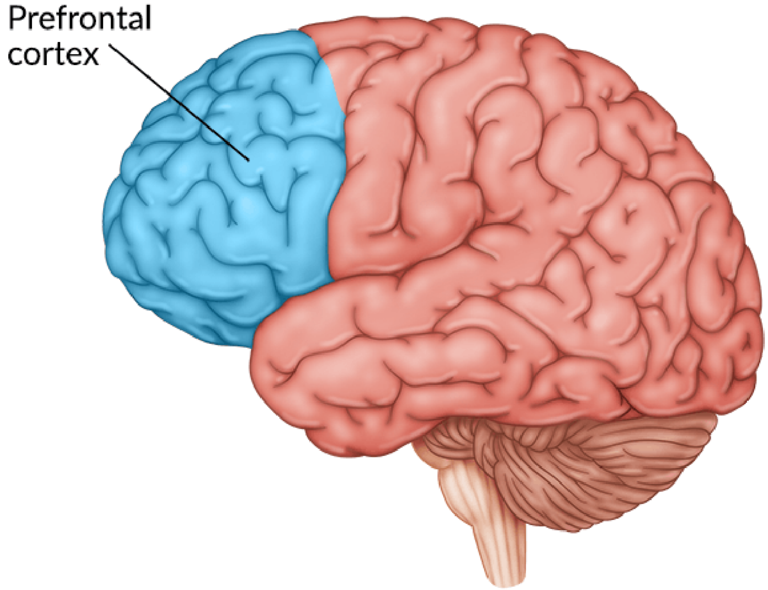

Figure 2.1: The prefrontal cortex (PFC) location in the human brain from [14]

Memory

Memory is one of the most important cognitive functions. It allows us to store and retrieve information that we previously acquired. It is believed that the functions of memory are carried out by parts of the brain called the hippocampus[3] and the cerebrum[31], not the prefrontal cortex as the previously mentioned attention and decision-making. As previously mentioned in the overview of all six main cognitive functions, memory is closely related to learning. Memory is defined as a behavioral change caused by an experience and learning is defined as a process for acquiring memory.[31] Memory can be classified by its time duration of storing information.

Short-term & Long-term memory

Their distinction is self-explanatory. Capacity-limited short-term memory enables us to remember actions and observations from the recent past (*„When did I last eat today?“*). If these stored units of memory are repeatedly accessed and/or stored, long-term memories can eventually develop. Long-term memory stores information like one's name, other people's names, visualizations of places, etc.) Long-term memory can be further distinguished.[44]

Declarative & Procedural memory

Long-term memory can be split into declarative and non-declarative (procedural) memory. Declarative memory serves the purpose of storing information concerning events, and facts and is available to our consciousness. It is the type of memory most people think of when talking about „memory“. Procedural memory, on the other hand, is not available to consciousness and people don't realize they are using it. It is needed, for example, to use a skill we already learned e.g. riding a bike or reading. We can improve our skills by practicing and thus get better at these activities by deepening our procedural memories. It is proven that declarative memory and procedural memory are independent. There are patients with only one of these types of memory impaired, while the other is completely intact.[31] Declarative memory consists of two subcategories.

Episodic & Semantic memory[6][37]

The first type of declarative memory is episodic memory. Its purpose is to process and store information about past events and experiences such as remembering what you were doing last Friday. Without it, social interaction and day-to-day life would be very difficult. Semantic memory takes care of conceptual information eg. knowledge or facts. For example, the rules of ice hockey. They are not essential knowledge and missing out on them would not be a big problem for a common person. Though it may seem that semantic memory is less important, it is proven that this crucial memory system is widely useful in many cognitive domains such as correctly interpreting words and sentences, recognizing objects, recalling previously learned concepts, and acquiring new information from reasoning and perceptual experience.

Summary

Cognitive function is a set of brain-based skills needed for everyday life. These skills usually serve different purposes but are closely intertwined. Most cognitive skills can be further divided into subcategories. The ones that will be the focus of this work are attention, memory and decision-making (problem-solving). The goal is to assess these cognitive abilities using a set of touchscreen games.

2.3 Assessment

Assessing cognitive function is an important but a complicated task. Every person is different and there is no simple way to say if a person is „cognitively healthy". This section discusses why the assessment of cognitive function is important and methods that can be used for it.

Motivation

Disruptions or impairments in any of the mentioned cognitive functions can have significant implications for an individual's overall functioning and quality of life. These impairments usually appear in more than just one domain as they are closely intertwined. It's only logical that e.g. people with bad memory won't be the best planners. If impairments are severe to the point that the person is unable to live a normal life without treatment or help, then this condition is classified as a cognitive disorder.

Cognitive disorders

Cognitive disorders are part of neurocognitive disorders.[5]. These disorders affect tens of millions of people worldwide.[25] The most common cognitive disorders are Alzheimer's disease, motor skills disorders, developmental disorders, and many more. The prevalence rates for the Alzheimer's disease in the U.S. are 11% of people aged 65+ and shocking 32% of people over 85 years of age. Treatment of these disorders is very complicated, long-term, and often does not fulfill the patient's or his family's expectations as fighting these conditions once they're fully developed is extremely hard and grueling. An important factor in treating these disorders is time. The impairments start to show up very slowly and unnoticeably. It is very hard to spot cognitive impairments in other people and even harder in yourself. If these symptoms are discovered in time, the patients can preemptively train and strengthen themselves in those slightly damaged cognitive domains and severely slow down the illness or avoid it whatsoever.

Methods

Plenty of evaluation methods have been developed to detect impairments in individuals's cognitive function before they start to affect their life. These instruments often come in the form of tests. These tests have been improved over decades and are fairly accurate. Tests are a short and easy way of evaluating subjects according to their answers. However, not every cognitive domain can be fairly assessed by a simple test question. So over time, more interactive ways of assessing cognitive dysfunctions and impairments were developed.

Assessments in the form of interactive face-to-face interviews, planning and problem-solving tasks, group conversations, or long-term projects give way to properly assessing different domains and make testing more reliable and enjoyable for the patients. It is important, especially for the control group with actual dysfunctional patients, to answer questions naturally and give true corresponding value to the assessment, not be anxious.[7] Unconventional ways of assessing cognitive impairments provide more flexibility and comfort to patients experiencing them thus resulting in more truthful and straightforward insight to their minds. On the other hand, more advanced forms of assessment require a skilled examiner and place more demands on the examinee than just choosing a test answer. [16]

Some of the instruments are constructed to target a single cognitive process (e.g. attention) in detail, while other assess a spectrum of different cognitive processes. Again, both approaches have their upsides and downsides. Single skill examination reduces the demand on the examiner and examinee but leaves a place for overlooking important deficits in other cognitive abilities. The multi-domain assessment provides a global indication of the individual's cognitive skills but puts high demands on both the examiner and examinee, is time-consuming, and usually only scratches the surface compared to a single process in-depth analysis.[16]

Assessment methods consisting of several tests, or other innovative ways of assessment are called batteries. Those specifically targeting cognitive function are called cognitive batteries.

Cognitive battery

In psychology, a cognitive battery is a set of neuropsychological assessment methods implementing multiple measures and covering one or more cognitive skills in order to evaluate a patient's overall weaknesses and strengths in cognitive function.[51] Batteries are either „fixed“ or „flexible“. Meaning they either stay the same (which provides more reliable data throughout all patients) or are individually formed and are developing throughout the assessment depending on patients' previous test outcomes and clinical evaluation. The approach to assessing cognitive functions in the form of a mobile game is most suitable for implementing a fixed cognitive battery as the core of the evaluation method. Many successful and well-known batteries have been developed throughout the years.

2.4 Video game assessment methods

Assessment in the form of a mobile game is not a new concept and several existing games have been more or less successful in the evaluation of cognitive function. Here are some interesting examples i studied in order to develop a good game:

TENI (Test de Evaluación Neuropsicológica Infantil)[45]

This instrument was developed to asses cognitive abilities in children between 3 to 9 years of age. It combines modern technology and games as tools to improve children's cognitive skills. This method is implemented on a touchscreen device and allows evaluation of higher cognitive functions. It consists of 10 subtests. Average playtime for all of the games is 30 minutes and evaluator can choose the order and filter out games, which turns out to be a good detail. The instructions for each game are communicated orally by the instructor. Most games are automatically scored by a standardized method based on the Chilean standardization. The report is provided to the user in a convenient format after completing the games. TENI encompasses a wide range of cognitive abilities including games for memory and attention I am interested in.

Focused attention

For focused attention, a simple „*find the difference*“ game is implemented. The difficulty gradually increases. The child has to tap on the difference with their finger before the time runs out. Evaluation is done by the level the child reached. This seems like a good idea for a minigame.

Sustained attention

Sustained attention is evaluated by a test based on the continuous performance task model (T.O.V.A.).[24] The child sees of similar looking elements (apples) moving from one side of the screen to the other. The child is instructed to tap the screen when it notices an anomaly in the element (a worm in an apple). This monotonous task is 6 minutes long and so forces the child to sustain it's attention.

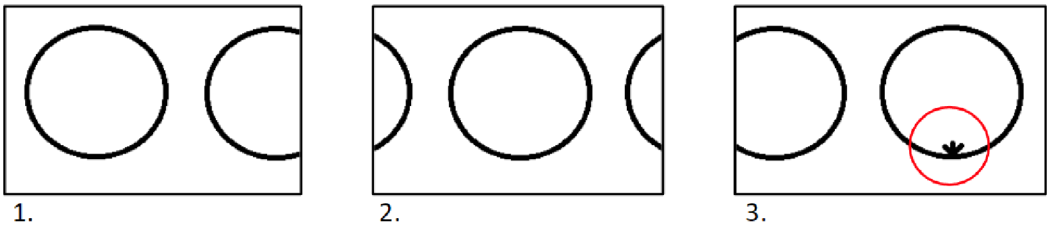

Figure 2.2: Sustained attention test mockup inspired by T.O.V.A.[24]

Short-term memory

TENI includes a game called „*Molly the Mole*“ which shows a 3×3 matrix on the screen. The child's objective is to follow a sequence of highlighted matrix cells (the mole goes through them) and then reproduce that sequence by tapping on the cells in the correct order. The sequence gets progressively longer and the game ends when two unsuccessful attempts on a sequence of the same length are made by the child.

Conclusion

TENI[45] is a simple, working method of children's evaluation and provided a good source of information and inspiration. The limitation of this method is the target audience, which is the age of elementary school pupils. It contains 7 more not-mentioned games that could provide a good source of inspiration for assessing different cognitive domains such as language, perceptual-motor control or social cognition.

Panoramix[47][48][13]

This battery is based on gamification, virtual reality and machine learning. It encompasses abilities such as attention, executive functions and different types of memory. It was made to non-intrusively evaluate early marks of cognitive alternations leading to cognitive disorders in senior population. It consists of 7 games evaluating different cognitive areas. With six of them focusing mainly on memory, attention and executive function.

Attentix

This game asseses the attention capabilities of players. The promise of the game is very simple. A series of colors is shown to the player and he then attempts to repeat it by tapping colored blocks. Number of colors can be altered and the color sequence gets extended by one for each correct answer. Player data consisting of average response time, total playtime, number of hits, errors and the difficulty of the last sequence played (players are not forced to complete all levels to avoid frustration).

Workix

This game focuses on working memory. It is based on Corsi's Block-Tapping task[10] and is quite similar to previously mentioned Attentix game. The difference is that the player is required to tap the blocks in reverse order of the shown sequence. This makes the difference between assessing working memory and attention. Variables used to calculate a final score include total length of the game, average response time, execution mode, and number of successfully repeated sequences.

Executix

Executix assesses the executive function of the player. The game is a representation of world's famous „Tower of Hanoi“ [21] (figure 2.3), invented by Eduard Lucas in 1883. [32] Players have to relocate a certain number of different-sized discs on three rods to get to a certain predefined state, moving only one disk at a time.

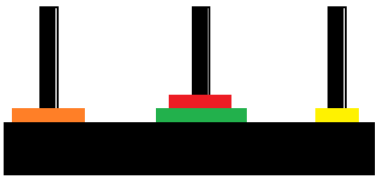

Figure 2.3: Visualization of the „Tower of Hanoi“

This forces the player to use his executive skills to anticipate possible outcomes, plan his strategy, and make foreseeing decisions.

Episodix

Episodix puts emphasis on imitating real life. Players are subjected to a virtual walk through a town and several objects and sounds are presented to them. Players are then asked to recall as many of them as possible over several phases, and from this information, episodic memory is assessed.

Procedurix

Procedurix focuses not only on procedural memory but also includes motor coordination and executive functions. It is based on the pursuit rotor task [18].

Semantix

The base for the Semantix game is the Pyramids and Palm Trees game [22]. It is used to evaluate semantic memory. The test consists of 52 cards, each with three images on them. The given stimulus, the target stimulus and the distracting stimulus. Based on the given stimulus, the player decides which of the other two would most likely go together with it. E.g. on figure 2.4, the concept of a palm tree is closer to the concept of a pyramid. Both pyramids and palms resemble tropical deserts. Based on the number of mistakes and time spent, semantic knowledge and memory are assessed.

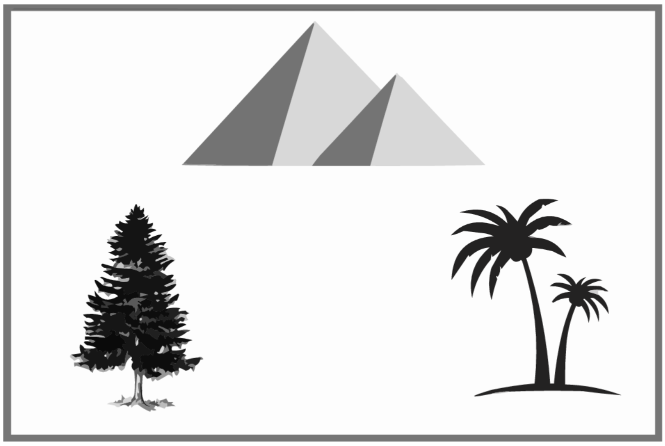

Figure 2.4: The Pyramids and Palm Trees Test, image acquired from [17]

Conclusion

Panoramix is another successful adaptation of multiple cognitive tests and provides a great candidate for executive function testing. The Tower of Hanoi is a simple but solid test of executive function. Attention and short-term memory can be efficiently assessed by exercises based on repetition. Sematix, Procedurix and Episodix, with it's innovative take on episodic memory assessement, were for their success in cognitive status classification selected to be integrated into the Gatekeeper project, a large-scale e-health platform developed under the European Union H2020 program.[13] [1] Panoramix serves as a good source of inspiration for creating a mobile cognitive assessment game. Turning known tests that have stood the test of time into a game is a reliable and a fairly easy solution.

Summary of existing games

There are more and more video games emerging focused on this problem. Previously mentioned are these that show good results and would be good adepts for a touchscreen environment (using simple controls) and assess the chosen cognitive domains. It is fair to say that most used techniques for assessing each cognitive domain are similar. Why bother implementing a new, complicated task, when well-established tasks, that have stood the test of time and been studied thoroughly are available? E.g. recalling a memorized sequence of blocks[10] or numbers is the basic assessment method recommended by the Diagnostic and Statistical Manual of Mental Disorders 5[5] as well as many others utilized in the aforementioned games.

Often, tasks like these can be turned into touchscreen games very effectively simply because of how fun and easy they are to grasp. If the game is fun to play, user doesn't even have to realize the assessment is happening. That is a sign that game batteries based on simple evaluation tasks are good subjects for a non-invasive method of assessment.

Chapter 3

Working in Unity

Unity is a multiplatform game engine[1] with support for most common platforms, whether it is PC (Windows, Linux, MacOS), game console (Xbox, Playstation) or mobile gaming (iOS, Android). It was developed by Unity Technologies in 2005 and has only grown ever since, including more and more platforms and functionalities. It is suitable for creating cross-platform games, both in 2D and 3D. Except the cross-platform development, Unity has lot's of advantages, such as a very user-friendly interface, comprehensive documentation, and an active community including the Asset store, where developers can share/sell/buy their created assets for Unity games. Unity uses C# as the scripting language, which is a powerful and versatile language for both advanced developers and novices.

3.1 Basic terminology

To create a mobile app focused on assession of the cognitive domain, not only knowledge of cognitive functions is needed. To understand the terms of the Unity engine that i have chosen to work with, let's take a look at some basic terminology and functionalities that are necessary for understanding the implementation and design of the app.

Scene

A scene is a closed environment where the app is being created. It contains all the necessary items that the scene utilizes (objects, cameras, light sources, etc.). Usually, a game consists of multiple scenes. Each scene has a dedicated number and name. The scene number 0 is usually the Menu screen, as it loads first and then serves as a crossroad between other scenes. Another scene can be the settings screen. It is very common that each level of a game has its own screen. Because the scene's assets load upon entering the scene and deload when leaving, utilizing the scenes as much as possible makes the game less demanding and memory-dependent. When working in the Unity editor, only the one scene that is currently being worked on is loaded. We can see the preview of the scene in the Scene window, as shown in figure 3.1.

[1] https://unity.com/products/unity-engine

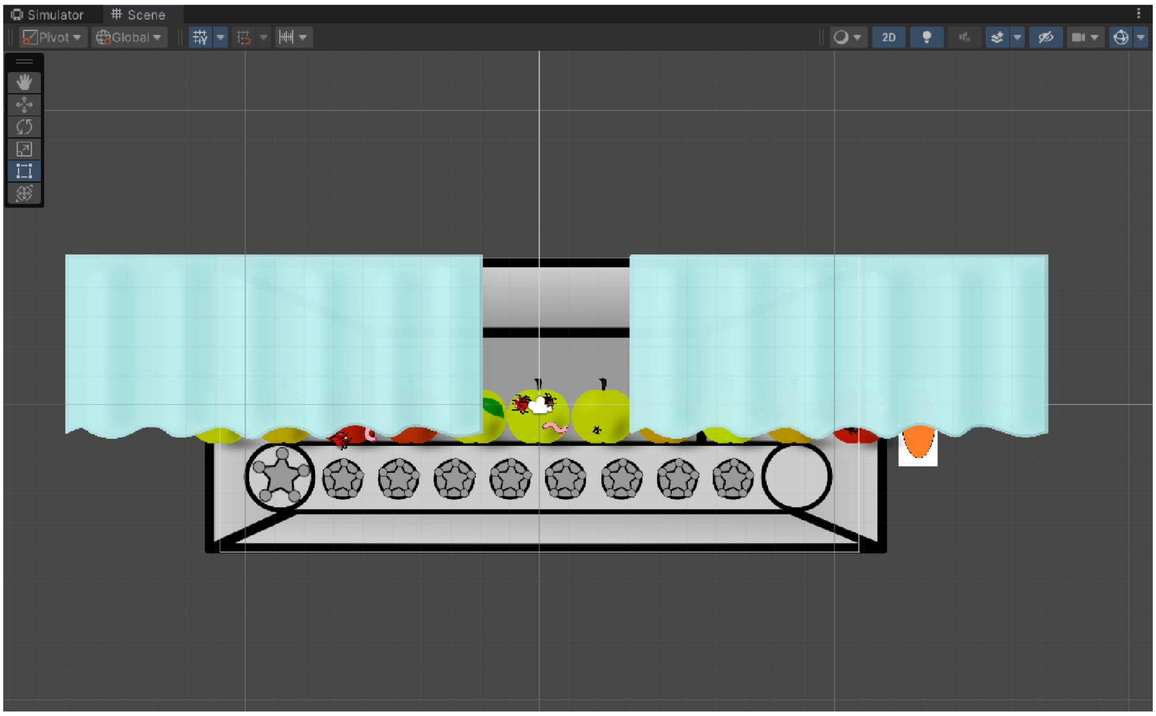

Figure 3.1: Scene window of the Unity editor

GameObject

GameObject is the base class for any object included in a scene. Whether it is your character, background image, UI element, or some other entity, it is a GameObject. But using this fundamental class alone makes almost no sense. The GameObject serves more as a base that we can build upon to create practical entities by adding Components, which implement the desired functionality. We can also use GameObjects as parent objects for other GameObjects. Every scene has a hierarchy of GameObjects that are present in it. We can see it in the Hierarchy window of the Unity editor in picture 3.2. GameObjects can also be used to create Prefabs. Prefabs are reusable, pre-configured templates for GameObjects. Button GameObjects created using a prefab (blue) can also be seen in fig 3.2.

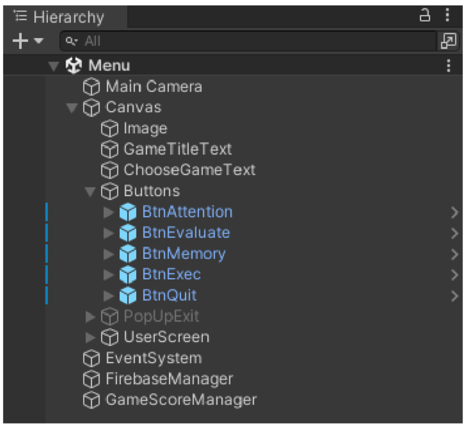

Figure 3.2: Hierarchy window in the Unity editor

Component

Component is also a base class. All types of Components derive from this class. Components can be assigned to a GameObject to implement its properties or functionality. There is one non-removable component assigned to every GameObject by default - Transform. Transform is a component describing the position, rotation, and scale of the game object.

Other useful components are:

- Sprite Renderer, Image - graphic visualization
- Canvas, Text, Button, Layout Group, InputField - UI elements
- Rigidbody - physics
- Collider - collision detection[2]
- Script - logic

Components are assigned to GameObjects via the inspector window of the Unity editor (picture 3.3). Public variables of logic scripts can also be accessed through the inspector window, which saves time during testing or debugging.

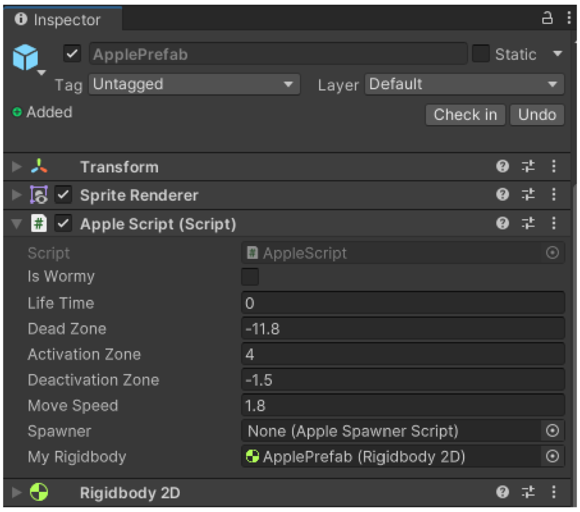

Figure 3.3: Inspector window in the Unity editor

[2]Can be used to detect mouse/finger collision via the `OnMouseDown()` method.

Chapter 4

Proposed solution draft

From the analysis of existing touchscreen games focusing on the assessment of cognitive function, it is clear that most of the existing games take inspiration in classic cognitive tasks.

There are some successful attempts of innovative approaches that try to turn the well-established tasks into a more pleasant experience using modern technology. Especially for the elderly, games such as Episodix[47] are a great alternative. This game is designed specifically for this part of population. And together with other games from the Panoramix battery is then also tested on a sample consisting of people this age in the Galicia region. Another successful touchscreen game battery is aforementioned - TENI[45]. Similarly to Panoramix, this game battery is also targeted and tested on a certain age group. In this case it's children. Those batteries show great results and have been a good source of inspiration for drafting my own touchscreen game battery.

However, I want to try a different approach on assessing cognitive function via a touchscreen game battery. Instead of limiting the test sample to a certain group of people and basing the results on predetermined norms of the tasks, I decided to look the other way. I want to try to utilize the advantages of a touchscreen device to the maximum and take advantage of the ever-growing popularity of smartphones by basing the evaluation method on the average values of the large quantity of game results. The idea is that the user plays the 3 games designed to assess attention, memory and decision-making respectively while their performance data are collected and stored in the cloud. They are than able to view the comparison of their results with the average player and their position between other players. With every new playthrough, the data pool gets larger and larger and thus provides more genuine results for the comparison. If needed, the application can be altered and connected to a custom database. That can be useful for creating statistics for companies or schools.

Touchscreen technology is a great candidate for such use. It is widespread both geographically and generationally. The controls of a smartphone/tablet are very simple and straightforward, so games fitting this type of input must be picked and altered to provide a positive experience to the player. This can be done quite successfully due to the similarity of pen and paper used by traditional tests and a touchscreen. The simplicity of touchscreen input is also a great asset for collecting exact game data such as response time. A more complicated method of controlling the game would mean keeping track of multiple different values throughout the play which would be much harder to record, store, and process. A quick responsible tap on the screen is easier to analyze than e.g. two dimensional mouse movement in a more complicated game.

The games themselves will be inspired by the recommended assessment methods in DSM-5[5] and the aforementioned existing game batteries.

As mentioned before, assessing cognitive function is a very difficult task mainly because every person is developed differently in different cognitive aspects. Finding out how a person holds up to other users is sometimes the most straightforward form of evaluation.

Chapter 5

Creating a game battery

I decided to call the application GAMP (Games for assessing Attention, Memory, Problem-solving). It is a touchscreen Android application with cloud accessibility designed to assess the cognitive domains of the human brain through simple games. Taking inspiration from existing video games focused on cognitive assessment [47] [45], several mobile games were thought up. The goal is to assess the 3 cognitive domains by editing or remaking classic assessment tasks that have shown good results into a set of mobile games that are able to collect reliable data for assessment and provide meaningful feedback to the user by comparing their results with other players' achieved score.

5.1 Design

The design of the app should be as simple as possible to make navigating it an easy task for users of any age group.

Login & Navigation

Upon opening the app, the user is welcomed with a prompt to enter their „user code". The app is not commercially available for now, it is expected to be used experimentally and instead of creating an account to store the data of the participant, a simple set of characters is used for identification of the player (the organizational pattern of the codes can be chosen by the examiner that decides to use this evaluation method). After entering the unique user code obtained from the examiner a new node is created for the user in the cloud.

The user then gets to choose between 3 games via buttons in the main menu. By choosing a game in the menu and navigating through the welcome screen which explains the rules of the chosen game and shows a short instruction video, the user starts the desired game. Underneath the three game buttons is an evaluation button, which becomes interactable after completing at least 1 game. This button can be revisited after completing or replaying all the games so the user gets a complete visualization of his cognitive skills.

Attention game - Applention

Applention is a 2D mobile game focused on identifying deficits in sustained attention. Sustained attention is the ability to focus on a certain task for a long period of time, and was selected for reasons mentioned in 2.2.

The premise of the game is very simple and takes the idea from the TENI attention game and T.O.V.A.[45][24], the player oversees a 2D conveyor belt transporting a total of 100 different apples from right to left. Each apple has a different color, some have leaves or even bugs or dirt on them. These impurities do not matter in this virtual world because the apples will be cleaned and sorted afterward, they are on the apple just as a distraction. The player's point of interest on these apples is the pink worms, that are sometimes sticking out of the apple.

The player's goal is to focus on the conveyor belt and tap on those apples, that have a worm coming out of them. The worm can be partly hidden under previously mentioned leaves, bugs, etc. So it is not always easy to spot it. The beginning and end of the conveyor belt are veiled behind a blue curtain. The gap in the middle of the belt is the only place players can actually tap the apple. The curtain isn't hiding the incoming apples completely as it is too short. This allows the player's attention to drift and look for worms in the not-yet completely visible apples. This distraction can cause the player to miss out on the apples in the gap or at least slow down their reaction. A screenshot of the game can be seen in figure 5.1.

Once all 100 apples are checked by the player, he can leave the game by tapping the exit text that appeared at the top of the screen.

The number of correct and incorrect taps as well as the reaction time of correct taps is collected. Although this is a test of attention and not reflexes, slower reactions indicate the loss of attention and thus have to be considered in the evaluation.

One session of this game is about 3 minutes long, the time is chosen deliberately this long, to really question the ability to sustain attention even on a monotonous task for long periods of time.

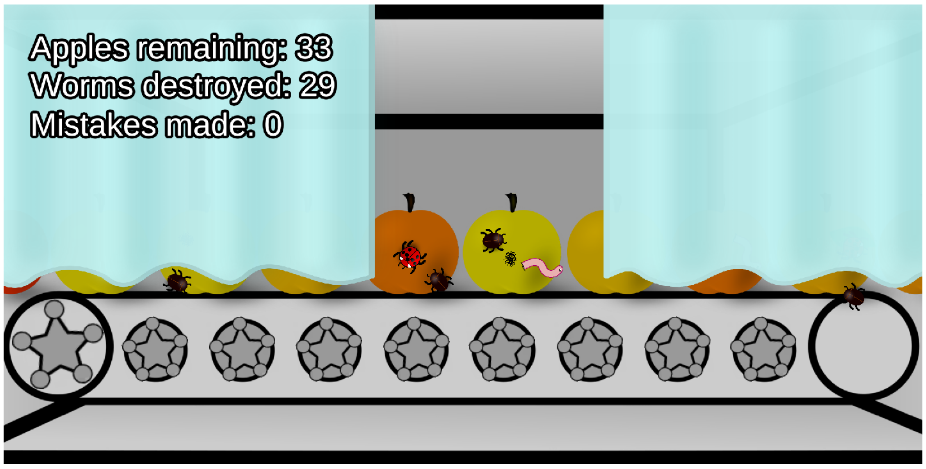

Figure 5.1: Screenshot of the attention assessing game - Der Applention

Memory game - MeMo

The game focusing on memory is called MeMo and specializes in the assessment of working memory.

This game is also very simple, it is inspired by Workix[48] and based on reversed Corsi's Block-Tapping task.[10] The player is presented with a 3x3 grid of buttons, as seen on figure 5.2. An increasingly longer sequence of buttons lights up in orange color for the player at the beginning of every level. The player is then instructed to repeat the sequence in reverse order (from last to first shown). Doing this task in reverse order forces the player to store information using working memory. This way, memory is the cognitive domain being challenged and not attention.[48] If the player successfully taps the blocks in the correct order, he advances to the next level, and the sequence is prolonged by one button tap. After a wrong button tap, the player loses 1 of his 5 lives and a new sequence starts from the beginning. An exit button also appears on the right side of the screen, in case the player is sure they can't reach a better score.

The stats recorded are the highest level reached from the five playthroughs. As memory is the domain being assessed, reaction time or other data seems irrelevant to measure.

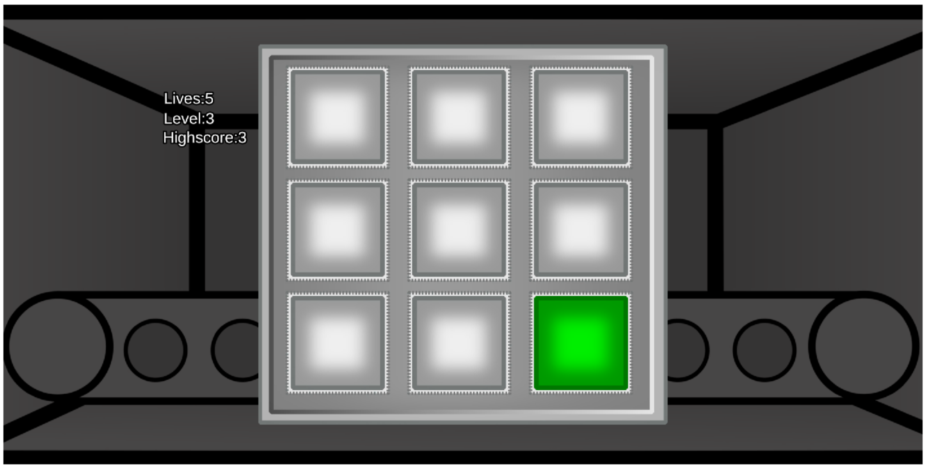

Figure 5.2: Screenshot of the memory assessing game - MeMo

Decision-making/Problem-solving game - Ringle

The last of the 3 games is Ringle, which assesses the decision-making and problem-solving skills of the player. As previously mentioned, problem-solving and decision-making are closely intertwined. To solve a problem, you have to make decisions and sometimes making a decision is a sub-problem by itself. That's why this game assesses both of these skills.

This game is based on the Tower of London task[40], which is a popular task focused on assessing executive function, which includes decision-making. In Ringle, the player works with 3 pillars with 4-6 differently-colored rings stacked onto them, present in figure 5.3. The player can only move one, topmost ring at a time and is instructed to recreate the state of the rings shown to him on a virtual screen in the background. By tapping a pillar with rings on it, the topmost ring of this pillar is selected, and then, by tapping another pillar, it is transported onto it. Unlike the classic Tower of London, a timer set to 6 seconds on the left side of the screen forces the player to make quick decisions while solving the task. If the player doesn't make a move in time, the current level is over for him. Successfully getting to the predetermined state takes the player to the next level, where the optimal number of moves is higher or the level is more complicated in some other way. This game consists of 8 levels and after completing or failing the last one, the player can go back to the menu.

The number of moves taken and the optimal number of moves for the level are collected after every level as well as if and how fast was each level finished by the player. The impulsive decision-making combined with foreseeing and predicting the future states to solve the problem make a good combination for the assessment of these skills.

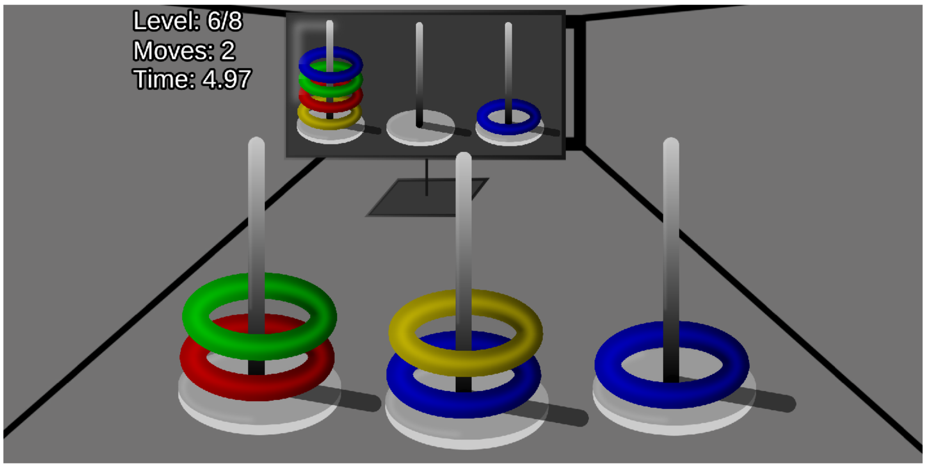

Figure 5.3: Screenshot of the decision-making skills assessing game - Ringle

5.2 Implementation

The chosen platform for implementing this set of mobile games is Android. Mainly because it is more user/developer-friendly than other touchscreen operating systems. The game was made using the Unity game engine as it is a powerful tool for creating simple (and advanced) games and provides great opportunities for a project like this.

List of software used for the project:

- Visual Studio Code 1.88.1[1] - writing code
- Unity 2022.3.10f1[2] - app design/compilation
- Android Studio 2023.1.1.[3] - build
- Firebase[4] - database
- Inkscape 1.1.2[5] - graphics/sprites

All of these technologies are free for personal and commercial use.

Project metrics & tree structure

The most important folder in a Unity project is the `Assets` folder where all the necessary files for the project (scripts, images, ...) are stored. I used a tree structure to divide the created files into folders based on the game they belong to to make the organization more clear. Each game folder contains 3 subfolders filled with different types of assets: `Scripts`, `Sprites`, and `Prefabs`. The purpose and importance of these types of assets is briefly explained in chapter 3 Visualization of the tree structure can be seen in figures 5.4 and 5.5.

The whole project consists of about 2300 lines of code and 25 custom-made sprites.

[1] https://code.visualstudio.com
[2] https://unity.com/products/unity-engine
[3] https://developer.android.com/studio
[4] https://firebase.google.com
[5] https://inkscape.org

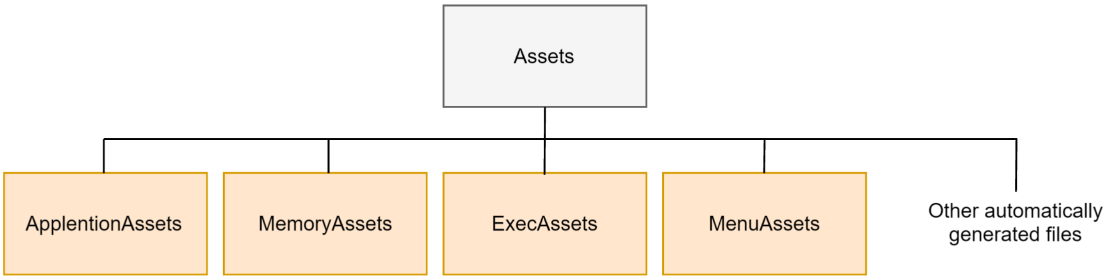

Figure 5.4: Tree structure of the `Assets` folder of the Unity project[6]

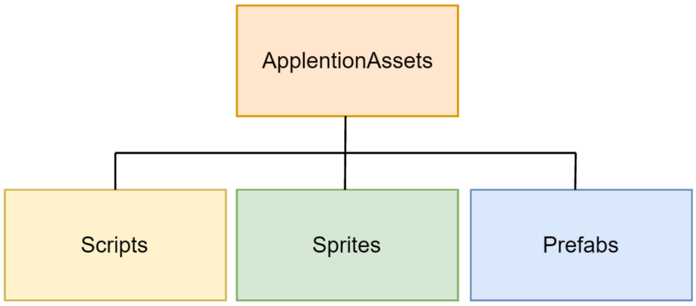

Figure 5.5: Example of the tree structure of the individual scene folders

Scenes

The application consists of 8 Unity scenes (Menu, 3 games, 3 introduction screens and an evaluation screen). Each scene has their own assets and GameObjects, the only singleton GameObjects existing throughout the scenes are the `FirebaseManager`, `GameScoreManager` and `UserScreen`, which are used to store and load user data. By choosing a game in the menu, the user appears in the welcome scene which explains the rules of the chosen game and shows a short instruction video. Example of a welcome screen is shown in figure 5.7. The user can then continue to the game scene, this is where the playthrough takes place and where data are collected.

Sprites

Graphics are an important component of a game because they make the user experience more pleasant. All of the visual elements of this application are original and were created for this purpose using Inkscape. Inkscape is an open-source graphic editor utilizing the Scalable Vector Graphics format (SVG). A total of 25 unique sprites were drawn and exported as high-resolution bitmap images to provide a visual representation for the GameObjects.

[6]Shortcut „exec“ was used for decision-making and problem-solving as these skills are part of the executive function domain.

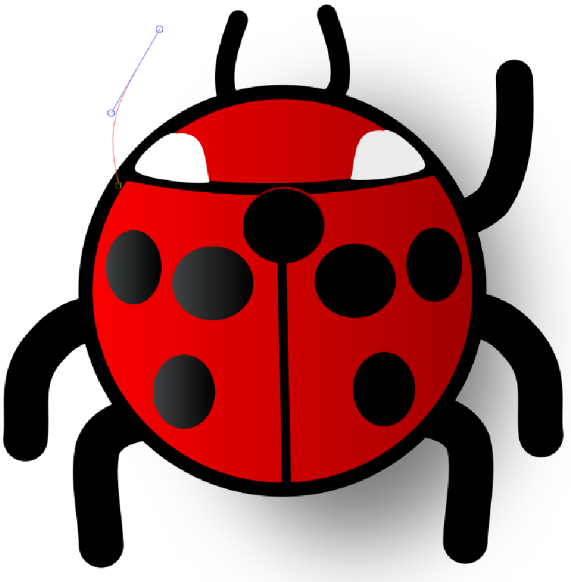

Figure 5.6: Screenshot of the ladybug sprite creation using Inkscape

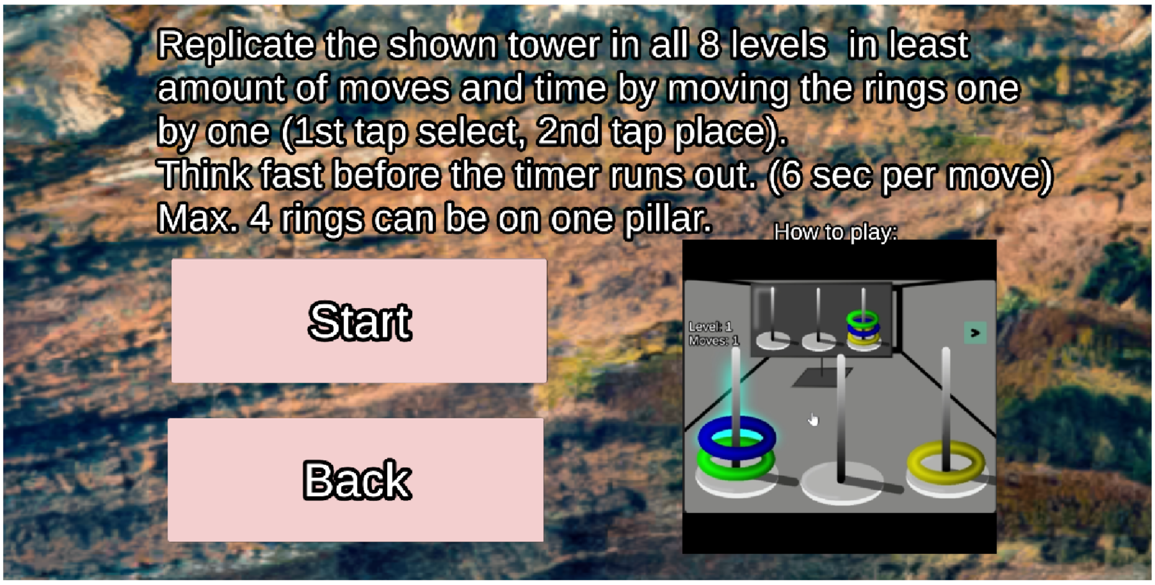

Figure 5.7: Welcome screen of the Ringle game

Database

GAMP uses a Realtime Firebase Database to store and access user data. It is a fast and reliable database and its simplicity is ideal for this kind of application. By using a user code that isn't already in the database, a new node is created for that name and other stats will then be saved inside of it. The database stores lots of information about the gameplay of the user, including basic stats like score or level but also stats that aren't normally visible to the player such as reaction time of the user. In the Applention game, user data are sent to the database by exiting the game when finished. In MeMo and Ringle, data for every level/life are sent throughout the play. The structure of a player's data .json file looks like this:

```
"user1": {
    "Attention": {
      "Final: ": {
        "Avg time": 0.8985721468925476,
        "Score": 50,
        "Worms spawned": 51,
        "Wrongs": 0
      }
    },
    "Exec": {
      "Level: 1": {
        "Completed": true,
        "Moves": 9,
        "Time": 9.190985679626465
      },
      .
      .
      .
      "Level: 8": {
        "Completed": true,
        "Moves": 15,
        "Time": 16.178075790405273
      }
    },
    "Memory": {
      "Life: 2": 9,
      "Life: 3": 3,
      "Life: 4": 3,
      "Life: 5": 1
    }
  },
```

5.3 Evaluation

Assessing any cognitive function is not an easy task. Measuring the needed information is just the first part. Using the acquired data to evaluate and make conclusions about one's well-being is much harder. Every person lives with different levels of cognitive skills and there is no such thing as a standard or healthy norm for cognitive functioning. That's why I chose to assess the cognitive skills of the player by comparing them to the average results of other players. This solution has a big advantage. It gets more precise and reliable over time as more and more people play the game and thus extend the data pool used for comparison. The final results of the comparison are then interpreted by the users themselves.

Dataset

For this solution to work correctly, a large set of user data is needed. Data collection is not an easy task, but one of the key features of the application helps out a lot. Cloud accessibility makes the collection of player data much easier, as people from all over the world can install this application on their phones and contribute their measured game values to the Firebase database. Collection of the base data was done on friends, colleagues, family, neighbors, etc. partly together with the testing of the app. The dataset currently consists of 45 entries for each game, each for one user. The structure of the database can be seen in 5.2. The limiting factor for this solution is the fact that Android devices are becoming less and less popular in Europe throughout the years.[2] But the motivation for the users to dig out their old Android devices and play is still there because they get something in return - feedback.

Calculation

When the user decides to see their results, the calculation of their score has to be done. The measured values are dynamically uploaded to the database during the playthrough of the games and stored there together with data from other players. Every time the user enters the Evaluation scene, the `Start()` method of `EvaluationScript.cs` is called and computing begins. `EvaluationScript.cs` processes every entry in the database to acquire the average values of measured statistics as well as values for the current player.

Overall score

The measured data are then used to create an „overall“ score for each of the existing user entries and the current user. This overall score is created for each of the games and combines the collected values to create a whole number resembling a complex outcome of the gameplay. The formulas for calculating a complex score (X) for each game are following:

Applention:

$$X_a = \left\lfloor \frac{\alpha}{4} - 2\beta - \gamma \right\rfloor$$

where:

- α = success rate (worms tapped to worms spawned ratio)
- β = number of mistakes
- γ = average reaction time

MeMo:

$$X_m = \alpha$$

where:

- α = highest achieved score

Ringle:

$$X_r = \left\lfloor \alpha \cdot 6 - \frac{\beta}{5} - \frac{\gamma}{2} \right\rfloor$$

where:

- α = number of successfully completed levels
- β = total number of moves
- γ = average completion time per level

The constants have been empirically chosen to create overall scores that are not too distant from each other but also don't compress the actual data into fewer values and thus lose the precision of the evaluation. More important user data have been prioritized and less important values were given less impactful constants (e.g. the number of completed levels is more important than an average level time). By calculating the overall score client-side, the formula can be changed and tampered with in the source code if time shows that it needs a slight change. The overall scores in the form of whole numbers are important for the final part of the evaluation process - visualization.

Visualization

To provide the user with useful information, the outcome of the data analysis has to be processed and turned into a user-friendly form. The presentation of user's performance in comparison to other players happens in the scrollable area of the evaluation screen of the app. The user is presented with an analysis of his performance in a text form, as seen in figure 5.8. This summary informs the user about the collected metrics of their gameplay for each game and how they compare to an average user. It also compares the overall score of the user with the datapool's average and informs the player about the total number of players/entries in the database.

All of the overall scores are also visualized in a bar chart underneath the text version, as shown in figure 5.8. The user's score bar is highlighted to give the user a more intuitive look into how their results stood up to the „competition“ and allow them to interpret them themselves. The bar chart is one of the reasons the overall score in form of a whole number was implemented. It is important to provide variant means of presenting the player data because every person prefers a different approach to understanding the received feedback. However, some values would be much harder to visualize in a chart or it straight up wouldn't make sense to do so.

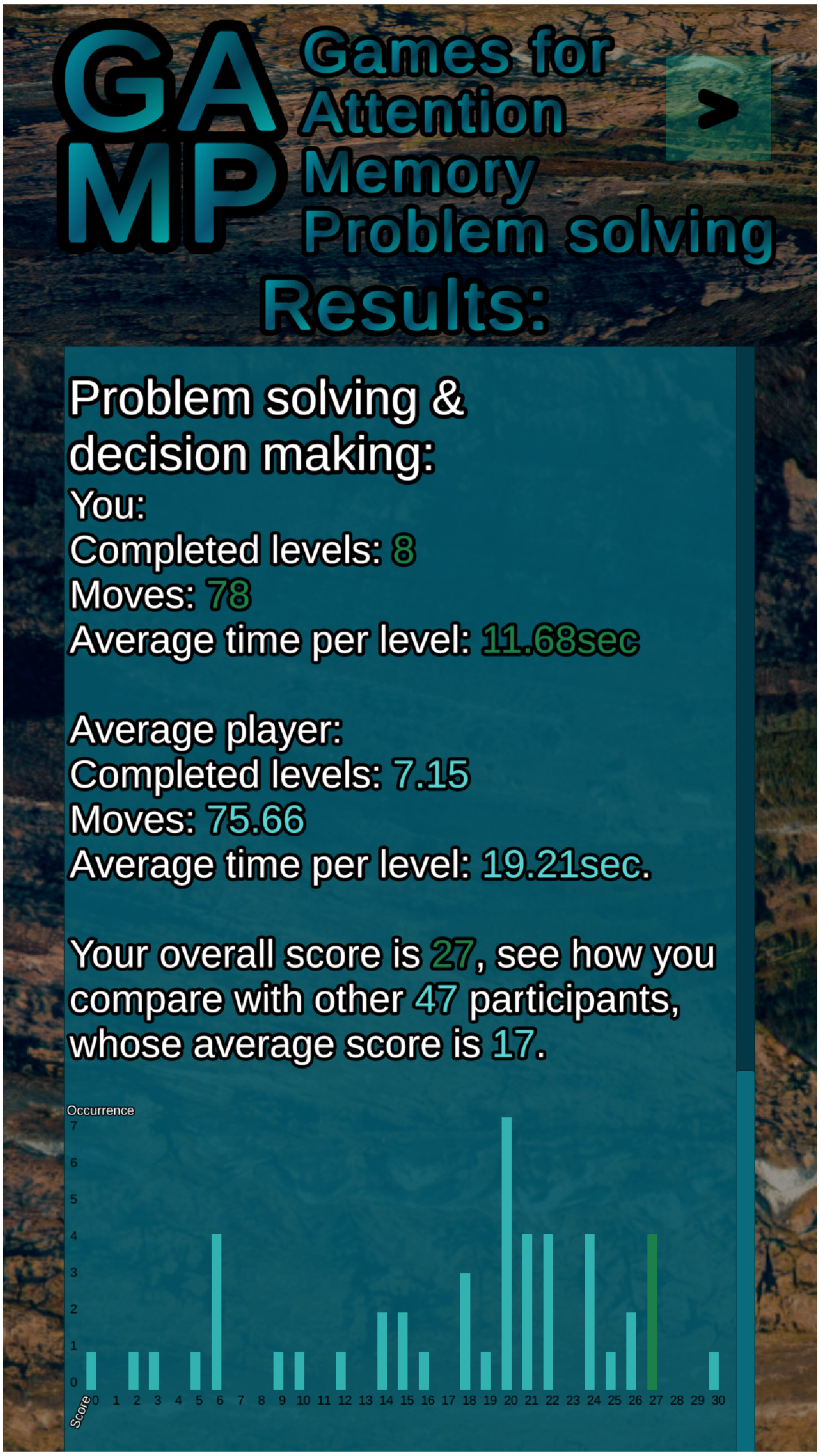

Figure 5.8: Evaluation screen (Ringle game scores section)

Chapter 6

Results

In order to validate and discuss the quality of the presented assessment methods, an analysis of the user experience and results of this work has been carried out.

6.1 Validation

Total of 45 people took part in the data collection, which was done together with user testing (6.2). Data were collected on 2 demographic groups of volunteers. The first group consisted of young people under 20 years of age and the second group was made out of people 20 years old or older. Most of them were of Czech origin and the younger group conisted mainly of high-school students. To be able to identify the individual test subject's group, the two groups of participants were separated by the different starting letters of their unique user code. The collected data and calculated overall scores were used to create a comparison between both demographic groups.

Expected results vs. acquired data

Three hypotheses regarding the results of the age groups comparison for each game based on relevant study findings were presented to add rigor to the test results:
Attention

Before comparing the differences between the overall scores of age groups in Applention, a game designed to measure sustained attention, the normative data for T.O.V.A.[1] [24], a task this game is based on, were studied and used for the creation of the testing hypothesis. A large meta study[49] has also shown that older adults react slower to the target stimuli than younger participants. But overall make less mistakes during the test.

- **Hypothesis 1** - Younger test group will have faster average reaction time but make more mistakes compared to the older group while playing Applention.

Result:

Results of the comparison for Applention metrics is shown in figures 6.1 & 6.1. As can be seen, younger test group scored better in both questioned metrics and also the overall score calculated using them. This does not support the presented hypothesis. Older test group made significantly more mistakes during the playthrough. The reason for this observation can be bad game design, optic or motoric problems in older people, or worse familiarity with touchscreen games. Either way, **Hypothesis 1** was **not confirmed**.

[1] Test of Variables of Attention

	<20	20+
Average reaction time(sec)	1.11	1.25
Average number of Mistakes	$0.\overline{45}$	0.75
Average overall score	$21.\overline{45}$	20.125

Table 6.1: Table visualization of Applention metrics for both demographic groups

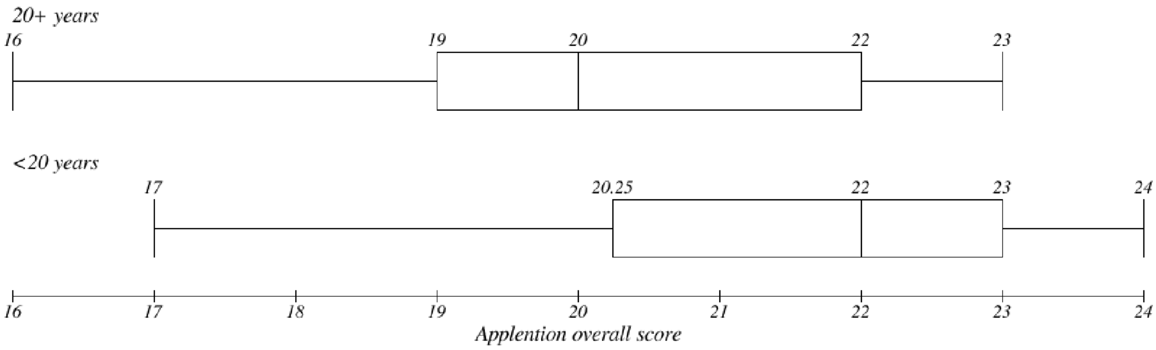

Figure 6.1: Box plot comparing achieved Applention scores of both demographic groups

Memory

The presented hypothesis for the comparison of working memory results from the game MeMo is based on the expectation that the quality of working memory tends to decrease with age.[11][27][36] This belief is also confirmed by existing normative data[34][8] for the reverse Corsi's block tapping task[10], which this game is based on.

- **Hypothesis 2** - Younger test group achieves a better overall score in MeMo compared to the older group.

Result: Comparative data shown in figure 6.2 confirm that younger test group indeed achieved a better average highscore in the working memory game. For this reason, it can be stated that **Hypothesis 2** was **confirmed**.

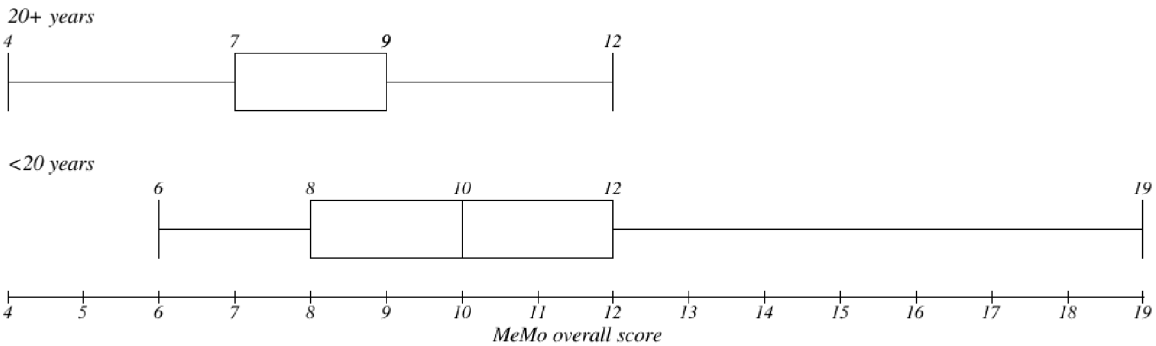

Figure 6.2: Box plot comparing achieved MeMo highscores of both demographic groups

Decision-making/Problem-solving

The last game to be verified by comparing the results of the two groups comparison with existing findings and studies is Ringle, a game based on the Tower of London task.[40] Studies show that the results of this game get better with age.[4][26] As well as decision-making and problem-solving in general.[20][33][46]

- **Hypothesis 3** - Younger test grup will achieve worse overall results in Ringle compared to the older group.

Result:

As can be seen in figure 6.3, younger participants really scored lower in the Ringle game compared to their older counterparts. This means that **Hypothesis 3** was **confirmed**.

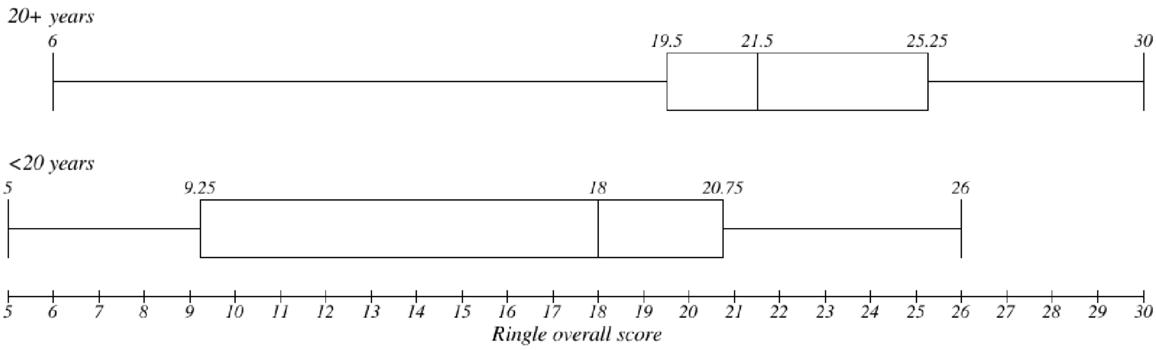

Figure 6.3: Box plot comparing achieved Ringle scores of both demographic groups

Conclusion

From the presented hypotheses, 2 out of 3 were confirmed and analysis of possible causes has been made. Results show that implemented games can assess some of the selected cognitive domains reliably. More in-depth and statistical methods of evaluation can be used for further and more precise evaluation of the created assessment method.

6.2 User testing

To confirm that this game battery does what is expected of it, user testing was conducted. The user testing was split into two phases and was conducted on total of 45 volunteers.

Phase 1 - Base data collection

During the first phase, participants were asked to simply play the 3 games to supply some basal data for the database, as previously mentioned in 5.3.

The testing process of phase 1 consisted of physically meeting the test subjects and handing a touchscreen device with the application running to them. They were asked to fill in the unique user code which was given to them in advance. I was present during the gameplay and ready to assist the participants in case some aspects of the rules were not clear to them. I also kept notes of how the subjects interacted with the app to improve the user experience in the finished version of the app. Some minor bugs were found and fixed during phase 1.

The initial data collection was conducted on 22 people and was also utilized to gather feedback on the game design. After the participants finished playing, they were asked to fill out an online form with closed questions regarding the 3 games. The results of the survey can be found in 6.2.

The base game data collected during the testers' playthroughs were then analyzed to figure out the rough intervals where the scores will occur. This knowledge was used to correctly set coefficients for calculating the overall score and customize the evaluation scene to fit the expected content. By acquiring those data, the application was able to be finished and phase 2 of user testing could begin.

Phase 2 - Application evaluation

Phase 2 of testing focused more on the quality of user experience and players' thoughts on the evaluation outcome and its form.

The testing process was very similar to phase 1, but remote. The participants were encouraged to download and install the application on their devices to reduce the data gathering time and make the data collecting more effective. The application was finished at this point and players had mostly no problems understanding the rules of the games and were independent. The .apk file and a unique usercode was sent to each participant together with a form.

On top of the data collection and questions from phase 1, more questions were added to the form in phase 2. This part of the testing wasn't mainly focused on the quality of the games, but more importantly on how the participants perceive their evaluation and understood the results presented to them. Total of 23 participants (with little to no overlap with phase 1 participants) took part in phase 2 of the testing, significantly extending the data pool and providing comprehensive feedback on the evaluation experience.

Survey results

I worked with the combined total of 45 filled out forms from phase 1 and 2. This number of survey responses is more than suitable to be used in a pilot study like this one. Let me present a set of hypotheses proposed before the testing that the survey results will either confirm or deny.

Hypotheses concerning the games:

Hypothesis 1 - Rules and controls of the games are easy to understand.

Hypothesis 2 - The attention-assessing game is less enjoyable to play than other games.

Hypotheses concerning the evaluation of the results :

Hypothesis 3 - The users can easily tell how they compare to other players.

Hypothesis 4 - The visualized overall score matches the user's performance.

Hypothesis 5 - Graphic visualization of the result is more preferred over text form.

The format for most of the questions was a scale from 1 to 10 points. With 1 being the most negative and 10 the most positive answer. Every question was present 3 times, each time in relation to a different game. By combining the answers from every triplet, we can calculate the average number of points for each question and look for any interesting deviations in regard to individual games and address them. The values have been rounded up to 2 decimal places.

Results:

1. **Understanding the rules and controls** - 8,8 points.

   The Applention game had a slightly better score (9,3 pts.) than the remaining 2 games, which scored around 8,5 pts. This is understandable, as the controls are much simpler in this game. It is safe to say that most players understood the rules and controls right away in every game.

2. **Enjoyability of the game experience** - 7,3 points.

   In this question, Applention scored just 6,6 pts. The second most enjoyable game is MeMo (7,3 pts.) and the user favorite is Ringle with (8 pts.) Games were mostly enjoyed by the users, but a deviation can be observed. Applention has a significantly worse score compared to the other games, as seen in figure 6.4. Of course, the games should be easy and fun to play. But in the case of a game like Applention, which was specifically designed to assess sustained attention, it is expected that the gameplay will be so boring the player loses interest and his attention starts to drift away.

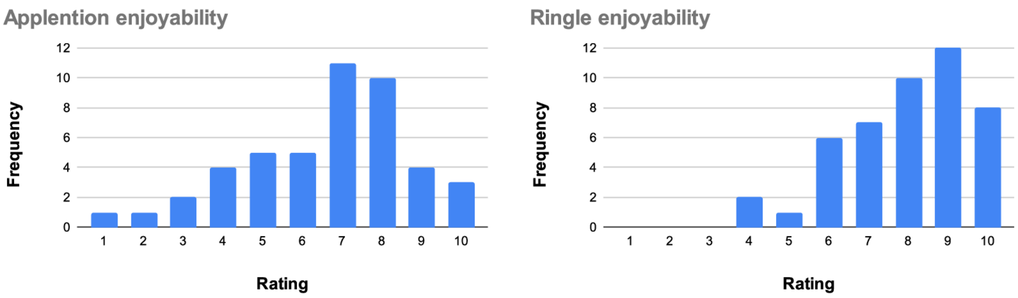

Figure 6.4: Visualization of Applention's enjoyability rating compared to Ringle's results

3. **Understanding the evaluation** - 8,3 points

   All of the games scored a little bit above 8 points. One interesting piece of information is the fact that MeMo scored the lowest (8,1 pts.). Despite being the simplest to evaluate as the reached high score was the only metric used, it seems that users prefer more comprehensive ways of evaluation calculation and understand shown results.

4. **Overall score corresponding with actual performance** - 8,5 points

   All of the games had a similar rating on this issue. It shows users trust the overall score calculated by the evaluation system for them.

5. **Text vs. chart preference**

   This is the only two-answer question. For every game, users chose chart visualization over text. The difference is significant but less than I expected. Every fifth user would rather see the textual form of the evaluation result.

By reviewing the analyzed answers, we can state that:

Hypothesis 1 was **confirmed** because rules and controls truly are very easy to understand.

Hypothesis 2 was **confirmed**, as Applention truly was the worst rated of the three games in terms of enjoyability.

Hypothesis 3 was **confirmed**, results show that users indeed understand the evaluation

Hypothesis 4 was **confirmed** because according to the users, their calculated overall score corresponds well with their performance

Hypothesis 5 was **confirmed** but less conclusively then expected. As 20 % of users would still prefer text form.

Results of other supplementary questions:

Graphic design of the games - 7,6 points

Replayability of the games - 6,9 points

Ringle achieved an exceptional rating of 7,9 pts. The other two games both scored under 7.

Satisfaction with achieved performance - 6,2 points

Users often overestimated themselves.

6.3 Critical analysis & future study

To make claims of this work even more solid, a critical self-assessment has been carried out together with improvement proposal.

An open question marked „suggestions for improvements“ was also present in the mentioned survey (6.2). Let's start the evaluation of the work done by analyzing the thoughts of test subjects and discussing the most common answers.

Game design

One thing that sticks out immediately is the large number of complaints regarding the simplicity of the Applention game. As mentioned before, this game is supposed to be slow and boring. But truth be said, apart from boring, this game is indeed almost too easy for anyone playing, even more than was expected. There were attempts during the development process to make the game harder by adding more distracting elements such as another type of bug and dirt. A blue curtain covering most of the screen was even added. These changes made the game a bit harder, but still, not much room to make errors was created.

As presented in 6.1, this game failed to satisfy the expected behavior and assesses the chosen domain only partially. The game still successfully distinguishes between a good and a bad performance. Overall, this game can be considered the weakest point of this work. It definitely needs improvements and is something that has to be worked on for the possible next version of the battery.

In contrast, Ringle received sensational feedback from the testers. There were multiple suggestions voiced to turn Ringle into a standalone game and add iOS support. Upon discussing this theme further, it was found, that the fast-paced controls combined with the familiar concept of the game [40] make a great combination to really immerse the player.

The critical evaluation of the implemented games has shown that reliable and time-tested methods of assessment can be successfully digitalized to work naturally in a touch-screen environment. These methods can be built upon by adding new features that enable the collection of more data and make the game more enjoyable. However tweaking of the ingrained methods has to be done carefully and in moderation to prevent creating a game too simple or distant to the core of the method. If left unmodified, the assessment method also serves its purpose successfully when correctly implemented.

Evaluation method

The evaluation part of data processing was the hardest. In order to compare the user's score to the broad spectrum of results in the data pool, hundreds of values had to be extracted from the database and processed by the program. The calculation of an average score from all the values collected for each user was a strenuous but quite simple task. It is the calculation of the overall score that is not yet perfect. As mentioned before, formulas were designed to utilize all of the collected user data for each game and combine them into a whole number representing the user's overall score. Pre-established constants were used during the calculation. The used constants were chosen based on the expected significance of each measured value. But were also affected by the desire to shrink the values into a smaller interval so they could be visualized and understood by the user more easily.

These constants could be further improved upon in the possible continuation of this work empirically by studying the number of occurrences for each overall score and determining if scores tend to hoard up around a certain value. And by conducting a more in-depth analysis of the given tasks to more conclusively identify the most important collected values of each game and adjust the constants based on the findings.

Continuation of this work should be mainly focused on aforementioned mistakes in the game design (Applention) and a more thorough validation of the evaluation method and statistical evaluation. Some specific recommendations for future research might include:

- More sophisticated user interface and visualization methods
- Addition of more cognitive domains to be assessed
- Improved replayability of the games
- Ability to add and challenge friends
- Enhance the feedback with personalized cognitive training tips

and many more...

Both the game design and the evaluation part of the proposed and implemented cognitive game battery are a success, although there is still room for improvement. The goal of assessing the chosen cognitive abilities was successfully achieved.

Chapter 7

Conclusion

The goal of this work was to assess the 3 chosen cognitive domains - attention, memory and decision-making/problem-solving by using an assessment method in the form of a touchscreen game battery. As was explained, problem-solving was assessed together with decision-making as these skills overlap and one is part of the other.

In the beginning, a thorough familiarization with the studied area was performed. A definition of cognitive domains was done as well as an explanation of some of the needed terminology from the field of cognitive science.

After successfully identifying and defining the cognitive domains chosen to be assessed, existing work regarding the assessment of these domains was studied. Video-game based methods for cognitive assessment were thoroughly analysed with special attention paid to the three domains.

After discussing the advantages and disadvantages of the current solutions, an innovative approach to the problem was presented. A touchscreen game battery with an unconventional evaluation method utilizing a growing database for the assessment of cognitive skills. A draft of the application and the game battery was drawn up and subsequently implemented for Android using Unity. The application consists of 3 games, each for one cognitive domain. After collecting the base data, the game battery was tested on volunteers. The collected data were split into two groups based on the age of the participant and comparison between the groups was made. The assessment method was evaluated by comparing it to the results of existing studies. The provided feedback from the test subjects was analyzed and discussed.

A fairly large database of players' performance data was created by collecting gameplay information using cloud accessibility.

The cumulative data were then used to evaluate users' game performance and assess and identify deficits in their respective cognitive domains, the goal of the work was achieved.

Other major achievements of this work are the core parts of the implemented cognitive game battery. A set of 3 touchscreen games, an evaluation system based on a mutual comparison, and an extensive dataset of players' performance data collected for the assessment.

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Appendix A

Contents of the included SD card

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.
|-- ThesisPDF (folder containing the .pdf version of the thesis)
|   ‘-- xceska07.pdf
|-- ThesisLaTeX (folder containing the .tex project files)
|-- APK (folder containing the APK file)
|   ‘-- -GAMP.apk
|-- GAMP (folder containing the project files)
‘-- Documentation (folder cotaining the project documentation)
    |-- documentation.pdf
    ‘-- documentation.md
```