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Design and implementation of Game-Based Cognitive Screening Instruments for Older Adults

by Fernanda Tavares Vasconcelos Oliveira

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of
A/Prof. Valerie Gay and Dr. Jaime Garcia

University of Technology Sydney
Faculty of Engineering and IT

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Fernanda Tavares Vasconcelos Oliveira, declare that this thesis is submitted in fulfilment of the requirements for the award of the degree Doctor of Philosophy, in the School of Electrical and Data Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

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FERNANDA TAVARES VASCONCELOS OLIVEIRA

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Achievements

PEER-REVIEWED CONFERENCE PAPERS

1. Oliveira, F., Garcia, J., Gay, V. 2021, 'Games for the Cognitive Assessment of Older Adults', paper presented to the *6th International Conference on Gamification and Serious Games (GSGS'21)*, Lausanne, Switzerland.
2. Oliveira, F., Garcia, J., Gay, V. 2022, 'Evaluation of CogWorldTravel: A Serious Game for Cognitive Screening', paper presented to the *10th International Conference on Serious Games and Applications for Health (SeGAH'22)*, Sydney, Australia.
3. Oliveira, F., Tong, B., Garcia, J., Gay, V. 2022, 'CogWorldTravel: Design of a Game-based Cognitive Screening Instrument', paper presented to the *Joint Conference on Serious Games 2022 (JCSG 2022)*, Weimar, Germany.

GRANT

1. 2021 UTS Social Impact Grant (AUD 10,000.00)

This was the result of a successful application for the amount of AUD 5,000.00 under the 2021 Social Impact Grants from the Centre for Justice and Inclusion, which was matched by the Faculty of Engineering and IT. The funding received enabled to pay for two game developers as casual employees to assist in the development of CogWorldTravel.

PRESENTATIONS

1. 2022 SEDE Talks
2. Podcast 'A game to support dementia diagnosis' at 2sER L07.3 (Available here)
3. 2020 SEDE HDR Showcase
4. 2020 CS HDR Showcase

AWARDS

1. Best Paper Award in the 6th lnternational Conference on Gamification and Serious Games (GSGS'21), Lausanne, Switzerland (Evidence here)
2. Runner up in the 2021 HDR wiEIT Awards
3. 1st Place Poster Presentation in the 2020 School Computer Science HDR Showcase

GAME

1. CogWorldTravel

CogWorldTravel is a serious game that is paving the way towards an alternative Cognitive Screening Instrument. A computer version of the game is available here, which can be accessed under request of the password.

ETHICS

1. UTS HREC ETH21-6184 – Games as Cognitive Screening Instruments for Older Adults
2. UTS HREC ETH21-6304 – Games as Cognitive Screening Instruments for Older Adults

The protocol for the pilot study with older adults was approved by the Human Research Ethics Committee (HREC) of the University of Technology Sydney (UTS). The ethics approval number that refers to this study is UTS HREC REF NO. ETH21-6184. The protocol for the semi-structured interviews with the experts was approved by the same HREC. The ethics approval number that refers to this study is UTS HREC REF NO. ETH21-6304.

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List of acronyms

ACE	Addenbrooke's Cognitive Examination
ACE-R	Addenbrooke's Cognitive Examination Revised
AD	Alzheimer's disease
ADL	Activities of Daily Living
ANPA	American Neuropsychiatric Association
AR	Augmented Reality
AUC	Area Under the Curve
CAM	Confusion Assessment Method
CLVT	California Verbal Test
CRT	Choice Reaction Time Test
CSI	Cognitive Screening Instrument
DI	Delirium Index
DSM-V	Diagnostic and Statistical Manual of Mental Disorders
DVT	Digit Vigilance Test
ETAM	Erlangen Test of Activities of Daily Living
GDD	Game Design Document
MCI	Mild Cognitive Impairment
MMSE	Mini Mental State Examination
MoCA	Montreal Cognitive Assessment
PAL	Paired Associates Learning
Ph.D.	Doctor of Philosophy
RASS	Richmond Agitation-Sedation Scale
RAVLT	Rey Auditory Verbal Learning Test
TMT	Trail Making Test
UTS	University of Technology Sydney
WHO	World Health Organization

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Abstract

Dementia is a neuropsychological disorder that has physical, psychological, social, and economic impact on the individual, their families and society in general. Still, it is underdiagnosed worldwide. With nearly 10 million new cases every year, according to the WHO, there is an urgent need to develop assistive technologies to the dementia care context. Dementia is characterized by a decline in one or more cognitive domains and the early detection of cognitive changes and possible underlying dementia is possible with the use of Cognitive Screening Instruments. Traditionally, these instruments are pen-and-paper-based, but recent studies have investigated the use of video games as an alternative to the traditional method. Most previous studies have followed an exploratory approach and used existing games, bespoke games, or activities-of-daily-living games to investigate the correlation between performance on validated tests and performance on the game. While those studies have proven that data collected during gameplay correlate with cognitive performance, there still exists plenty of opportunities to explore new designs that improve the experience of the older adult undertaking the cognitive assessment, but most importantly, incorporate the same criteria of traditional Cognitive Screening Instruments. This research work focused on the design and implementation of CogWorldTravel, a serious game for the cognitive screening of older adults that features six mini-games targeting at least one element of each major cognitive domain. A literature review on the use of games for such purpose is performed and the design, implementation, and evaluation processes of CogWorldTravel are described. A pilot study was conducted with older adults to verify that they would be able to play the game. In addition, semi-structured interviews with experts in assessing dementia were performed, who confirmed that CogWorldTravel is paving the way towards an alternative cognitive screening instrument. The lessons learnt from both studies are integrated and a series of design recommendations is captured for improvement in future iterations. New mini-games can be added to test additional cognitive elements not included in this first version. It is expected that the use of game-based Cognitive Screening Instruments will contribute to the global dementia underdiagnoses issue. By being a self-administrated instrument,

it reduces the time required from the healthcare professional. It also offers the opportunity to include several cognitive elements, which is helpful for clinicians in differentiating diagnosis. Finally, the introduction of game elements may improve the experience of people being tested and hopefully alleviate the anxiety experienced during cognitive screening.

Keywords: Serious Games, Game Design, Games for Health, Cognitive Screening, Cognitive Assessment, Cognitive Screening Instruments, CogWorldTravel, Older Adults, Dementia

1. Introduction

This chapter presents an overview of the context in which this study is fitted. The research problem is defined along with the research questions, aims, and objectives. The significance and contribution of this study are explained. The methodology used for accomplishing the research objectives is described. Finally, the organization of the thesis is outlined at the end of the chapter.

1.1 Background

Dementia is an umbrella term for several neurocognitive disorders that represent a decline in cognitive function compared to a previously attained level of functioning (American Psychiatric 2013). While there is no current treatment to prevent or cure dementia, the early detection of the disease benefits patients, their families, and society. Early diagnosis enables prompt access to available medications and medical attention, which may help in the management of symptoms, as well as preparation for the future in the best possible way (Rasmussen & Langerman 2019). Despite the importance of early detection, dementia is often underdiagnosed worldwide. The World Health Organization (WHO) recognizes the disease as a public health priority and published a global action plan on the public health response to dementia covering the period 2017-2025 (Cahill 2020). The call from the WHO addresses multiple dementia-related issues, including the development of assistive technologies. With very limited treatment options and an urgent need to act on the burden caused by dementia, there is a priority to improve diagnosis rates so that effective measures can be applied to prevent disease progression (Rasmussen & Langerman 2019).

Cognitive screening is a common clinical practice for detecting dementia, which can also be used for tracking disease progression and treatment response (Malloy et al. 1997). Cognitive screening is performed using cognitive tests, known as Cognitive Screening Instruments (CSIs) (Larner 2013). Although these tests are not diagnostic, they are helpful in the early detection of cognitive changes and possible underlying

dementia, which is the first step toward accurate diagnosis. Ideally, these CSIs should sample all major cognitive domains, namely complex attention, executive function, learning and memory, language, perceptual-motor, and social cognition (American Psychiatric 2013).

There are several well-researched CSIs available, which have been used for nearly 50 years (Malloy et al. 1997). Their first versions were based on pen-and-paper, with many evolving to digital versions. Until these days, however, the proper use of CSIs have several limitations. A relevant barrier for such instruments is the time required for administration in clinical settings. It is also well known that the environment where the cognitive test is undertaken may affect the performance of the individual (Larner 2013). Especially for pen-and-paper-based instruments, results may vary across examiners (Malloy et al. 1997). In addition, most instruments depend on language, and scores must be validated independently in each language as they may vary when cognitive tests are translated. Similarly, educational and cultural biases are evident in many instruments (Larner 2013). Developing CSIs that are less sensitive to language, education, and culture is still highly encouraged (Molnar et al. 2020).

Serious games are regarded as games that entertain players while accomplishing another primary purpose. Generally speaking, the rationale for using game technology for serious purposes is the ability to motivate participation and increase adherence to a certain activity (Johnson et al. 2016). It has already been proven beneficial in delivering several personalized healthcare solutions for older people (Martinho et al. 2020). As the detection of early signs of cognitive changes is a first step towards dementia diagnosis and there is a need to improve diagnosis rates, in the last years, the research community has dedicated efforts to investigate the potential of using serious games for cognitive screening purposes. The use of serious games as CSIs offers advantages in overcoming some of the limitations of those traditional instruments, particularly when compared to pen-and-paper-based versions. As game-based instruments can be self-administrated, they can be used in clinical settings more efficiently, or even remotely, which may overcome the barrier related to the time required for administration. The use of game elements can improve the experience and feeling of being tested, which helps in avoiding lower performance due to anxiety. Because total and partial time-based

measures for diverse tasks can be collected, and scores can be calculated, recorded, and tracked automatically over time, game-based CSIs reduce the risk of biased administration. Random stimuli can be generated to avoid possible learning effects when the older adult is required to be assessed again in a relatively short period of time. Serious games also offer endless possibilities of creating instruments that are not dependent on language, education, or culture.

Serious games for cognitive screening is still a relatively new field of research (Valladares-Rodríguez et al. 2016). Most of the previous studies evaluated the use of games to screen cognition by correlating game scores with results from a validated test used as a reference. While the outcome of these studies found the use of serious games as alternative CSIs feasible, it does not necessarily mean that those games meet the criteria of CSIs. An ideal CSI should sample all major cognitive domains, and the games investigated do not necessarily cover elements from all domains. The games are certainly requiring some cognitive elements from the player and the scores achieved in the game may correlate with the scores from a test that tests overall cognition. However, if the game is to be used solely as a CSI, it may miss some important elements. Investigating design approaches that satisfy the same criteria of traditional CSIs and are suitable for older adults is still an open challenge. This research project further investigates these design approaches with a focus on the design, implementation, and evaluation of CogWorldTravel. It is expected that the lessons learnt throughout these processes will enable one more step to be taken towards the use of game-based CSIs.

1.2 Research Questions

In order to further investigate the design of serious games for older adults that can be used as alternative CSIs to improve diagnosis rates of dementia, the research questions defined in Table 1.1 have been formulated.

Table 1.1 - Research Questions

RQ 1	**What features should a serious game have to be used as a CSI for dementia?**
RQ 2	What is the overall perception of older adults and experts towards CogWorldTravel?
RQ 3	What cognitive elements are involved in CogWorldTravel?
RQ 4	What are the lessons learnt from CogWorldTravel?

1.3 Research Aims and Objectives

This research aims at designing and developing a serious game for the cognitive screening of older adults, which follows the same criteria of traditional CSIs and is suitable for older adults. In order to achieve the goal of this research, the following objectives have been identified:

- Objective 1: To identify the criteria of traditional CSIs for dementia.
- Objective 2: To identify how a serious game can be suitable for most average older adults.
- Objective 3: To design a serious game that incorporates the same criteria of a traditional CSI for dementia and is suitable for older adults.
- Objective 4: To run a pilot study with older adults to verify whether they can play the game with no issues.
- Objective 5: To validate if the proposed game has the potential to be used as a CSI for dementia by conducting semi-structured interviews with experts in cognitive assessment.
- Objective 6: Capture the lessons learnt from CogWorldTravel and provide design recommendations for future iterations of the serious game.

1.4 Significance and Contributions

The significance of this research lies in the urgent need to develop assistive technologies in the dementia care context. While dementia affects approximately five percent of the world's elderly (Dua et al. 2017), most people with dementia do not

have a diagnosis. This diagnosis gap may be resolved by improving the use of CSIs (Larner 2013).

There is no current treatment to prevent or cure dementia; however, improving detection rates of dementia is beneficial to patients, their families, and societies (Rasmussen & Langerman 2019). If early diagnosed, patients can access available resources and support to maximize their quality of life, be involved in decisions about their future, and use available medications and alternative therapies more effectively. With access to the right services, people can take control of their condition and live independently in their own home for longer (Rasmussen & Langerman 2019). For families and carers, it is also better if they are given the time to prepare themselves. Dementia can last for several years, changing the lives of the people who need to support individuals physically, emotionally, and financially (Rasmussen & Langerman 2019). While a significant part of the costs of dementia falls on the families, another significant part is accounted for as formal care. Economic benefits exist for families, communities, and society if people at risk have access to interventions and the onset of dementia is delayed (Lewis & Torgerson 2017).

This research is also aligned with the preferences of older adults on how they would like to be assessed. A study conducted by National Australia in a project named 'better ways of assessing cognitive health' surveyed 547 older adults aged between 55 and 96. The results demonstrated that the majority of participants indicated a preference for a computer or tablet-based cognitive screening. Only 9.9% preferred pen-and-paper-based instruments. They also revealed to prefer at-home cognitive test administration, and very few (3.6%) stated that they would like to be accompanied by a health professional during the cognitive screening procedure (Earl 2017). The combination of preferences reported by the participants shows that serious games could be a compelling method to deliver cognitive screening.

The key contribution of this research project is that it is another step toward using serious games as alternative CSIs for dementia. While the primary outcome of this research is CogWorldTravel as a potential game-based CSI for older adults, it is also expected that the lessons learnt during the literature review, design and evaluation

processes will benefit other researchers. Ultimately, it is expected that this research will provide guidelines on how to develop a better game-based CSI for older adults.

1.5 Research Methodology

This research work was conducted in a series of phases that are described in the following:

Phase 1: Literature Review

The first phase of this research consisted of a comprehensive examination of the literature to understand the state of the art in using serious games for the cognitive screening of older adults. It was analysed the methodologies followed by previous works and the achievements in this area. Research gaps and needs were identified.

Phase 2: Requirements Definition

After research gaps and needs were identified and the research goal was outlined, requirements that would guide the design of the game-based CSI for older adults were defined. This phase included the examination of classical instruments to understand their design criteria and the cognitive domains assessed by them. In addition, recommendations available in the literature for designing suitable games for older adults were taken into consideration.

Phase 3: Design & Development

After the requirements were defined, the next phase consisted of designing a solution to meet them as far as possible. This resulted in the proposal of the serious game CogWorldTravel, which was documented as a Game Design Document (GDD) containing the necessary guidelines for implementation. CogWorldTravel was developed using the game engine Unity.

Phase 4: Pilot Study with Older Adults

A pilot study was performed with older adults, who are the target audience of CogWorldTravel. This study aimed at investigating if there were any usability or

acceptability issues. Older adults were invited to play the serious game in a Zoom session and then share thoughts about this experience.

Phase 5: Validation with Experts

Semi-structured interviews with experts in the assessment of dementia were conducted via Zoom to request feedback on whether the mini-games included in CogWorldTravel had the potential to measure the cognitive elements that they were designed to measure. The six mini-games were demonstrated, including the rationale and the detailed description of the game activity.

Phase 6: Closing the Loop

The results from the pilot study with older adults and the semi-structured interviews with the experts were integrated and translated into design recommendations for future iterations of CogWorldTravel.

1.6 Thesis Organization

The rest of this thesis is organized as follows:

Chapter 2 provides a comprehensive literature review of serious games for the cognitive screening of older adults. This chapter will describe approaches followed in previous studies and what has been achieved in this field of research.

Chapter 3 describes the design process of CogWorldTravel. It will be explained the requirements that were defined so that the serious game could be used for cognitive screening purposes and be suitable for older adults. The game tasks will be detailed.

Chapter 4 presents the pilot study in which older adults were involved. It includes results obtained from usability and acceptability investigations performed with older adults.

Chapter 5 describes the validation stage of the game that involves experts in dementia assessment. It includes results obtained from the semi-structured interviews that were conducted to request feedback on the game.

Chapter 6 closes the loop by integrating the findings from the pilot study with older adults and the semi-structured interview with the experts. It also provides the foundations for future iterations of CogWorldTravel.

Chapter 7 concludes this research by summarizing the key findings, limitations, and future research opportunities.

2. Literature Review

A literature review was performed to understand the use of traditional cognitive screening methods and the state of the art of using game technology for the cognitive assessment of older adults. This review sought to provide a broader perspective of the methodologies previously used and the achievements in this field of research so far.

2.1 Introduction

Dementia progressively affects cognition, behaviours, and the ability to perform activities (Nash 2019). There are different types of dementia, with most common causes being Alzheimer's disease, Lewy body dementia, and frontotemporal dementia. Symptoms may also differ across the different types but neuropsychiatric symptoms are considered universal, which include psychotic symptoms, such as paranoia, hallucinations, and mood symptoms, disruptive motor or vocal activity, sleep disturbance, apathy, wandering, disinhibition, hyperphagia, and hoarding (Nash 2019).

Although there is no treatment capable of reversing cognitive impairment caused by dementia, there are evidence that interventions can slow the progression of certain types of the disease. The early detection and differentiation between the types of the disease is particularly important to improve the chances of treatment (Nash 2019). People who have a diagnosis are given the right to live the best quality life as possible while they are able, be involved in decisions about their future, access available treatments and support systems (Rasmussen & Langerman 2019).

The detection of dementia requires evidence of cognitive decline in one or more cognitive domains when compared to a prior level of functioning (Rose 2019). The assessment of cognition is traditionally performed with the use of neuropsychological tests that contain skill-based components separately. Scores obtained in individual cognitive abilities are compared to normed standards (Larner 2013). In the following section, an overview of traditional cognitive screening instruments will be presented, followed by a review of the state of the art of game-based cognitive screening. To

perform the literature review, related works were searched in five electronic databases: ACM Digital Library, IEEE Xplore, MEDLINE, PsycINFO, and ScienceDirect. The selected articles focused on the use of games for the assessment of cognitive abilities of older adults, written in the English language, published as journal articles, book chapters, or in conference proceedings between 2010 and March 2022. The databases mentioned above were searched using the strings defined in Table 2.1. After title and abstract screening were performed, the articles were selected for full-text reading. Finally, 27 articles were included in this review.

Table 2.1 - Strings used in the search of related works

Scope	String
Games	(gamif* OR game) AND
Cognition	(cognit* OR neurocognit* dementia OR mental) AND
Screening	(assess* OR screen* OR measur*) AND
Older Adults	(elderly OR older adult OR senior)

2.2 Traditional Cognitive Screening Methods

Cognitive screening is a clinical practice that seeks to detect a neurocognitive disorder, which CSIs facilitate. There are a very large number of published CSIs; however, this section aims to provide a high-level overview and present only two of the very well-known and most widely used cognitive tests (Larner 2013), as it would be impractical to describe every available test. These two cognitive tests were selected because they are often used as a benchmark against new proposed instruments, including many of the game-based ones included in this chapter. In addition, performance tests assess the ability to perform Activities of Daily Living (ADL) and have been used to screen for dementia (Gold 2012). This section briefly introduces these performance tests and describes an example that has been validated to detect the early stages of dementia.

CSIs should sample all major cognitive domains and be able to detect a given disease with reasonable sensitivity and specificity. Many of the available instruments have been validated to detect dementia. Nevertheless, even the most well-known and accepted tests can never have perfect sensitivity and specificity. While highly sensitivity

tests can detect early stages of dementia, there is an increased risk of making false-positive diagnoses. On the other hand, highly specific tests reduce the risk of making false-positive diagnoses but at the risk of missing early cases (Larner 2013).

The Mini-Mental State Examination (MMSE) is the cognitive test most commonly used by clinicians when screening for various neurocognitive disorders (see Figure 2-1) (Folstein, Folstein & McHugh 1975). However, studies have shown that the MMSE is more accurate when screening for moderate or severe dementia than early dementia (Larner 2013). The MMSE is divided into two sections. The first requires verbal responses and tests orientation, memory, and attention. In the orientation part, the patient is asked about the date and location. Memory is required to recall the names of three objects. Attention is tested by asking the patient to spell a word backward. In addition to attention, calculation is also involved in the serial-seven task. The second part of the MMSE covers the ability to name, follow verbal and written commands, write a sentence spontaneously, and copy a polygon. The maximum total score on the test is 30, and a study indicated that a score of 20 or less was found only in patients with dementia and not in normal older people (Folstein, Folstein & McHugh 1975).

Unlike the MMSE, the Montreal Cognitive Assessment (MoCA) was developed to detect Mild Cognitive Impairment (MCI) and is widely used to detect the early stages of dementia (see Figure 2-2). It is a pen-and-paper cognitive test that assesses memory, language, executive functions, visuospatial skills, calculation, abstraction, attention, concentration, and orientation. Memory is assessed through a short-term memory recall task with two learning trials of five nouns and a delayed recall five minutes later. Visuospatial abilities are tested in the clock-drawing and the cube-copying tasks. Multiple executive function aspects are tested in the modified Trail Making Test (TMT), where the patient alternately connects letters and numbers, the phonemic fluency task, and the two-item verbal abstraction task. Similar to the MMSE, the MoCA uses serial seven and backward word spelling. These two tasks, combined with the letter *A* tapping task, measure attention, concentration, and working memory. Language is tested with the confrontation naming activity, where the patient needs to name three low-familiarity animals, the repetition of two complex sentences, and the same

phonemic fluency task used to measure executive functions (Nasreddine et al. 2005). In the phonemic fluency task, the patient needs to say as many words starting with the letter *F* as possible, which requires coordination of lexico-semantic knowledge, shifting from word to word, working memory, searching strategy, and inhibition of irrelevant words (Larner 2013). Finally, and again similar to the MMSE, orientation is tested by asking the patient time and place (Nasreddine et al. 2005).

Mini-Mental State Examination (MMSE)

Patient's Name:_____ Date:_____

Instructions: Ask the questions in the order listed.
Score one point for each correct response within each question or activity.

Maximum Score	Patient's Score	Questions
5		"What is the year? Season? Date? Day of the week? Month?"
5		"Where are we now: State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible. Number of trials: _____
5		"I would like you to count backward from 100 by sevens." (93, 86, 79,72, 65, ...) Stop after five answers. Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.) 
30		**TOTAL**

Figure 2-1 - Mini Mental State Examination (MMSE)

Source: (Aligizakis, Nektarios & Gryllaki 2021)

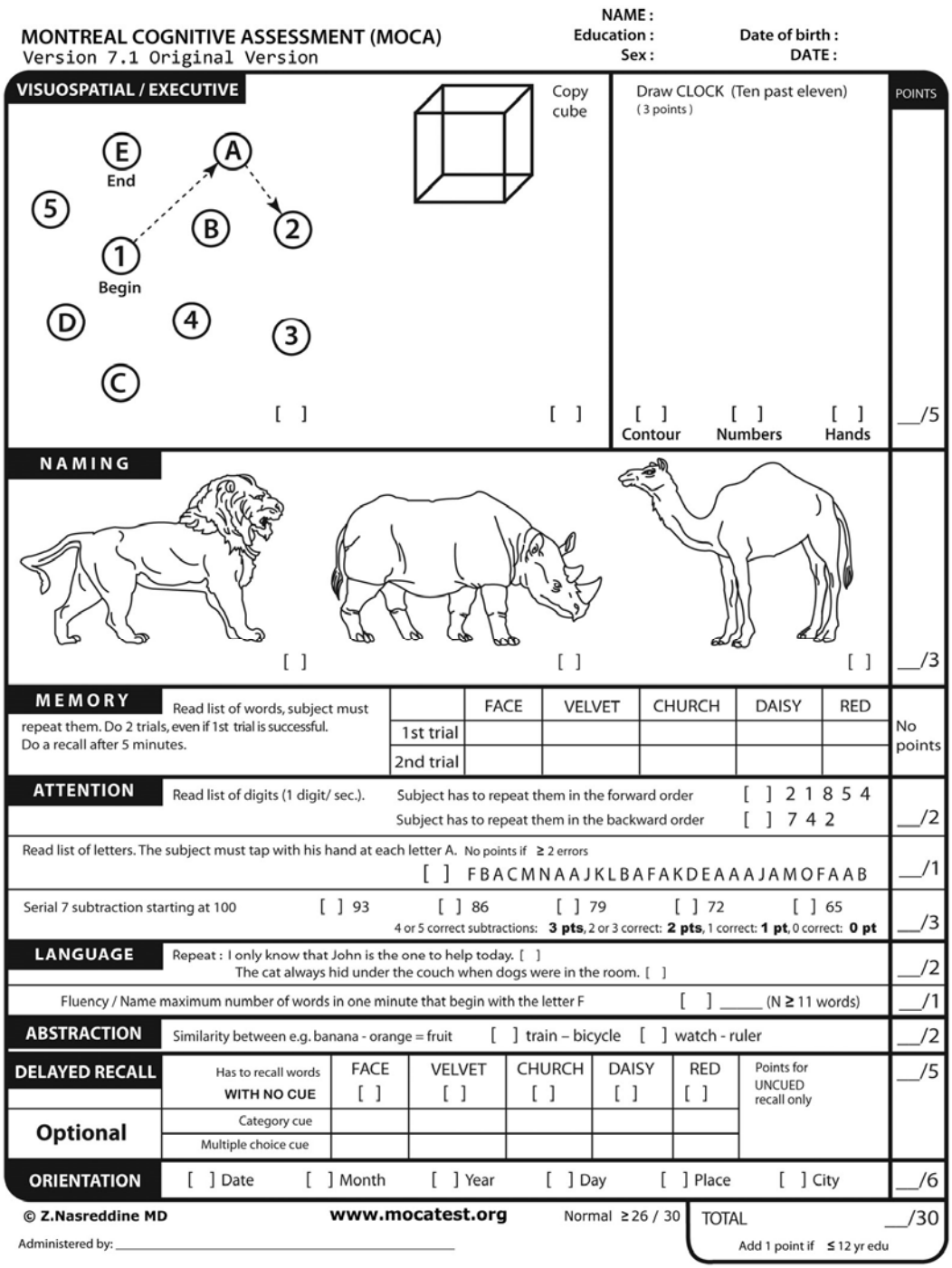

Figure 2-2 - Montreal Cognitive Assessment (MoCA)

Source: www.mocatest.org

Initially, cognitive tests required only pen and paper for administration. Later, computerized tests were developed, including versions of existing tests and new ones. Administration of the MoCA using a tablet to enhance the in-person testing experience

was made available. On their website (Nasreddine 2022) and in the validation study of the electronic MoCA (eMoCA) described in (Berg et al. 2018), the advantages are listed as increased precision by providing integrated instructions for administration and scoring, automatic partial and total scoring, and timed tasks. Moreover, also on their website, at the time that this thesis was being written, it is advertised the upcoming MoCA solo, which is a new version of the test that enables self-administration with the use of voice recognition technology and artificial intelligence to receive, analyse, and accurately score the test. The rationale for self-administration is to save healthcare professionals' time in busy clinical settings and improve the user's experience by allowing them to take the test in the comfort of their homes (Nasreddine 2022).

As dementia causes a decline in the capacity to perform ADL, there also exists the performance tests as an alternative approach that assesses the ability of older adults to perform such activities. Those tests typically involve observing the older adult perform instrumental ADL, questionnaires, and interviews for both the patient and an informant (Gold 2012). In the same way as the cognitive tests, performance tests do not have a single standard; however, the Erlangen Test of Activities of Daily Living (ETAM) can be used as an example as it was validated to differentiate between healthy individuals, MCI, and moderate dementia. The ETAM includes six items that cover the functioning domains of communication, mobility, self-care, domestic life, and major life areas. The activities faced by the participant involve making a phone call, understanding traffic situations, understanding a train timetable, administering medications, making a cup of tea, setting the alarm, washing the dishes, and managing finances (Luttenberger et al. 2016).

To date, no single cognitive screening test is appropriate for use in all settings or with all populations. For decades, significant attention from the research community has been dedicated to adapting and improving existing CSIs (Larner 2013) and developing new ones. More recently, game technology has also been investigated to improve cognitive assessment (Valladares-Rodríguez et al. 2016). The common approaches involved using existing games, developing bespoke games that target

specific cognitive aspects, or developing game tasks that replicate ADL. Those approaches will be reviewed in the following.

2.3 Cognitive Screening Using Existing Games

A number of previous research focused on investigating if the player's performance in existing games could indicate their cognitive abilities. To investigate this approach, Gielis *et al*. proposed a toolbox kit for the Microsoft Solitaire Collection that captures the player interaction without modifying the original game (see Figure 2-3). The authors listed player actions and mapped them to cognitive functions with the assistance of experts in cognitive assessment. The player actions were correlated with mental flexibility, inhibitory control, working memory, selective attention, visuospatial ability, object recognition, apraxia, cognitive planning, and processing speed (Gielis, Abeele, et al. 2021). They trained machine-learning models to differentiate between MCI and healthy older adults and achieved an Area Under The Curve (AUC) > 0.877. They analysed that the results are comparable to the MMSE and the MoCA, which previously had a mean AUC of 0.780 and 0.883, respectively (Gielis, Vanden Abeele, et al. 2021).

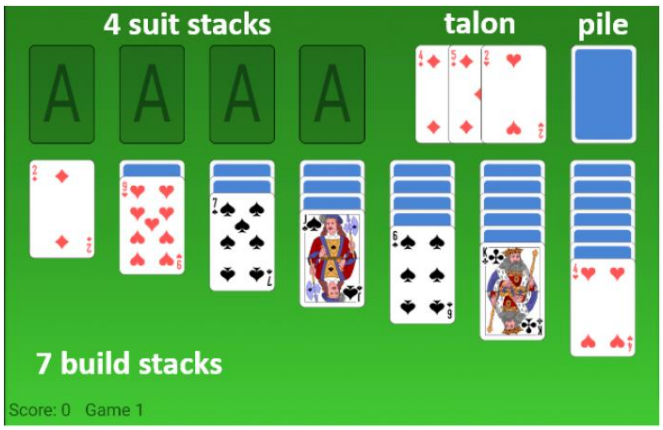

Figure 2-3 - Game developed by Gielis et al.

Extracted from (Gielis, Abeele, et al. 2021)

Following a similar approach, Intarasirisawat *et al*. developed their version of the games Tetris, Fruit Ninja, and Candy Crush Saga so that they could collect in-game data (see Figure 2-4). They selected those three games to explore different demands on cognitive function. Visuospatial ability was investigated in Tetris, response inhibition

and attention in Fruit Ninja, and visual search in Candy Crush Saga. The authors collected maximum scores, response time, touch gestural interaction, and device motion patterns and correlated them with cognitive assessment scores. They found that better game performance and specific interaction patterns were associated with increased cognitive performance (Intarasirisawat et al. 2019).

Figure 2-4 - Games developed by Intarasirisawat et al.

Extracted from (Intarasirisawat et al. 2019)

Krebs et al. also developed their version of the Match-3 puzzle, which is similar to Candy Crush Saga and the player finds rows of three identical tiles by swapping two adjacent tiles (see Figure 2-5). They added an eye-tracking mechanism to the game and investigated the correlation between cognitive performance and eye movements. Significant correlations were found with the TMT (Krebs et al. 2021).

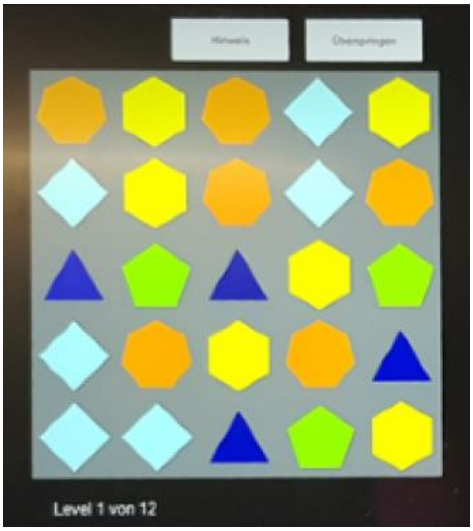

Figure 2-5 - Game developed by Krebs et al.

Extracted from (Krebs et al. 2021)

Bonnechere *et al*. investigated the correlation between cognitive function and the scores obtained from eight mini-games of the Peak mobile app, a commercial brain training set of games (see Figure 2-6). The Babble Bots involves word fluency, and vocabulary as the player needs to form words with given letters. The Word Pair involves semantic access and vocabulary, as the player should pair words according to rules. The memory sweep involves attention, spatial memory, and working memory as the player needs to memorize the position of highlighted times in a 4x4 matrix. The Size Count involves attention, spatial memory, working memory, and arithmetic, as the player needs to do some calculations to determine which card is larger or if they are equal. Square Number involves quantitative reasoning, arithmetic, and working memory, as the player needs to add cards to match a target. Must Sort involves response control and task shifting, as the player sorts cards. Unique involves visual attention and visual recognition, as the player needs to tap the odd item considering its shape and colour. Rush Back involves sustained attention, visual recognition, and working memory, as the player needs to memorize cards and determine if the current card matches a card that came before. The game scores presented a mean correlation of 0.72 with the MMSE and 0.81 with the Addenbrooke's Cognitive Examination Revised (ACE-R), which indicates that the app can also be used to assess cognition (Bonnechère et al. 2018).

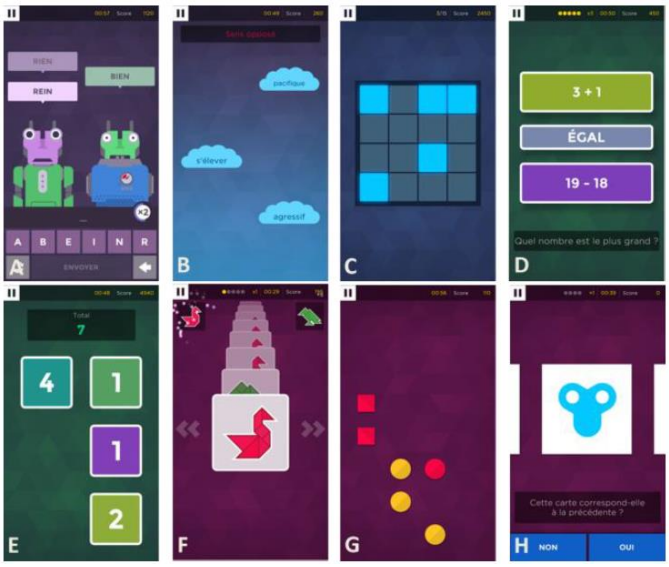

Figure 2-6 - Peak Games used by Bonnechère et al.

Extracted from (Bonnechère et al. 2016)

Siraly *et al*. decided to study the classical 'Find the pairs' memory game, where the player flips two cards at a time to find the matching ones. They analysed the number of trials and the time needed to complete the game. Correlations were found between the Paired Associates Learning (PAL) test and the number of attempts to complete the card game, and between the Addenbrooke's Cognitive Examination (ACE) and the Rey Auditory Verbal Learning Test (RAVLT) total scores and the time needed to complete the memory game. The sensitivity and specificity to detect MCI were 83% and 62% for the number of trials and 82% and 67% for the time to complete (Sirály et al. 2015).

The related works that used this approach are summarized in Table 2.2, including the cognitive elements involved in each game.

Table 2.2 - Cognitive Screening Using Existing Games

Author	Game	Cognitive Elements
(Gielis, Abeele, et al. 2021)	Microsoft Solitaire Collection	Mental flexibility, inhibitory control, working memory, selective attention, visuospatial ability, object recognition, apraxia, cognitive planning, and processing speed.
(Intarasirisawat et al. 2019)	Tetris, Fruit Ninja, and Candy Crush Saga	Visuospatial ability, response inhibition, attention, and visual search.
(Sirály et al. 2015)	'Find the pairs'	Memory
(Krebs et al. 2021)	Match-3	Visual search
(Bonnechère et al. 2018)	Peak mobile app	Fluency, vocabulary, semantic access, attention, spatial memory, working memory, arithmetic, quantitative reasoning, response control, task shifting, visual attention, and visual recognition.

2.4 Cognitive Screening Using Bespoke Games

In order to increase the control over which cognitive domains could be assessed through gameplay, another number of researchers opted to develop bespoke games. Valladares et al. presented the Panoramix suite for detecting MCI and Alzheimer's disease (AD). The battery includes six serious games and assesses memory, executive functions, attention, and gnosis. Episodix is a gamification of the California Verbal Test (CLVT), and the player conducts a virtual walk where they learn a list of objects. In the end, they are challenged with yes or no recognition, free recall, short and long-delayed recall, primacy, semantic clustering, response to inhibitions, etc. Attentix presents a colour sequence that the player must repeat. The length of the sequence is incremented by one after a correct answer, for a maximum length of 10 colours. Semantix challenges the player with a target stimulus, and then they must select the given stimulus among others. Workix reproduces the Corsi's Cubes Test, with the sequences being requested to be repeated in both the same and reverse orders. In Procedurix, the player should track a rotating circle as accurately as possible using the mouse. Gnosix involves the recognition of shapes, colours, expressions, or feelings, or a random combination of them. Each game task was individually correlated with several cognitive tests, and correlations were found for all of them (Valladares et al. 2018).

The COGNIPLAT game platform was designed by Goumopoulos et al. Each game in the platform focuses on a specific cognitive area, including language, space and time orientation, attention, memory, executive functions, and abstraction. The platform exercises include a puzzle, a maze, a recall task, calculations, naming objects, memory cards, sound matching, message comprehension, and creating a story. They used machine learning to train the model to discriminate between MCI and healthy individuals and achieved an accuracy of 91.79% (Goumopoulos et al. 2021).

The Brain Aging Monitor–Cognitive Assessment Battery (BAM-COG) proposed by Aalbers et al. consists of four puzzle games for measuring working memory, visuospatial short-term, episodic recognition memory, and planning. In Conveyer Belt, the player should select items from a grocery list. In Sunshine, the player should

reproduce a visual pattern in a 5x5 cloud matrix. In Viewpoint, the player should memorize a stimulus and select the exact match among other options. In Papyrinth, the participant should slide columns and rows to connect pieces of road and create a path. The results from the game were compared with traditional cognitive tests, and the researchers evaluated that three of the puzzles provided promising psychometric characteristics. Still, Viewpoint did not provide a good measure for episodic recognition memory as they expected (Aalbers et al. 2013).

Silva Neto et al. studied three mini-games (see Figure 2-7). In the first, the player needs to separate sheep according to their colour. In the second, identify the number of sheep that appear in the enclosure, and, in the third, which they called the Cow Milking game, the individual needs to remember and indicate the order in which cows were milked. The results obtained from the game showed a correlation with results obtained in the MoCA for all cognitive domains, except for abstraction (Silva Neto, Cerejeira & Roque 2018).

Figure 2-7 - Games developed by Silva Neto et al.

Extracted from (Silva Neto, Cerejeira & Roque 2018)

Fukui et al. tested four mini-games: flipping cards, finding mistakes, arranging pictures, and beating devils (see Figure 2-8). Flipping cards is the same as the classical find the pairs and was the only one they evaluated as capable of differentiating healthy from MCI individuals. The three other games were only sensitive to detecting patients with AD. The authors highlighted that the cognitive functions involved in each game were unclear but they expect that the flipping card game involves recent memory, the finding mistakes game involves attention and discrimination, the arranging pictures game involves processing and remote memory and the beating devil game involves judgment. (Fukui et al. 2015). Influence of culture can be easily observed in this game.

Figure 2-8 - Games developed by Fukui et al.

Extracted from (Fukui et al. 2015)

Boletsis and McCallum proposed Smartkuber and assessed its relationship with the MoCA. Smartkuber consists of five mini-games, which assess attention, memory, motor skills, visual and spatial processing, language, and executive functions. The game uses Augmented Reality (AR) and the manipulation of tangible cubes. The player uses those cubes to memorize and reconstruct flags (see Figure 2-9), memorize and reconnect pairs of friends, provide the result of calculations, and form words and shapes. During their test with 13 participants, concurrent validity of 0.81 was found with the MoCA. They also concluded that learning effects did not affect the game scores (Boletsis & McCallum 2016). A drawback of this specific approach is the need for physical objects, which makes it unsuitable for remote administration.

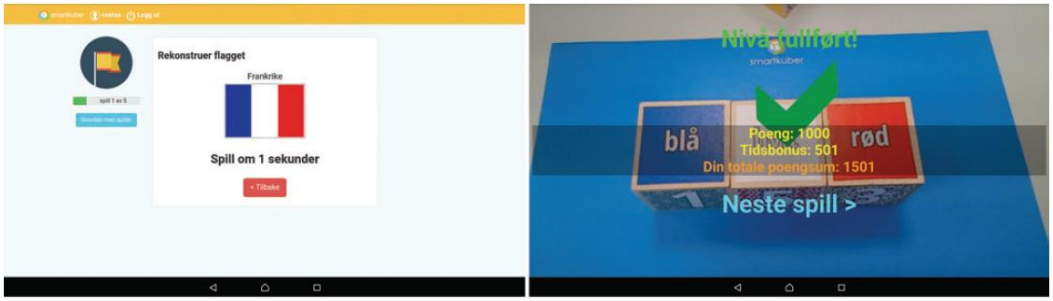

Figure 2-9 - Game developed by Boletsis and McCallum.

Extracted from (Boletsis & McCallum 2016)

Liu et al. proposed a table tennis game where the player is requested to hit the ball according to its colour (see Figure 2-10). They plan to use historical data to adapt the game's difficulty to suit the older adult's physical and cognitive conditions. The performance in the task was correlated with the classical Go/No-Go Discrimination Task, as the game involves inhibition abilities (Liu et al. 2016).

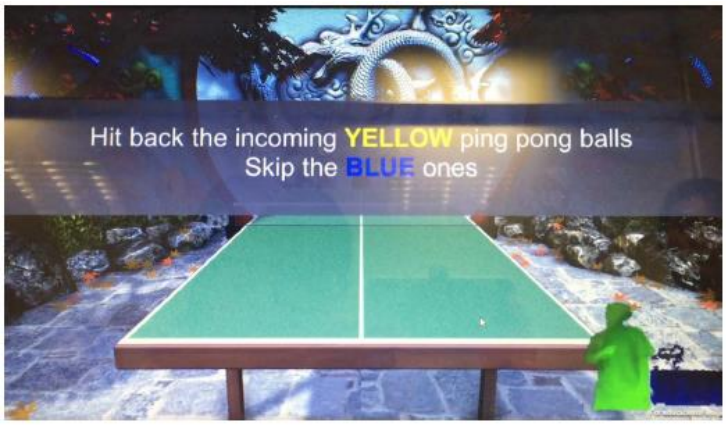

Figure 2-10 - Game developed by Liu et al.

Extracted from (Liu et al. 2016)

The Game-Based Intelligent Test (GBIT) was used by Lin et al. to predict the performance on the MMSE. The GBIT consists of a 16-grid keyboard device (see Figure 2-11) to test attention, coordination, and memory by asking participants to react, judge, or answer correctly after seeing signals displayed on the keyboard. The authors found that the tool accurately predicts 88.20% of MMSE results (Lin, Mao & Huang 2021). Although promising results were found in this research and the tool is considered based on a game, it is unclear what game elements are involved in this tool.

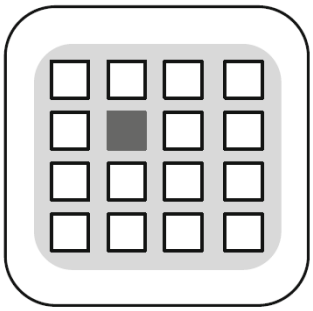

Figure 2-11 - Game developed by Lin et al.

Extracted from (Lin, Mao & Huang 2021)

Tong et al. proposed the Whack-a-Mole game, which mimics features of the classical Go/No-Go Discrimination Task (see Figure 2-12). The reaction time in the game task was significantly correlated with MMSE, MoCA, Confusion Assessment Method (CAM), Delirium Index (DI), Richmond Agitation-Sedation Scale (RASS), Digit Vigilance Test (DVT), and a choice reaction time (CRT) task scores (Tong et al. 2016). Later, they proposed the addition of distractors to the game as they hypothesized that this change in the game should provide a measure of response inhibition ability. They recruited participants and confirmed that performance on the game strongly correlated with the standard Go/No-Go discrimination task (Tong, Chignell & DeGuzman 2019). More recently, Urakami et al. conducted further research on the Whack-a-Mole game and proposed a design that includes new features to the game that enable the assessment of other cognitive elements. Cognitive speed is measured by hitting the mole as quickly as possible. Response inhibition is measured by avoiding hitting distractor moles. Working memory is required when the player needs to memorize a number in the T-shirt of the mole and hit a mole wearing the same number three positions later. Dimensional shifting is included by switching the rule that dictates what mole should be hit. Spatial attention is required to create awareness of where the mole may appear next. Visual short-term memory is measured when the player is required to memorize the colours of moles that should be hit. Finally, inhibition of processing conflict is included when moles of different sizes and wearing different numbers appear, and the player should hit the larger T-shirt number regardless of the physical size of the mole. The evaluation of their game design is yet to be performed (Urakami, Hu & Chignell 2021).

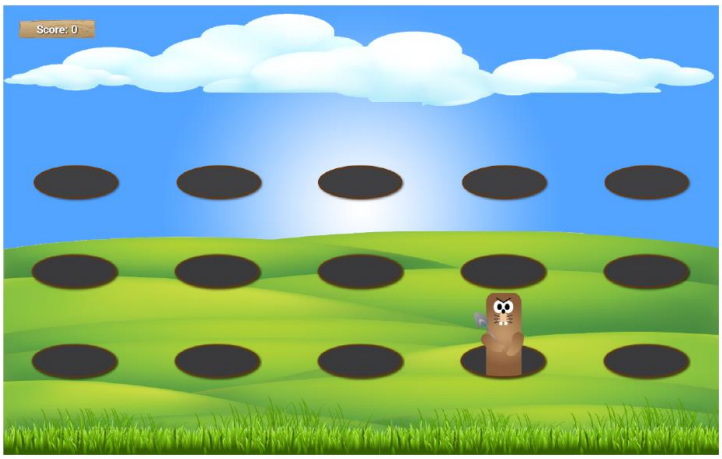

Figure 2-12 - Game developed by Tong et al.

Extracted from (Tong et al. 2016)

Hou et al. developed the virtual nostalgic game, where the individual is presented with small tasks based on nostalgic therapy and personalized material (see Figure 2-13). The tasks involve asking the player which items they have seen before, which clothes are appropriate for each situation, and questions related to a scene described earlier. It addresses the screening and monitoring of healthy individuals at home for the early detection of impairment. Final game scores were correlated with the MMSE and the MoCA, and an accuracy of 86.4% was achieved when evaluating MCI (Hou et al. 2017). Although it is desirable for a CSI to be independent of culture, this game is highly personalized for the Taiwanese population.

Figure 2-13 - Game developed by Hou et al.

Extracted from (Hou et al. 2017)

House et al. studied four mini-games from BrightScreener: Breakout 3D, Card Island, Tower of Hanoi 3D, and Pick-and-Place (see Figure 2-14). Breakout 3D tested executive function, and attention as the player bounces balls to destroy rows of crates. Card

Island is the same as the ‘Find the Pairs’ memory game and tested short-term visual memory and attention. Tower of Hanoi 3D tested executive function (task sequencing and problem-solving) while the player is required to stack disks in poles without placing larger disks on the top of smaller disks. Pick and Place tested working memory and divided attention, as the individual has the movement of the hand traced while placing balls on targets. BrightScreener is designed to evaluate elderly with various degrees of cognitive impairment, and results found a correlation of 90% with the MMSE (House et al. 2016).

Figure 2-14 - Game developed by House et al.

Extracted from (House et al. 2016)

The related works that used this approach are summarized in Table 2.3, including the cognitive elements involved in the games.

Table 2.3 - Cognitive Screening Using Bespoke Games

Author	Game	Cognitive Elements
(Valladares et al. 2018)	Panoramix	Memory, executive functions, attention, and gnosis
(Goumopoulos et al. 2021)	COGNIPLAT	Language, space and time orientation, attention, memory, executive functions, and abstraction
(Aalbers et al. 2013)	BAM-COG	Working memory, visuospatial short-term, episodic recognition memory, and planning
(Silva Neto, Cerejeira & Roque 2018)	Cow Milking	Attention, executive function, orientation, and visuospatial ability
(Fukui et al. 2015)	Flipping Cards, Finding Mistakes, Arranging Pictures, and Beating Devils	Recent and remote memory, attention, discrimination, processing and judgment*
(Boletsis & McCallum 2016)	Smartkuber	Attention, memory, motor skills, visual and spatial processing, language, and executive functions.
(Liu et al. 2016)	Table Tennis	Inhibition
(Lin, Mao & Huang 2021)	Game-Based lntelligent Test (GBIT)	Attention, coordination, and memory
(Tong et al. 2016)	Whack-a-Mole	Reaction time, inhibition
(Urakami, Hu & Chignell 2021)	Whack-a-Mole	Reaction time, inhibition, working memory, dimensional shifting, spatial attention, visual short-term memory
(Hou et al. 2017)	Virtual Nostalgic game	Not clearly defined
(House et al. 2016)	BrightScreener	Executive function, attention, short-term visual memory, and working memory

2.5 Cognitive Screening Using Activities of Daily Living Games

As the decline in the capacity to perform Activities of Daily Living (ADL) is also a central marker for people with dementia (Luttenberger et al. 2016), another number of studies focused on developing games that test the individual while performing virtual ADL. The Virtual Supermarket (VSM) proposed by Zygouris et al. is a serious game based on a groceries shopping activity. The player navigates through a virtual supermarket, buys the products indicated in a shopping list, and pays for them at the cashier (see Figure 2-15). The activity involves visual and verbal memory, executive function, attention, and spatial navigation, emphasizing executive function and navigation (Iliadou et al. 2021). The researchers assessed the performance of the Virtual Supermarket (VSM) in detecting MCI in older adults by comparison with the MoCA and the MMSE. The serious game displayed a correct classification rate of 81.97%, while the MoCA and the MMSE displayed 72.04% and 64.89%, respectively (Zygouris et al. 2020). Aiming at covering additional cognitive elements, including Virtual Reality technology, and aligning with the Chinese culture, Yan et al. conducted a similar study with another virtual supermarket serious game (VSP) and achieved a sensitivity of 85.9% and specificity of 79.0% for differentiating individuals with MCI and healthy controls (Yan et al. 2021).

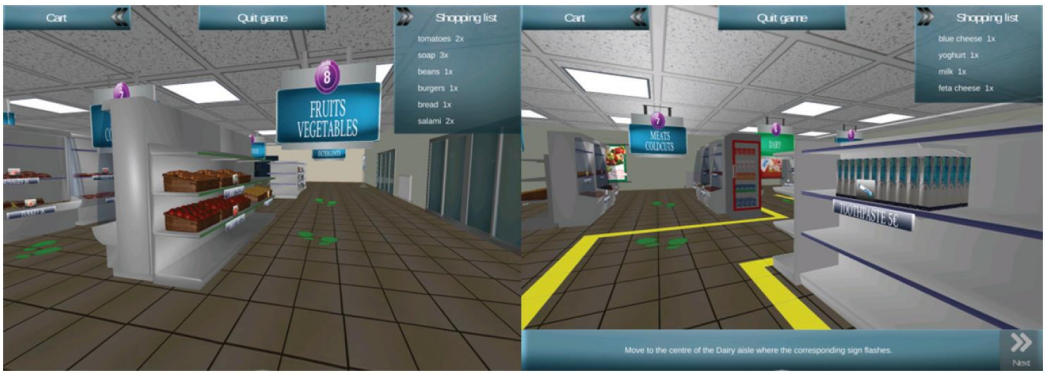

Figure 2-15 - Game developed by Zygouris et al.

Extracted from (Iliadou et al. 2021)

Vallejo et al. investigated the use of a virtual cooking task. They asked participants to execute the cooking activity in the game (see Figure 2-16) and in real-life and undertake a neuropsychological test battery so that they could examine the representability of the virtual task. Executive functions and prospective memory are

involved in the cooking task. The test battery results could predict how the participant would perform in the virtual and real-life tasks, which were correlated at 95.2% (Vallejo et al. 2017). Manera et al. also used the 'Kitchen and cooking' task, which involves executive functions and praxis and targets the assessment of MCI and Alzheimer's patients. They found correlations between performance in the game and traditional tests (Manera et al. 2015).

Figure 2-16 - Game developed by Vallejo et al.

Extracted from (Vallejo et al. 2017)

Bottiroli et al. developed the Smart Aging Platform for assessing MCI in the presence of a neuropsychologist. The platform uses virtual reality to replicate ADL (see Figure 2-17), such as making a phone call, searching for objects, and watering flowers while listening to the radio. Executive function, attention, memory, and visuospatial orientation are involved. Participants were assessed with the MMSE and the MoCA and played the game. Although the research was conducted with a small number of people, results indicated that a significant correlation with test results exists (Bottiroli et al. 2021).

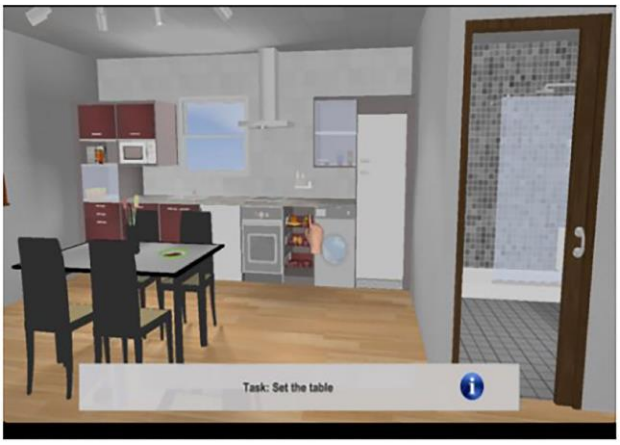

Figure 2-17 - Game developed by Bottiroli et al.

Extracted from (Bottiroli et al. 2021)

Dulau et al. designed the VR environment 'A Day to Remember'. This game involves executive function, language, short- and long-term memory, and orientation. The player is asked to perform familiar tasks, such as turning off an alarm and opening the fridge. Then, they are challenged with questions related to the activities they executed before. In addition, they are asked the name of animals to which they listen to the sound and orientation-related questions. A preliminary study found a potential to correlate scores with the MMSE (Dulau et al. 2019).

Paletta et al. proposed MIRA, a playful version of the anti-saccade task using an eye-tracking device to capture eye movement during gameplay. People with AD often demonstrate a dysfunctionality in continuously tracking stimuli. MIRA has game tasks related to ADL, such as feeding pets, gardening, and cooking, and evaluates executive functions, such as the inhibitory functionality of eye movements. A battery of tests was performed with participants, with the most significant correlations being found with the MoCA Visuospatial Executive component (Paletta et al. 2020).

The related works that used this approach are summarized in Table 2.4

Table 2.4 - Cognitive Screening Using Activities of Daily Living Games

Author	Game	Cognitive Elements
(Zygouris et al. 2020)	Virtual Supermarket (VSM)	Visual and verbal memory, executive function, attention, and spatial navigation
(Yan et al. 2021)	Virtual Supermarket (VSP)	Learning and memory, executive functions, language, time orientation, and complex attention
(Vallejo et al. 2017)	Virtual Cooking Task	Executive functions and prospective memory
(Manera et al. 2015)	'Kitchen and cooking'	Executive functions and praxis
(Bottiroli et al. 2021)	Smart Aging	Executive function, attention, memory, and visuospatial orientation
(Dulau et al. 2019)	'A Day to Remember'	Executive function, language, short- and long-term memory, and orientation.
(Paletta et al. 2020)	MIRA	Executive functions

2.6 Discussions

Previous research had an exploratory approach and investigated the feasibility of assessing cognitive performance using both well-known and non-conventional games. Significant correlations between game scores and classical CSIs were found, which demonstrates that games *have* the potential to generate useful cognitive-related information while people play them. The most significant advantages of using existing commercial off-the-shelf games are the practicality and their ability to entertain. The use of those games to provide meaningful play is specifically advocated by Gielis et al. (Gielis 2019). Although the cognitive screening activity per se does not require to be fun or entertaining, the rationale of merging games and CSIs is to benefit from the intrinsic characteristic of games to entertain and improve the experience of the older adult undertaking the test. However, using existing games is also disadvantageous because the researcher has no control over which cognitive functions are included in the game. Those games that were not designed for such purpose (i.e., to be a CSI) do not necessarily satisfy the criteria of a CSI. It is very likely that the commercial off-the-shelf

games will not sample and provide a measure of all cognitive elements required by the healthcare professional.

On the other hand, the greatest advantage of using bespoke games is the possibility of including a variety of mini-games that target specific cognitive aspects. This offers an opportunity to adapt the game-based instrument to the different needs of the healthcare professional, including test cognitive abilities separately to help with differentiating between diagnoses. However, an opposite challenge arises when compared to commercial off-the-shelf games. As the bespoke games target the measurement of cognitive elements and are often based on a standard test or the definition of the cognitive aspect they intend to measure, it is challenging to offer meaningful play that will improve the cognitive screening experience for older adults. While there is no doubt that previous works have demonstrated the potential of using games for the cognitive assessment of older adults, there is still plenty of opportunities to explore new designs that improve the experience of older adults undertaking a cognitive assessment, but most importantly, incorporate the same criteria of traditional CSIs. The main issues found in bespoke games previously investigated for cognitive assessment were: not having a clear definition of the game elements involved, being reliant on the culture of the player, not having a clear definition of the cognitive elements involved in a game activity, and not sampling all major cognitive domains. Furthermore, the aged cohort is very diverse, and there will not be a “one-size-fits-all” serious game, in the same way there is no “one-size-fits-all” CSI. There still exists opportunities and need to design and develop new game-based CSIs that target other additional cognitive elements, specific circumstances, or populations.

Although it is also important to estimate the ability of older adults to engage in ADL, the use of performance tests is much less frequent than the use of cognitive tests when screening for dementia in clinical practices, and there are very few instruments that have been validated to assess MCI (Luttenberger et al. 2016). The researchers that opted to use Activities of Daily Living-based games faced the same challenges as those researchers that focused on the bespoke games described above, particularly in terms of the delivery of playful content. In addition, the ADL-based games only covered a

limited range of functioning domains, which still requires investigating the relationship between cognitive processes and ADL (Gold 2012).

As bespoke games offer more control over which cognitive elements will be involved in the game, allow to measure multiple cognitive elements separately, and previous works did not focus on the particular issue of satisfying the same criteria of traditional CSIs, this research project will investigate further a serious game that samples at least one cognitive element of each major cognitive domain.

3. The Design of CogWorldTravel

This chapter describes the design of CogWorldTravel. First, the requirements definition process will be explained. General guidelines for the design of serious games for cognitive screening are elicited. Then, the serious game will be described in detail, including its mini games, story, instructions on how to play, data collected during gameplay, and rationale. The design of CogWorldTravel has been presented in the Joint Conference on Serious Games 2022 – JCSG 2022 and published in its conference proceedings (Oliveira 2022b).

3.1 Introduction

CogWorldTravel is a bespoke game for the cognitive screening of older adults that targets the detection of dementia. The aged cohort is very diverse, and there was no expectation of designing a 'one-size-fits-all' game. However, as traveling is an experience enjoyed by most people, this topic was chosen as the core theme of the game story. It features six mini games that involve specific cognitive aspects and are related to the context of traveling: *Familiar Faces, Padlock Combination, The Metro, Native Fauna, Messaging Home,* and *Time to Pack*.

The concept of the serious game began with a literature review, where the research gaps were identified, and the research goals were established. The following step was the definition of the requirements that would guide the design. The design was driven by the requirements of a traditional CSI and recommendations for designing for older adults so that the serious game would be suitable for them. Then, game tasks were brainstormed using the definition of the cognitive domains published in the latest version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) (American Psychiatric 2013). It was considered the working definitions of each domain, examples of symptoms, observations regarding impairments in everyday activities, and examples of assessments. The game tasks that were selected to be included in the game were the ones that appeared to satisfy the defined requirements as much as possible. The mini-games were defined using the framework proposed by Fullerton *et*

al. in (Fullerton, Swain & Hoffman 2008), and the set of mini-games was captured in the Game Design Document (GDD) that guided the development. A computer version was developed using Unity due to its versatility for developing game prototypes, and it is available at the following link: https://urfriendxd.itch.io/cogworldtravel. The Unity built-in recorder package supported the development of the tutorials and the data collected during gameplay are stored in a CSV file.

3.2 Requirements Definition

The requirements that would guide the design and development of the serious game considered the criteria of a traditional CSI. The Committee on Research of the American Neuropsychiatric Association (ANPA) established that an ideal CSI to be used in clinical practices should (Malloy et al. 1997):

- Allow being administered by a person at all levels of training,
- Take between 5 to 15 minutes to administer to most patients, and
- Sample all major cognitive domains.

Based on this, the requirements of the serious game were defined and are shown in Table 3.1. The rationale of each requirement and the intended procedure to verify are included in the Table and described in the following.

Requirement 01: If the game-based instrument enables self-administration, it goes beyond the criteria of an ideal CSI to allow administration by a person at all levels of training. This requirement means that people should be able to play the serious game at home or in clinical settings without direct supervision. While game scores should be stored to be analysed by the healthcare professional, medical supervision should not be required during gameplay. For this, the serious game should be easy to start and self-explanatory. This requirement enables a wide range of cognitive functions to be included while keeping a minimum use of medical time. This requirement seems to align with the upcoming Montreal Cognitive Assessment (MoCA) version, the MoCA solo, as mentioned in Chapter 2. It will be verified by inviting older adults to play the game and observing if they can complete it with minimal or no assistance.

Table 3.1 – Game Requirement Specification Matrix

ID	Requirement	Rationale	Proposed Verification Method
01	The serious game shall include instructions that allow self-administration.	Avoids the need for trained professional for administration, keeps the use of medical time at a minimum, resolves the paradox medical time vs. thorough test.	In the pilot study, observe if older adults can complete all mini games with minimal assistance.
02	The serious game shall be completed in up to 30 minutes.	Avoid player exhaustion.	Measure average time for completing all mini games.
03	The serious game shall sample at least one cognitive aspect of *Complex Attention*.	Satisfy the CSI criteria to sample all major cognitive domains.	In the interview with experts, ask their feedback to confirm if complex attention is involved.
04	The serious game shall sample at least one cognitive aspect of *Executive Function*.	Satisfy the CSI criteria to sample all major cognitive domains.	In the interview with experts, ask their feedback to confirm if executive function is involved.
05	The serious game shall sample at least one cognitive aspect of *Learning and Memory*.	Satisfy the CSI criteria to sample all major cognitive domains.	In the interview with experts, ask their feedback to confirm if learning and memory is involved.
06	The serious game shall sample at least one cognitive aspect of *Language.*	Satisfy the CSI criteria to sample all major cognitive domains.	In the interview with experts, ask their feedback to confirm if language is involved.
07	The serious game shall sample at least one cognitive aspect of *Perceptual-motor*.	Satisfy the CSI criteria to sample all major cognitive domains.	In the interview with experts, ask their feedback to confirm if perceptual-motor is involved.
08	The serious game shall sample at least one cognitive aspect of *Social Cognition*.	Satisfy the CSI criteria to sample all major cognitive domains.	In the interview with experts, ask their feedback to confirm if social cognition is involved.

Requirement 02: In regards to the time required for administration, as it was analysed by Brown in (Larner 2013), there is a paradox to be resolved in those CSI criteria of how to test the patient's cognition thoroughly while using a minimum of

medical time. The design of a CSI that can be self-administered is a potential solution to this paradox. Even though the self-administered instrument requires a minimum of medical time, the 30 minutes constraint was established as an attempt not to exhaust the player. It will be verified by measuring the average time to play all the six mini games.

In regards to the need to sample all cognitive domains, the last version of the Statistical Manual of Mental Disorders (DSM-V) defines the major cognitive domains as complex attention, executive function, learning and memory, language, perceptual-motor, and social cognition (American Psychiatric 2013). Each major cognitive domain involves multiple elements. However, the serious game should sample one aspect of each domain in its first release. By doing so, the serious game will comply with the requirement of a CSI to sample all major cognitive domains. These requirements will be verified by interviewing experts in the assessment of dementia, where the mini-game will be demonstrated, and they will be asked whether the task has the potential to measure the cognitive aspect that it was designed to measure.

Requirement 03: This requirements follows the CSI criteria to include complex attention. Complex attention encompasses sustained attention, divided attention, selective attention, and processing speed, which is associated with the ability to maintain attention over time, maintain attention in face of distractors, maintain attention to two tasks concurrently, and the amount of time spent to perform any task.

Requirement 04: This requirements follows the CSI criteria to include executive function. Executive function encompasses planning, decision making, working memory, responding to feedback and error correction, overriding habits and inhibition, and mental flexibility, also known as shifting. Planning can be associated with the ability to arrange objects. Working memory encompasses the ability to hold information for a brief period and manipulate it.

Requirement 05: This requirements follows the CSI criteria to include learning and memory. Learning and memory encompasses immediate memory span, recent memory (free recall, cued recall, and recognition memory), long-term memory, and implicit learning. Immediate memory span is associated with the ability to repeat a list

of words or digits. Recent memory involves recognition memory, which refers to the ability to recognize a stimulus that has been encountered previously.

Requirement 06: This requirements follows the CSI criteria to include language. Language involves expressive language, grammar and syntax, and receptive language. Receptive language refers to comprehension and performance of actions following verbal instructions.

Requirement 07: This requirements follows the CSI criteria to include perceptual-motor. Perceptual-motor encompasses visual perception, visuo-constructional, praxis, and gnosis. It is associated with the assembly of blocks and the integration of perception and movement.

Requirement 08: This requirements follows the CSI criteria to include social cognition. Social cognition encompasses the recognition of emotions in images of faces and theory of mind, which is the ability to perceive one's mental state or experience.

3.3 Design Recommendations for Older Adults

In addition to the requirements defined in the previous section, design recommendations for older adults were taken into consideration. The process of ageing is influenced by a variety of factors such as genetics, environmental context, behaviour and life experiences (Czaja et al. 2019). Therefore, the elderly population is very diverse, and a unique design strategy will not fit the needs, preferences, or abilities of all older people. However, some normative changes were considered when designing the serious games.

A large number of older adults present difficulty in hearing, vision, cognition, or mobility. Recommendations to compensate for age-related changes in vision include increasing luminance contrast, using contrasting colours, adapting the font size, minimizing the use of peripheral vision, using strategies to enhance motion perception, and minimizing glare. In terms of hearing, it is suggested to avoid high rates of words per minute, use well-structured speech content, control background noise, avoid the need to identify high-frequency stimuli, and avoid high levels of noise for a long time

(Gamberini et al. 2006). Older adults may have lower global and technology self-efficacy, which is related to the confidence in their ability, and affects behaviour and persistence to continue an activity. To avoid cognitive load, it is helpful to minimize the number of steps required in a procedure. This is particularly useful when designing both the access to the game and the tracked information. The various cognitive domains should be addressed in different tasks. Likewise, game elements such as procedures, rules, objectives, and conflict should be easy to understand and clearly communicated. The game should teach the basic skills at the beginning of the game; an engaging tutorial that stimulates gameplay is recommended. A combination of images and texts should be used to facilitate the interaction with the game. Incorporating metaphors of daily life may help the learning process (Gerling et al. 2012). The rewards provided should be meaningful and encouraging to enable immersion in the game. The player should not lose earned rewards; they must be able to visualize their progress during gameplay; and should not be penalized for the same error (Machado, Ferreira & Ishitani 2018). Considerations of mobility changes include reducing the complexity associated with movement control requirements (Czaja et al. 2019).

The preferences of older adults in terms of the game genre have also been investigated. A survey conducted by Salmon (Salmon et al. 2017) revealed that older adults play puzzles, strategy, and educational games more often. On the other hand, on the bottom of the preference list appeared shooting and party games. Another research conducted by (Chesham et al. 2017) findings revealed a preference for casual puzzle over simulation games and slower-paced games with an intellectual challenge over fast-paced games. Despite being the least preferred game genre, simulation games were rated as easy to understand because this type of game relates to real-world concepts.

The design of the serious game tried to accommodate these design recommendations and the preferences of older adults as far as possible. Any useability issues will be investigated during the pilot study with older adults where they will be observed during gameplay and an interview will be conducted.

3.4 Analytical Framework

Although the general game design approaches are useful when designing serious games, the design of serious games for cognitive screening also has its particularities. This section will describe some guidelines that were elicited to drive the design of CogWorldTravel and aims at assisting future researchers in the design and development of serious games with a similar purpose. The framework is presented in Figure 3-1, located in the next page, where yellow represents the aims, blue represents how to address them, and green shows what is involved. The framework consists of three major aspects, which is explained in the following.

3.4.1 Assess Cognitive Domains

This aspect of the framework is related to the primary purpose of the serious game. It is crucial that the design of a serious game for cognitive screening includes the assessment of multiple cognitive aspects. An ideal CSI shall sample all major cognitive domains and, therefore, an ideal game-based CSI shall follow the same principle. As each cognitive domain involves multiple cognitive aspects, the instrument should collect data that can be correlated to multiple cognitive aspects individually. Understanding what each cognitive aspect involves, what the symptoms in case of impairment are, and how those cognitive aspects are assessed may assist in the design of game activities.

3.4.2 Be Age-Friendly

In order to reliably measure cognitive aspects, it is important that those measurements are not impacted by other factors that are not related to the cognitive aspect of interest. The design of the serious game should provide the means to accommodate age related changes. As older adults are the ones that most likely will be assessed with the serious game, it is crucial that they can perform the activity independently. This includes not only accommodating probable decline in hearing, vision, cognition, and mobility, but also design activities that are often enjoyable for them and provide the right instructions. Finally, it is also important to consider that older adults have diverse cultural and educational background. An ideal serious game shall be as fair as possible to those diverse people.

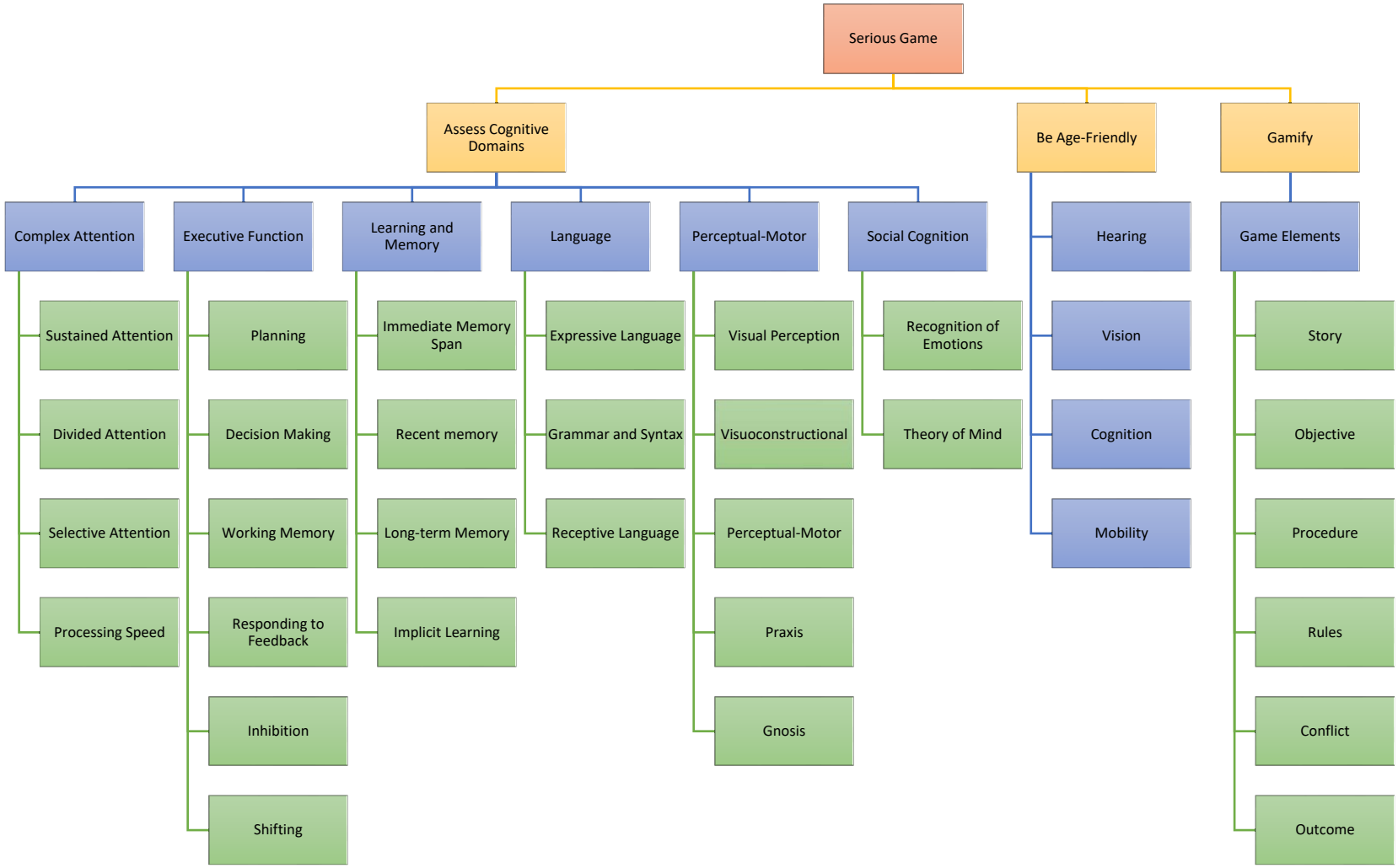

Figure 3-1 - Analytical Framework

3.4.3 Gamify

The addition of game elements may improve the user experience and make the assessment less intimidating for older adults. It is desirable that general game design approaches are used to make the serious games as enjoyable as possible. Game elements to be considered in the design of the serious game include story, objective, procedure, rules, conflict, and outcome.

3.5 CogWorldTravel

The requirements and recommendations that were defined leaded to the design of CogWorldTravel, which will be described in the following.

The six mini-games included in CogWorldTravel should be played in a given sequence, with the next mini-game only becoming available when the previous one is completed. This avoids any confusion related to what mini game the player should go next. The cognitive test is completed when all mini-games have been played. It is important to highlight that the primary purpose of CogWorldTravel is cognitive screening and as such each mini-game should be played once and only once to provide reliable scores, unless differently recommended by the healthcare professional. Figure 3-2 shows the initial screen of the game. Following the recommendations for designing for older adults and considering potential difficulties in vision, the colours chosen were royal blue, juxtaposed with lime green and white due to the easiness of differentiating these colours when closely associated. The design of main screen and mini-games are as simple as possible to avoid unnecessary distractions. Figure 3-3 shows the main menu, where the player can click to start playing the mini-games described in the following sections. Considering potential difficulties in hearing, CogWorldTravel includes relaxing instrumental background music, which can adjust the volume from a settings screen that can be accessed through a settings button located in the top right of the main and tutorials screens. All mini games start with a tutorial that cannot be skipped when playing for the first time. In addition, considering that older adults may have low familiarity with technology or games, the inputs required from the player

were designed to be as simple as possible. Except for *Time to Pack*, all other mini-games require only single clicks with the mouse.

Figure 3-2 - CogWorldTravel Initial Screen

Figure 3-3 - CogWorldTravel Main Menu

The six mini-games will be described in the following, using the framework described by Fullerton *et al.* (Fullerton, Swain & Hoffman 2008).

3.5.1 Mini-game 01: Familiar Faces

Story: The player arrives at the airport and finds out their luggage is gone. They will work closely with security to identify who has their luggage by mistake (see Figure 3-4).

Objective: The player's goal is to select as many faces as possible without choosing the same face twice.

Procedure: Sets of six to ten faces will be displayed at a time (see Figure 3-5). The player uses the mouse to select one face. After the face is selected, the whole set disappears, and a new set is displayed re-ordered, including faces already chosen by the player at any time and at least one face that has never been selected. The same process repeats until the player selects the same face for the second time.

Rules: The players click on the faces to help security identify people, but they cannot click on the same person twice as it would be awkward.

Conflict: This is a cognitive challenge, and the player may be limited by their ability to track the faces while performing the task. They need to resolve how to hold up to 50 different faces in memory to go through as many as possible.

Outcome: The game ends when the player selects someone for the second time, and the data collected during gameplay is the number of chosen faces before losing the game. It is expected that the number of faces achieved indicates recognition memory, sustained attention, and working memory performance, as these are cognitive abilities required in this task and represent elements of the major cognitive domains of learning and memory, complex attention, and executive function, respectively.

Rationale: This task was inspired by the Warrington Recognition Memory Test for faces (Warrington 1984), which assesses deficits in recognition memory, an important expression of episodic memory. The decline of episodic memory is a hallmark of cognitive dysfunction associated with dementia. In the original test, which has been previously considered to have the ability to detect dementia (Diesfeldt 1990; Soukup, Bimbela & Schiess 1999), 50 faces are presented to the participant, and later they are challenged with a pair of faces to identify which one they had seen before.

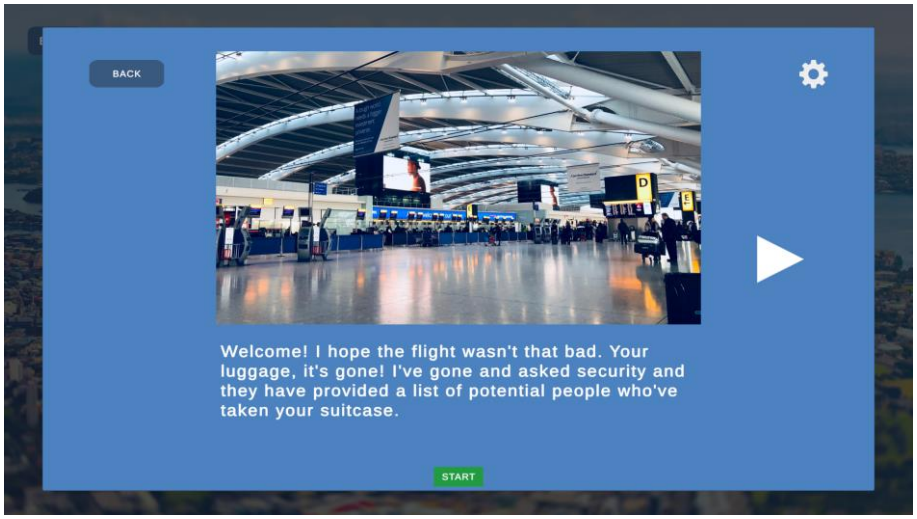

Figure 3-4 - Familiar Faces Tutorial

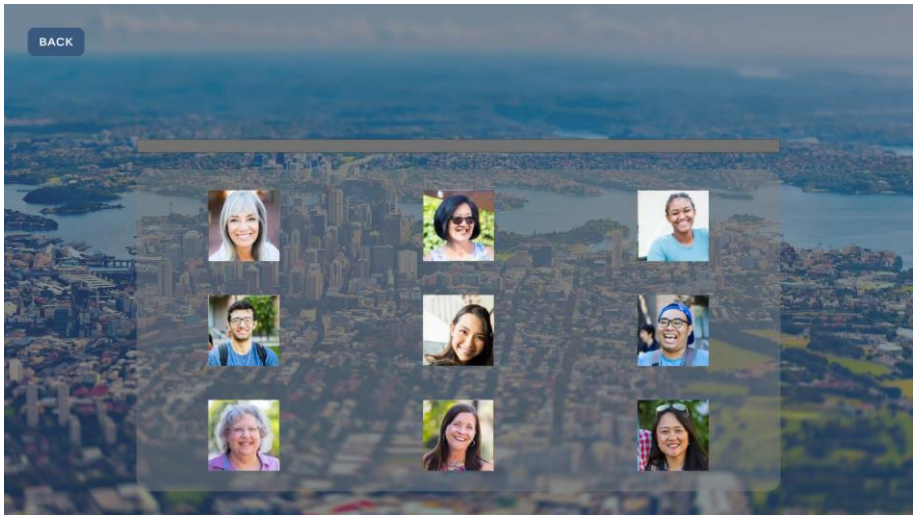

Figure 3-5 - Familiar Faces Game

3.5.2 Mini-game 02: Padlock Combination

Story: After the player retrieves the luggage, they realize they forgot the padlock combination to open it and will need to guess (see Figure 3-6).

Objective: The player should form as many words as possible with the given set of letters from the padlock.

Procedure: The padlock contains four letters (see Figure 3-7). Using the mouse, the player selects each letter to use it to form words. The player can unselect a letter by clicking again on it or clicking the clear button to delete all letters in one go. Once one word is formed, they click on the submit button. If the word is accepted, a green light appears. The yellow light is displayed if the word exists but has already been submitted.

A red light is displayed if the letters selected do not form an existing word. Each set of letters has a defined number of words that need to be formed. If the player completes it, a new one is given until the two-minute timer is over.

Rules: The words formed by the player must be composed of three or four letters and cannot include names. Each letter can only be used once for each word. The combination formed only can be submitted if it is an existing word. The same word cannot be submitted twice.

Conflict: This task is timed, and the number of words the player can generate is limited by the time provided to complete the task.

Outcome: The game ends when the time ends, and the data collected during gameplay is the number of successfully submitted words. It is expected that the number of words achieved indicates language and working memory performance as these are cognitive abilities required in this task and represent elements of the major cognitive domains of language and executive function, respectively.

Rationale: Although it is different due to the self-administration approach of the game-based test, the task is inspired by the language component of the Montreal Cognitive Assessment (MoCA) (Nasreddine et al. 2005), where the participant is asked to say as many words as they can starting with a given letter, name low-familiarity animals, and repeat a sentence. In this task, the player uses an element of language to recall words that can be formed with the letters and needs to hold the words already submitted in memory.

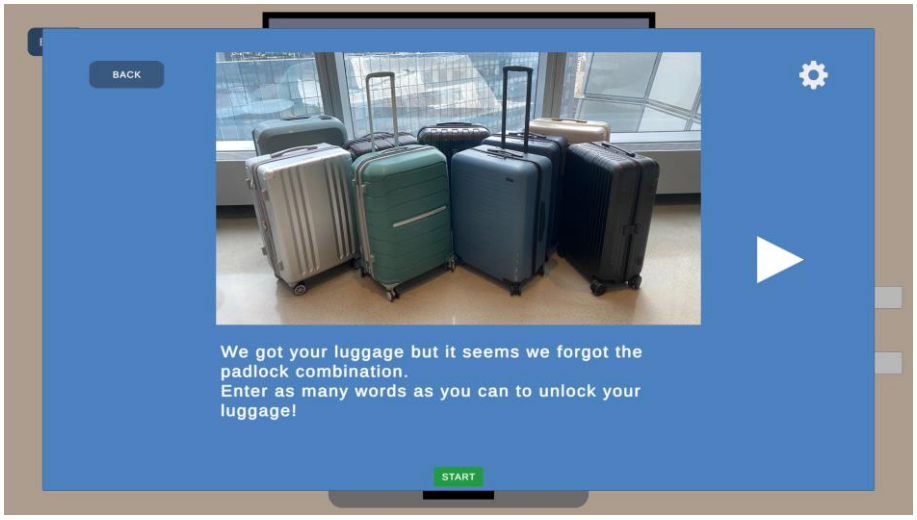

Figure 3-6 - Padlock Combination Tutorial

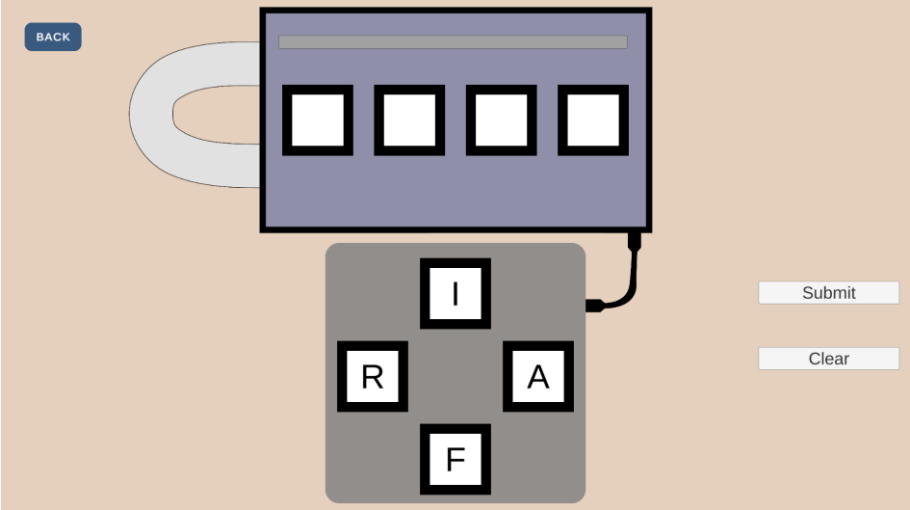

Figure 3-7 - Padlock Combination Game

3.5.3 Mini-game 03: The Metro

Story: After all luggage-related issues are resolved, it is time to enjoy the trip. The player can visit tourist spots around the city using the metro system. A local expert will show those spots on the map (see Figure 3-8).

Objective: Memorize and repeat the longest sequence of highlighted stations as possible.

Procedure: The player will see a metro map (see Figure 3-9). The stations on the map will be highlighted. The player needs to repeat the sequence highlighted by using the mouse to click on the stations in the same order they were shown. The game starts with a sequence of three stations. The player has two trials to attempt to repeat a three-stations-long sequence. If at least one sequence is correctly repeated, the following sequence will be incremented by one station. The process repeats until the player cannot repeat any of the two trials of a given length.

Rules: Two different sequences of the same number of stations will be displayed. One station is added to the number of stations highlighted if the player successfully repeats at least one of the sequences. The trial ends when the player selects the expected number of stations, even if it is incorrect.

Conflict: This is a cognitive challenge, and the player may be limited by their immediate memory span ability.

Outcome: The game ends when the player cannot repeat at least one of the trials for a given length. The data collected during gameplay is the maximum length achieved

and the total number of correct repetitions. It is expected that these data collected will provide an indication of immediate memory span, which is an element of the learning and memory domain.

Rationale: This task was inspired by the Corsi Blocks Test, which requires memorizing relative positions in space in a temporal order. The test consists of nine square blocks positioned on a board (Corsi 1972). The examiner taps the blocks starting with sequences of two cubes. The participant must reproduce the sequence by tapping the blocks in the same order. The test has been considered the single most important nonverbal task in cognitive assessment (Berch et al. 1998).

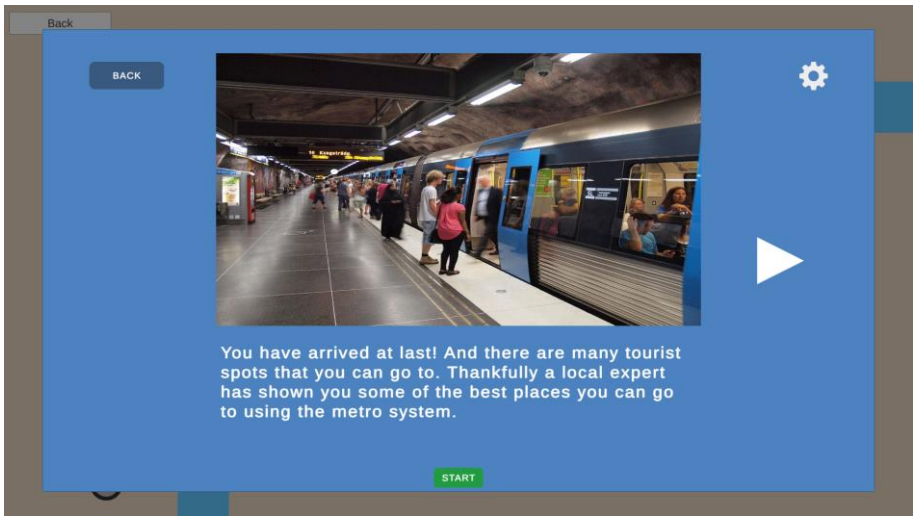

Figure 3-8 - The Metro Tutorial

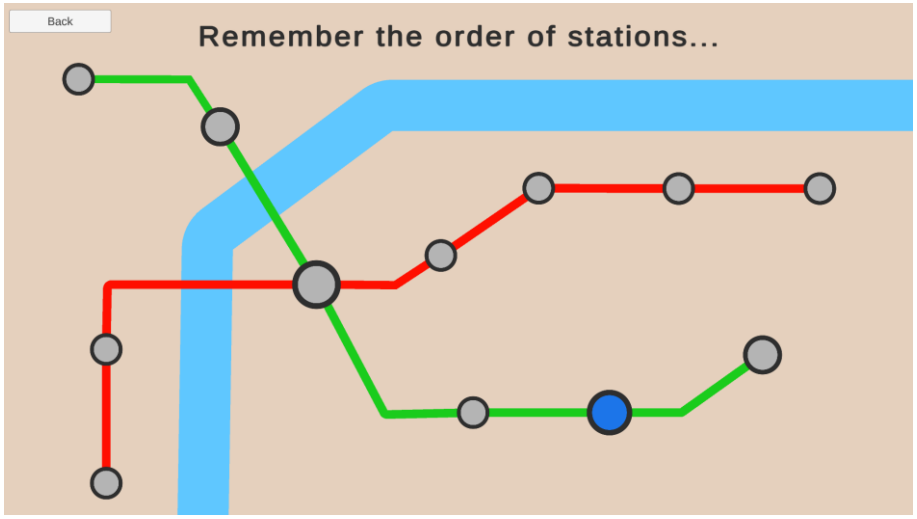

Figure 3-9 - The Metro Game

3.5.4 Mini-game 04: Native Fauna

Story: One of the places visited by the player is the beach. The player is instructed to take photos of the native wildlife at the beach (see Figure 3-10).

Objective: The player should take photos of flamingos that appear on the screen as quickly as possible and avoid photographing the coconuts.

Procedure: The player goes around the screen with the mouse, replicating the view from a photographic camera's lens. They should stay alert to the appearance of the flamingos on the screen. They must click on the flamingos as quickly as possible. Coconuts will also randomly appear as distractions, and the player must avoid taking photos of them (see Figure 3-11).

Rules: The player must click on the target (Flamingos) and avoid the distractions (coconuts). A green light is displayed when a target is hit, and red light is displayed when a distraction is hit.

Conflict: Coconuts are included to test inhibition. The player must stop themselves from responding when coconuts are seen.

Outcome: The player will be exposed to a defined number of targets and distractions, and the data collected during gameplay include reaction time, correct photos taken (target), wrong photos taken (distraction), and missed targets. It is expected that the data collected will measure processing speed, inhibition, and sustained attention, which are elements of complex attention and executive function.

Rationale: The task replicates the same mechanics of the letter A item from the MoCA (Nasreddine et al. 2005), where the participant listens to a list of letters and claps hands every time they listen to the letter A. One advantage of the game over the classical test is the ability to provide time-based measures, which enables the measurement of reaction time. Reaction time is acknowledged as an important parameter of cognitive efficiency (Collins & Long 1996). Adding the distraction element in the game also provides a measure of inhibition as it tests the ability to stop yourself from responding to a stimulus. This is measured in the go/no-go (Yechiam et al. 2006) cognitive test.

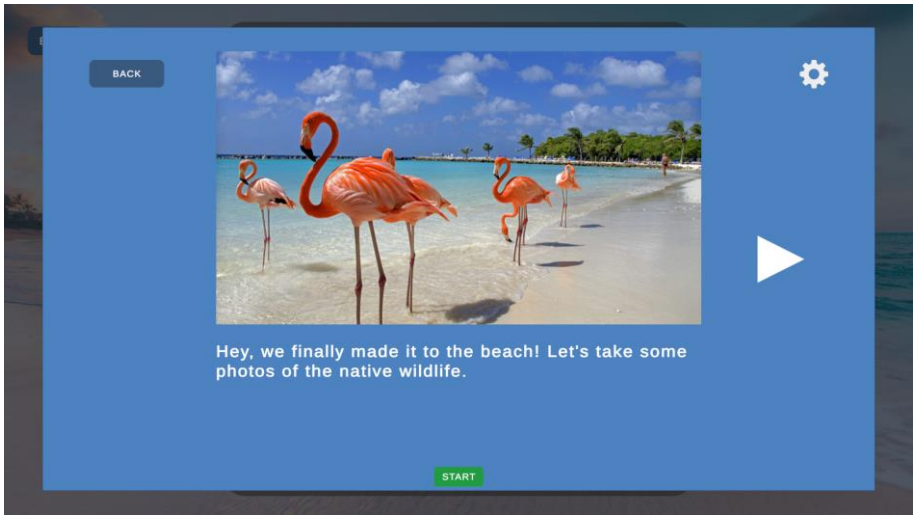

Figure 3-10 - Native Fauna Tutorial

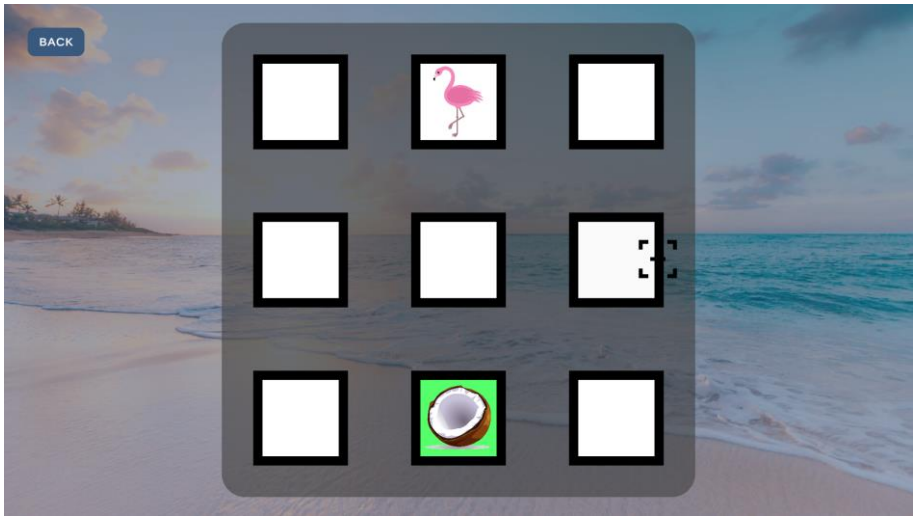

Figure 3-11 - Native Fauna Game

3.5.5 Mini-game 05: Messaging Home

Story: The player has a little break from the trip to check in on their family back home. They talk to a family member through a messaging app (see Figure 3-12).

Objective: The goal of the player in this game task is to select the correct sticker to support the conversation.

Procedure: A text conversation between the player and their daughter is displayed. In the conversation, feelings are mentioned. The player is asked to choose a sticker to support the feeling mentioned in the conversation from a set of six faces expressing the basic emotions: happy, sad, angry, surprised, disgusted, and scared (see Figure

3-13). All six emotions will be mentioned once, but the player is not aware of this beforehand.

Rules: The player must choose one face at a time to support the feeling in the conversation. There are six faces and six trials. Once a face is selected, the conversation continues.

Conflict: The correct face is shown among five other faces, and the player is limited by their ability to recognize emotions in faces when selecting it.

Outcome: There is no losing criteria or time limit. The player can take their time to select the most appropriate face. The data collected during gameplay is the total number of correct faces of six trials. It is expected that it will provide a measure of recognition of emotions, which is one aspect of social cognition.

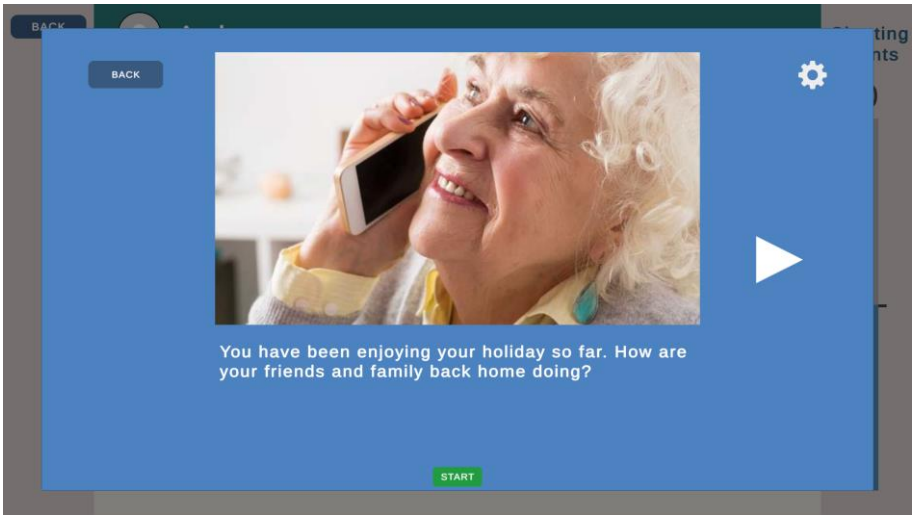

Figure 3-12 - Messaging Home Tutorial

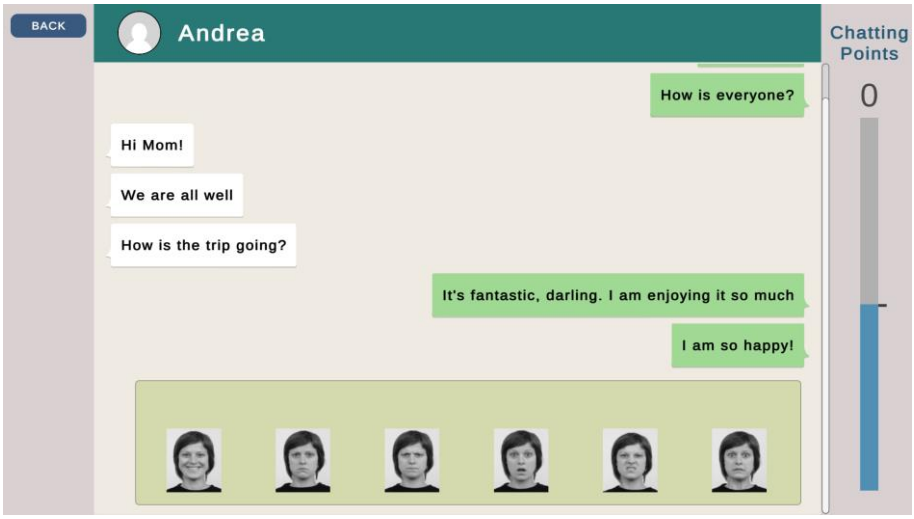

Figure 3-13 - Messaging Home Game

Rationale: Social cognitive deficits are commonly seen in people with dementia (McCade, Savage & Naismith 2011), even though this domain is often overlooked in classical and game-based instruments. The game task is very similar to the Emotion Recognition Task (Montagne et al. 2007), with the difference that the emotions are inserted in the context of the trip rather than simply showing a word.

3.5.6 Mini-game 06: Time to Pack

Story: In the end, the player must pack their luggage before flying home (see Figure 3-14).

Objective: The player should place tetromino-shaped items inside suitcases and complete as many suitcases as possible.

Procedure: The tetrominoes-shaped items will be displayed to the player alongside a suitcase (see Figure 3-15). The player needs to organize the items inside the suitcase, and they may need to rotate the items. Items are rotated 90 degrees clockwise by selecting them and clicking the right mouse button or pressing the space bar. Items must be dragged and dropped inside the suitcases. Once all items are placed inside the suitcase, it closes, and a new empty suitcase and new items are provided. This repeats until the two-minute timer is over.

Rules: Players can drag and drop items inside and outside the suitcases. The player can change the position of the items as many times as they wish after placing them inside

the suitcase. If the timer is over, the player cannot continue with the suitcase they were packing at that moment.

Conflict: This is a cognitive challenge where items must fit perfectly inside the suitcase. No spaces can be left. The game is limited by time.

Outcome: The game ends when the time ends, and the data collected during gameplay is the number of suitcases completed in the given time. It is expected to provide a measure of visuoconstructional, perceptual-motor, and planning abilities, which are aspects of perceptual-motor and executive function.

Rationale: This task was inspired by the Tetris puzzle game, which has been considered to involve rapid visual-spatial problem-solving and motor coordination skills (Haier et al. 2009).

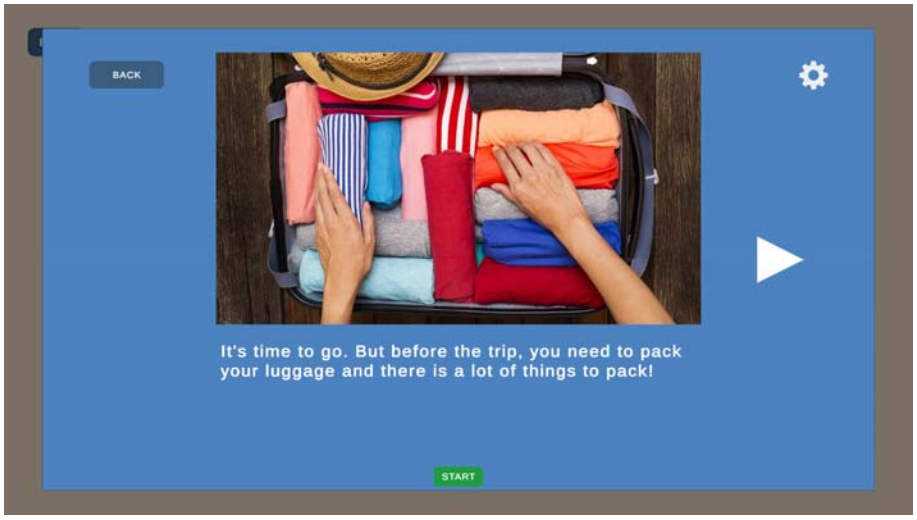

Figure 3-14 - Time to Pack Tutorial

Figure 3-15 - Time to Pack Game

3.6 Discussions

CogWorldTravel was designed to be used as an alternative CSI. The six mini-games have the potential to provide a measure of cognitive domains while entertaining older adults both in clinical settings and remotely. To complete the cognitive assessment with CogWorldTravel, each mini-game should be played once and only once. It is expected that the introduction of game elements can alleviate the anxiety of taking a test, motivate users, and improve the user experience. In addition, by removing the need of administration by trained professional, more people can be tested. As opposed to traditional CSI, busy clinical environments would not constrain the proper application of the game-based tool. In addition, older adults can be conveniently tested at home.

The design process was particularly challenging because of the interdisciplinary nature of this research. The mini-games needed at the same to entertain, accommodate the special needs of older adults, and involve different cognitive aspects. To accomplish all of that, the requirements defined with basis on the criteria of CSI were considered as essential and the recommendations for designing for older adults were considered as desirable. Table 3.2 shows how the design addressed each requirement, which will be verified through the pilot study with older adults and semi-structured interview with experts.

CogWorldTravel follows a modular approach. Because there are six major cognitive domains, six mini-games have been initially proposed so that at least one aspect of each domain could be addressed. However, new mini-games can be added to CogWorldTravel as new modules without impacting the current selection of mini-games. Likewise, mini-games can be replaced or improved if issues are detected during the useability study or during a clinical trial in the future.

Table 3.2 - Traceability between Requirements and Design

ID	Requirement	How the requirement is addressed in the design
01	The serious game shall include instructions that allow self-administration.	All mini-games include a tutorial that cannot be skipped. Tutorials were built using a combination of video demonstrations and instructions.
02	The serious game shall be completed in up to 30 minutes.	All mini-games were estimated to be completed between two and three minutes, which leads to a total of 12-18 minutes. Time to read a tutorial will vary with the player but it is estimated that each tutorial should take a maximum of two minutes.
03	The serious game shall sample at least one cognitive aspect of Complex Attention.	Attention is required in *Familiar Faces* and *Native fauna*.
04	The serious game shall sample at least one cognitive aspect of Executive Function.	Executive function is required in *Familiar Faces*, *Padlock Combination*, *Native Fauna*, and *Time to Pack*.
05	The serious game shall sample at least one cognitive aspect of Learning and Memory.	Learning and memory is required in *Familiar Faces* and *The Metro*.
06	The serious game shall sample at least one cognitive aspect of Language.	Language is required in *Padlock Combination*.
07	The serious game shall sample at least one cognitive aspect of Perceptual-motor.	Perceptual motor is required in *Time to Pack*.
08	The serious game shall sample at least one cognitive aspect of Social Cognition.	Social cognition is required in *Messaging Home*.

4. Pilot Study with Target Audience

This chapter presents the pilot study with older adults which aimed at investigating any useability issues, verifying if an average older adult can play the serious game with minimal or no assistance, and if they would enjoy playing it. Preliminary results of this study were also presented in the Joint Conference on Serious Games 2022 – JCSG 2022 and published in its conference proceedings (Oliveira 2022b).

4.1 Introduction

In Chapter 3, the requirements that guided the design and development of CogWorldTravel were defined. The design of the serious game was proposed, which includes six mini-games that require at least one aspect of each cognitive domain for completion. Recommendations for designing for older adults were also taken into consideration. During the design definition, it was also defined how each requirement would be verified. The verification and validation procedure of CogWorldTravel will be performed in two stages. In this Chapter, the pilot study with older adults will be described. The pilot study aims at investigating any useability issues when older adults play CogWorldTravel. The study will validate if older adults can play the game with minimal assistance, only by learning from the tutorials, which is one the requirements defined in the previous chapter. It will also investigate any other useability issues and lessons learnt will be captured.

People aged 60+ were invited to participate in the pilot study. The advertisement for the study was posted on social media and sent to a database of participants from previous studies who expressively said they were willing to participate in similar projects. People who were interested contacted the researcher via e-mail or phone call. Prospective participants were screened against the inclusion and exclusion criteria, which can be seen in Table 4.1.

Table 4.1 - Participants' Inclusion and Exclusion Criteria

Participants were included if they:	Were 60+ years old
	Were familiar with computers and owned one
	Had Sufficient English proficiency to understand the instructions
Participants were excluded if they:	Have never used a computer or had no access to one
	Were unable to understand the instructions in English
	Were unable to consent to participate

Participants who met the criteria were provided with the participant information sheet, which was sent by e-mail. They were given the time to read the sheet, sign the consent form, and ask any questions before the study. Once participants agreed to be part of the study and the consent form was signed and returned, a zoom meeting was scheduled.

During the zoom meeting, the objectives of the study were explained one more time and the participants were reminded that they could withdraw from the study at any moment, including while playing the game. Once they confirmed willingness to continue, they were asked personal information so that the demographics of participants could be understood. They were explained that the researcher would avoid assisting them during gameplay in order not to interfere with the outcome of the study. Then, they were instructed to start playing the mini-games in sequence and per the number of the mini-games in the dashboard. After playing each mini-game, the participant was asked a set of questions (see Table 4.2) related to the mini-game they have just completed, and at the end, they were asked what mini-game they liked the most and the least. The participant was observed during gameplay and any relevant behaviour or comment was captured. For ethical reasons, the pilot study was not recorded. Instead, a form was pre-prepared to be filled out during the study (see Appendix A). Two copies of the form were filled out for each participant, one by the researcher and one by a research assistant. After each session, the participant was de-identified and both copies of the form were compared to confirm both had the same perception towards the participant experience and, therefore, avoid bias in the results.

Table 4.2 - Questions that Guided the Verification Process with Older Adults

Questions	
Demographics	Age Bracket *Possible Answers: 60-65, 66-70, 71-75, 76-80, 80+*
	Highest Degree Achieved *Possible Answers: Primary, High, Vocational, Bachelor's, Master's, Ph.D.*
After each mini-game	Could you understand the game by seeing the tutorial? *Possible Answers: Yes, No*
	How did you like this game? *Possible Answers: Awful (1), Not very good (2), Okay (3), Really good (4), Fantastic (5)*
	How difficult was playing this game? *Possible Answers: Very difficult (1), Difficult (2), Neither (3), Easy (4), Very easy (5)*
	Did you have any issues playing this game?
After all mini-games have been played	Which game did you like the most? *Possible Answers: Familiar Faces, Padlock Combination, The Metro, Native Fauna, Messaging Home, Time to Pack*
	Which game did you like the least? *Possible Answers: Familiar Faces, Padlock Combination, The Metro, Native Fauna, Messaging Home, Time to Pack*
	What did you like?
	What did you not like so much?
	What would you keep?
	What would you change

The data collected throughout the experiment were found to be consistent. No divergences were reported when the results from both forms were compared. The two forms related to the same participant were merged into a single form to facilitate the analysis at the end of the experiments. Any additional data captured by only one of the researchers were discussed and transferred between forms. The data related to the

player performance that were automatically stored in the CSV file during gameplay were also transferred to the merged form.

After all semi-structured interviews were performed, the demographics were understood and recorded, and each mini-game was analysed individually. The data related to each mini game were combined into one single document and grouped according to the content to improve visualization and facilitate analysis.

Finally, a gift card was provided to the participants as an appreciation of their contribution to this research project, which was sent by email immediately after the session. The protocol for this experiment was approved by the Human Research Ethics Committee (HREC) of the University of Technology, Sydney (UTS). The ethics approval number for this study is UTS HREC REF NO. ETH21-6184.

4.2 Results

Given the nature of the research questions in this study, a small number of participants was enough to understand whether an average older adult would be able to play the game. Six participants were included in the study, referred to as P1, P2, P3, P4, P5, and P6. The profile of the participants can be seen in Table 4.3. The participants were aged between 66 and 80, including four women and two men. They played each mini-game once, and the questions defined in Table 4.2 were asked. Each zoom meeting lasted approximately 45 minutes. The feedback collected from the participants during these sessions will be described in the following.

Table 4.3 - Profile of the Older Adults that Participated in the Study

Participant	Profile		
	Age	Gender	Education
P1	66-70	F	High School
P2	76-80	F	High School
P3	76-80	F	Bachelor's Degree
P4	66-70	F	Master's Degree
P5	66-70	M	Bachelor's Degree
P6	66-70	M	High School

4.2.1 Mini-game 01: Familiar Faces

In general, the participants understood the goal of the game. P2 was the only participant who could not understand the game. She read the tutorial and said that the game was so easy that it would not need a tutorial, but actually, she chose a person in the first set of faces and the same person on the second set of faces. All other participants did well in the game. P3 mentioned she could not understand the context of the game related to the trip but could understand the task's objective. P4 said that the game was intimidating because she realized the game involves memory, and she explained that people at her age are scared of failing. P5 said he did not understand the thumbs-up appearing after selecting a face. The thumbs-up has been included in the game to provide positive feedback and motivate the player to keep going; however, P5 understood that thumbs-up could mean that you found who you are looking for and there was no need to keep going in the game. *Familiar Faces* has been chosen as the preferred game by one of the participants and the least preferred game by other two. Overall, an improvement in the game story is needed, but no major issues with the game activity itself have been reported. The feedback from the participants is summarized in Table 4.4, Figure 4-1, and Figure 4-2. Regarding their performance in the game, they were able to select 25, 1, 27, 4, 6, and 21 faces, respectively, before making a mistake.

Table 4.4 - Feedback on Familiar Faces

Participant	*Could you understand the game by seeing the tutorial?*	*How did you like this game?*	*How difficult was playing this game?*
P1	No	Not very good (2)	Very easy (5)
P2	Yes	Okay (3)	Very easy (5)
P3	No	Okay (3)	Neither (3)
P4	No	Okay (3)	Easy (4)
P5	No	Not very good (2)	Very difficult (1)
P6	Yes	Really good (4)	Neither (3)

Figure 4-1 - How the participants liked Familiar Faces

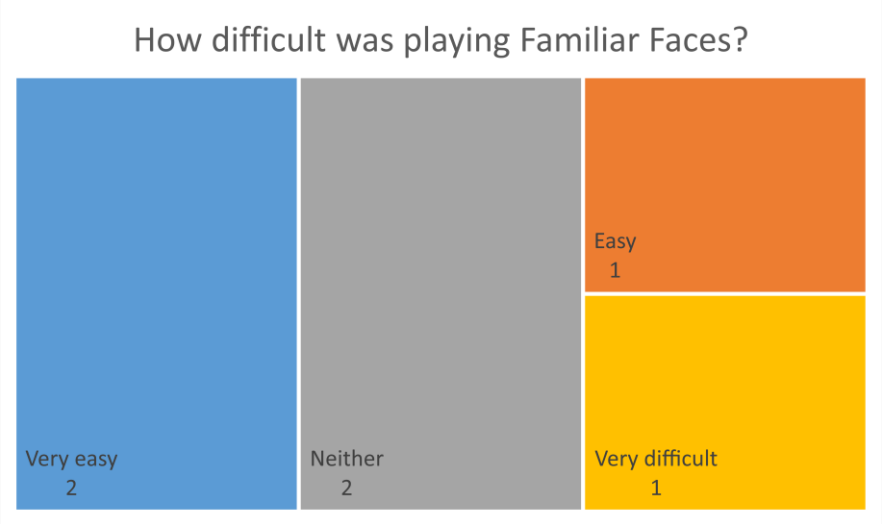

Figure 4-2 - How difficult the participants found Familiar Faces

4.2.2 Mini-game 02: Padlock Combination

In general, the participants were happy with this game and found similarities with a popular game called *Wordle*. They also easily understood what they needed to do. Word puzzles seem to be a well-accepted game activity among the targeted age group. However, some issues were still reported. Two participants missed the information that the words could be formed of three or four letters when reading the tutorial. This needs to be made clearer in the game itself. P4 was stuck in a set of letters and could not find new words. She explained that it is frustrating to be there without knowing new words and suggested to add hints after a certain period of time or maybe change the set of letters. She added that they feel better when they know what to do. She also said that the *Submit* and *Clear* buttons need to call more attention for themselves. P3 said she did not like the comparison with a padlock because it made her to expect to see numbers instead of letters. *Padlock Combination* has been chosen as the preferred game by one of the participants, and the least preferred game by another. The feedback from the participants is summarized in Table 4.5, Figure 4-3, and Figure 4-4. In regards to their performance on the game, the number of words formed by them was 12, 3, 5, 6, 12, and 4, respectively.

Table 4.5 - Feedback on Padlock Combination

Participant	*Could you understand the game by seeing the tutorial?*	*How did you like this game?*	*How difficult was playing this game?*
P1	Yes	Okay (3)	Very easy (5)
P2	Yes	Really good (4)	Very easy (5)
P3	Yes	Okay (3)	Neither (3)
P4	Yes	Really good (4)	Very easy (5)
P5	Yes	Really good (4)	Very easy (5)
P6	Yes	Really good (4)	Easy (4)

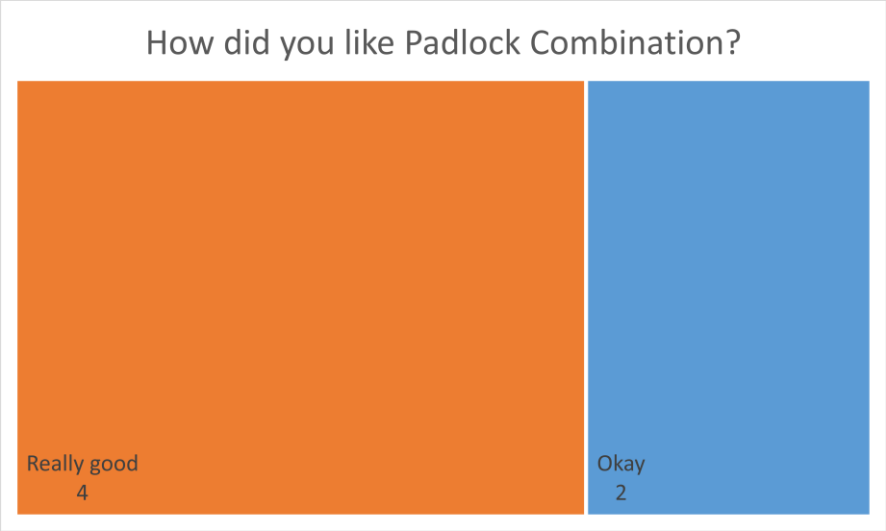

Figure 4-3 - How the participants liked Padlock Combination

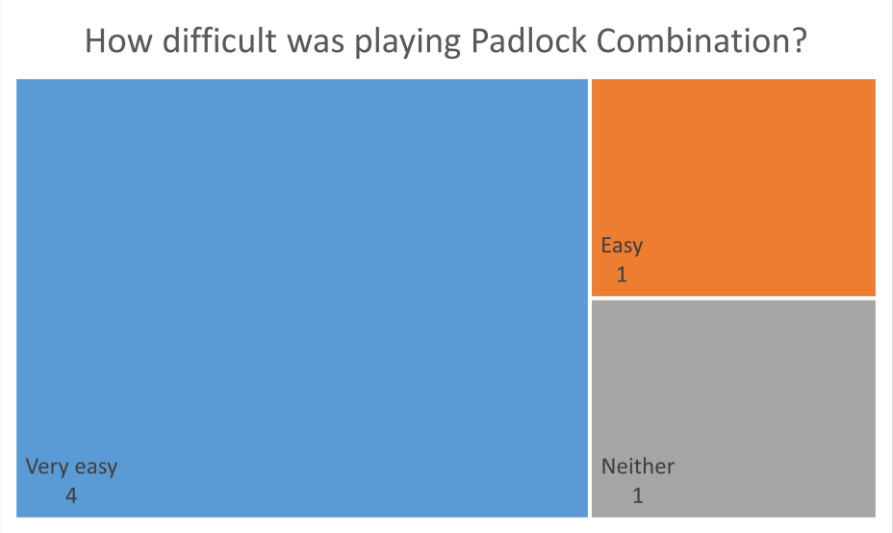

Figure 4-4 - How difficult the participants found Padlock Combination

4.2.3 Mini-game 03: The Metro

In this game, the participants were told they would see the sequence of stations being highlighted, and then they would repeat the sequence in the same order. As the game started with three stations, some participants expected that the following sequence would also be comprised of three stations. In this way, it was common to get confused with the sequence of four stations, as they would start to click on the first highlighted station before the end of the sequence. In addition, P3 reported an issue with the terminology “choose three more stations”. She said it implies more on top of

what you have seen. She suggested changing to “choose the three stations you have just seen”. With an improvement in the game's instructions, the game activity would be suitable for the aged cohort. Two participants have chosen *The Metro* as the least preferred game. The feedback from the participants is summarized in Table 4.6, Figure 4-5, and Figure 4-6. The maximum length achieved by the participants was 3, 4, 4, 5, 3, and 4, respectively.

Table 4.6 - Feedback on The Metro

Participant	*Could you understand the game by seeing the tutorial?*	*How did you like this game?*	*How difficult was playing this game?*
P1	Yes	Okay (3)	Easy (4)
P2	Yes	Okay (3)	Very easy (5)
P3	Yes	Really good (4)	Easy (4)
P4	Yes	Really good (4)	Easy (4)
P5	Yes	Really good (4)	Easy (4)
P6	Yes	Really good (4)	Easy (4)

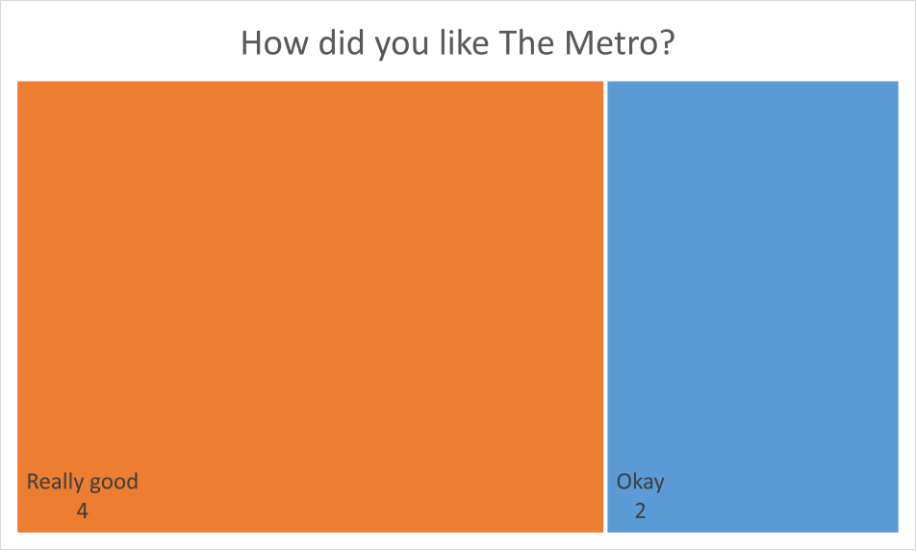

Figure 4-5 - How the participants liked The Metro

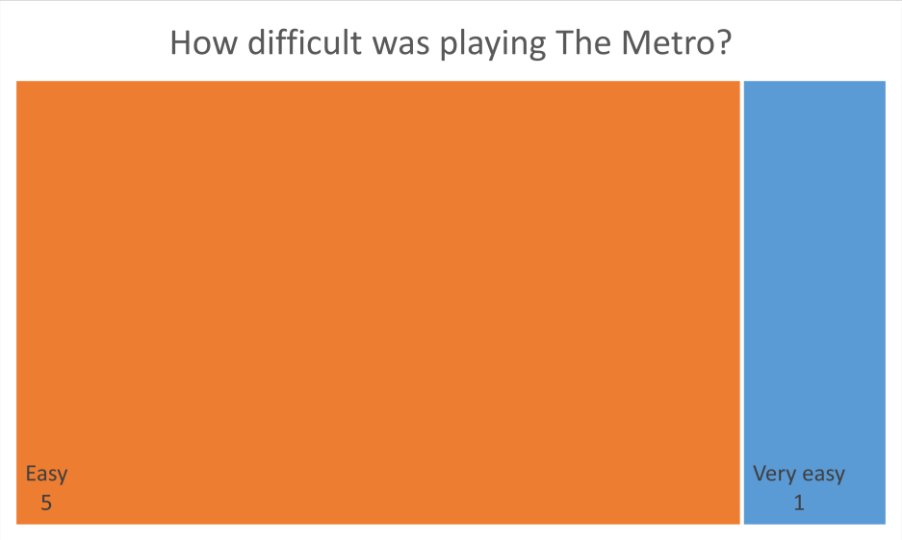

Figure 4-6 - How difficult the participants found The Metro

4.2.4 Mini-game 04: Native Fauna

Except for P1, who did not read the tutorial and asked what to do with the coconuts during the game, all participants understood the goal of the game and knew what to do. P2 and P6 mentioned that the game was speedy and needed to speed up. P5 also said there was not enough time to click on the Flamingos. He added that if you are in the top left of the screen and appear one in the bottom right, you don't get enough time to move across the screen. P4 said the only issue she had was the length of time. She was getting tired of repetitive clicking. She suggested considering shortening the time or giving a break. She said it could be split into two parts with something interesting to watch in between them. Still, one participant said *Native Fauna* was one of her preferred games. The feedback from the participants is summarized in Table 4.7, Figure 4-7, and Figure 4-8.

Regarding their game performance, the average reaction time was between 1.60 and 1.90 seconds for all participants. The coconut included as distractions did not make a difference in the game, as the participants have rarely hit it. P5 even suggested that the distraction should be more similar to the target to increase the difficulty. The participants have correctly taken 27, 9, 28, 35, 24, and 5 photos out of 36, respectively, meaning they have missed 9, 27, 8, 1, 12, and 31 targets.

Table 4.7 - Feedback on Native Fauna

Participant	*Could you understand the game by seeing the tutorial?*	*How did you like this game?*	*How difficult was playing this game?*
P1	No	Okay (3)	Easy (4)
P2	No	Really good (4)	Difficult (2)
P3	No	Okay (3)	Easy (4)
P4	Yes	Fantastic (5)	Very easy (5)
P5	No	Really good (4)	Difficult (2)
P6	Yes	Okay (3)	Difficult (2)

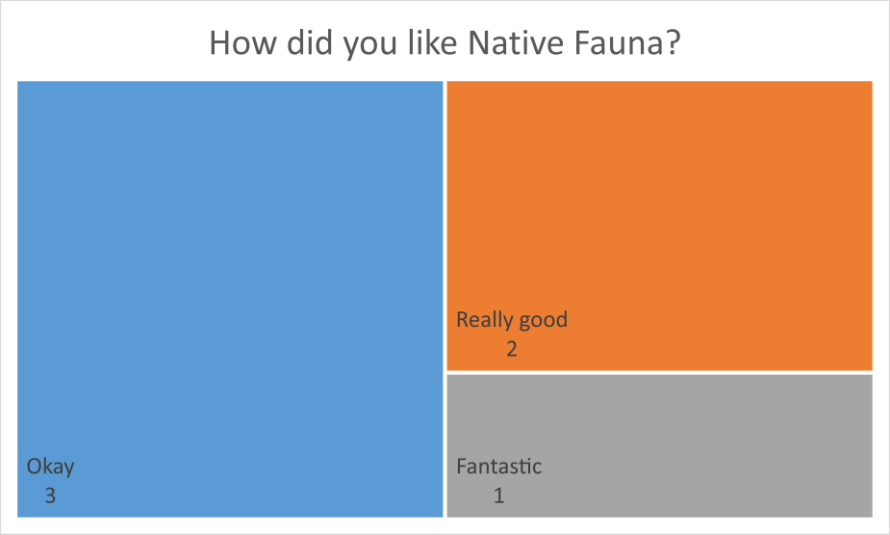

Figure 4-7 - How the participants liked Native Fauna

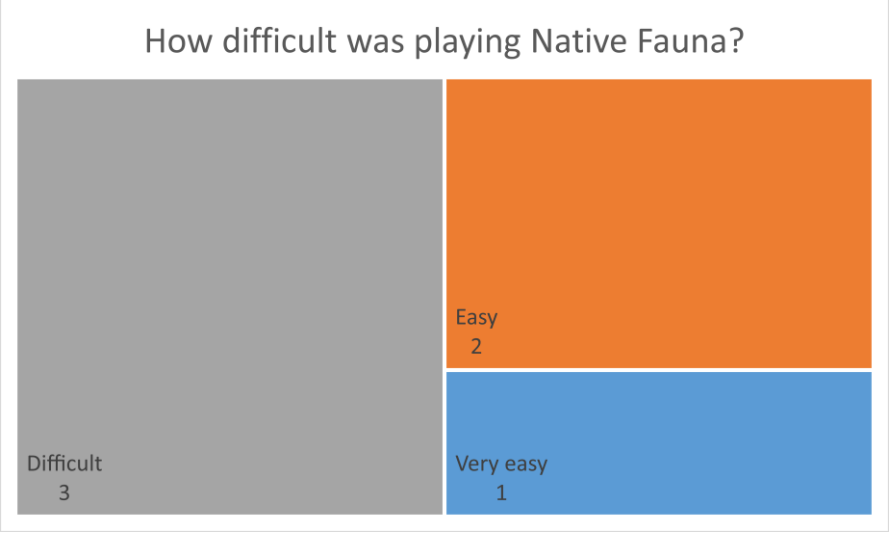

Figure 4-8 - How difficult the participants found Native Fauna

4.2.5 Mini-game 05: Messaging Home

In general, the participants understood the game very well. Only P2 had an issue. She did not know whether she had to click on the messages in the conversation and could not understand the tutorial. On the other hand, P5 said that this game had the best tutorial and no other participants reported issues with the game task itself. Although understating the task, P4 said she had difficulty distinguishing the facial expressions because they were small and monochromatic. She said the game might have been easier if it was coloured or bigger. The feedback from the participants is summarized in Table 4.8, Figure 4-9, and Figure 4-10. The participants correctly selected 4, 3, 5, 6, 6, and 4 out of 6.

Table 4.8 - Feedback on Messaging Home

Participant	*Could you understand the game by seeing the tutorial?*	*How did you like this game?*	*How difficult was playing this game?*
P1	Yes	Not very good (2)	Neither (3)
P2	No	Really good (4)	Neither (3)
P3	Yes	Okay (3)	Easy (4)
P4	Yes	Really good (4)	Easy (4)
P5	Yes	Really good (4)	Very easy (5)
P6	Yes	Fantastic (5)	Neither (3)

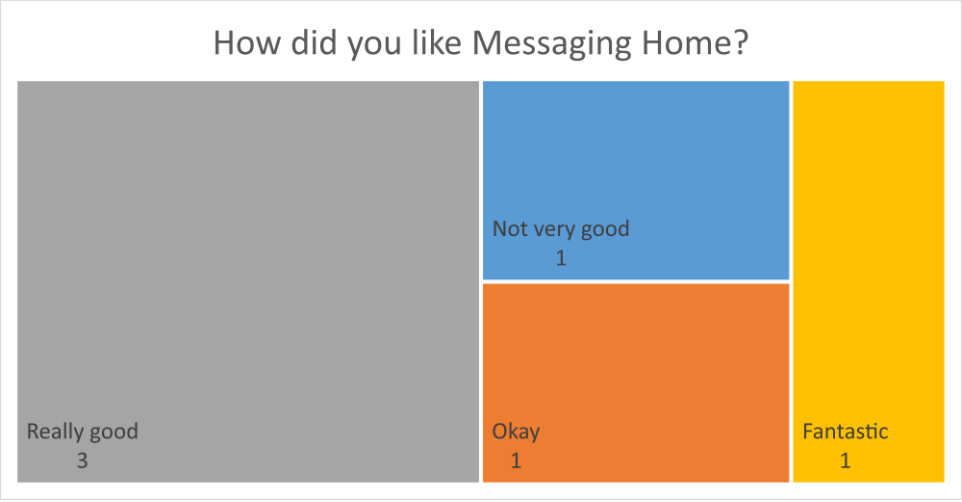

Figure 4-9 - How the participants liked Messaging Home

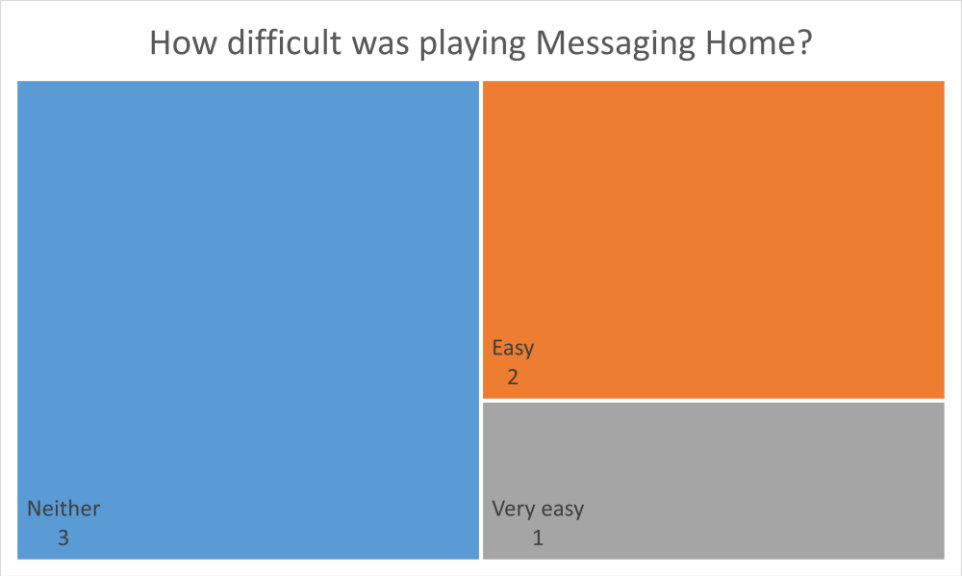

Figure 4-10 - How difficult the participants found Messaging Home

4.2.6 Mini-game 06: Time to Pack

This game required the most complex input, as participants needed to drag, drop, and rotate items. Four participants did not have any issues performing the task. Still, two participants said it was difficult. P6 said that the task was very easy and that he enjoyed very much playing this game. Still, we could observe that he did not perceive that the task should be completed as quickly as possible so that he could finish as many suitcases as possible in the given time. This information needs to be added to the player. No other issues were observed, although P2 said she would prefer to see clothes instead of blocks to be packed. Besides being expected to be the most challenging game, *Time to Pack* was reported as the preferred game by 50% of the participants. Still, one participant said it was the least preferred. She felt frustrated for being stuck in one suitcase for a long time, and we noticed that the game should end when it happened. The feedback from the participants is summarized in Table 4.9, Figure 4-11, and Figure 4-12. Regarding their game performance, the participants completed 1, 1, 3, 3, 2, and 2 suitcases.

Table 4.9 - Feedback on Time to Pack

Participant	*Could you understand the game by seeing the tutorial?*	*How did you like this game?*	*How difficult was playing this game?*
P1	Yes	Okay (3)	Very difficult (1)
P2	Yes	Okay (3)	Difficult (2)
P3	Yes	Really good (4)	Easy (4)
P4	Yes	Fantastic (5)	Very easy (5)
P5	Yes	Fantastic (5)	Neither (3)
P6	Yes	Fantastic (5)	Very easy (5)

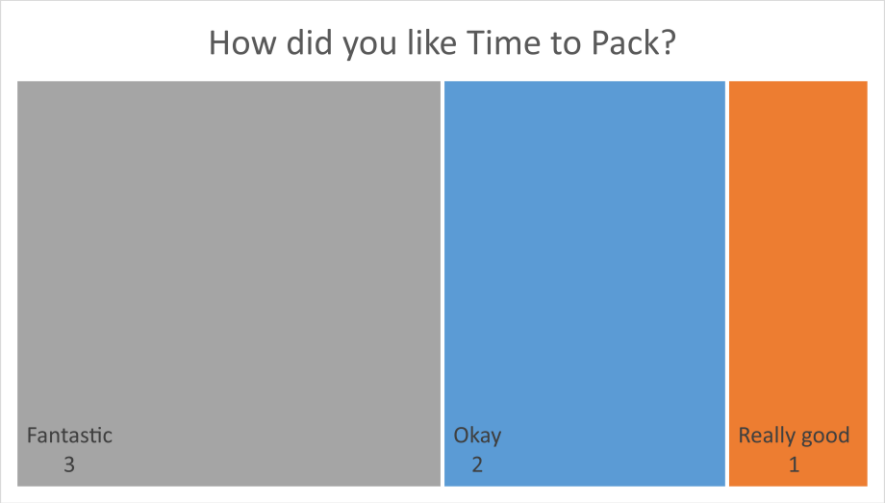

Figure 4-11 - How the participants liked Time to Pack

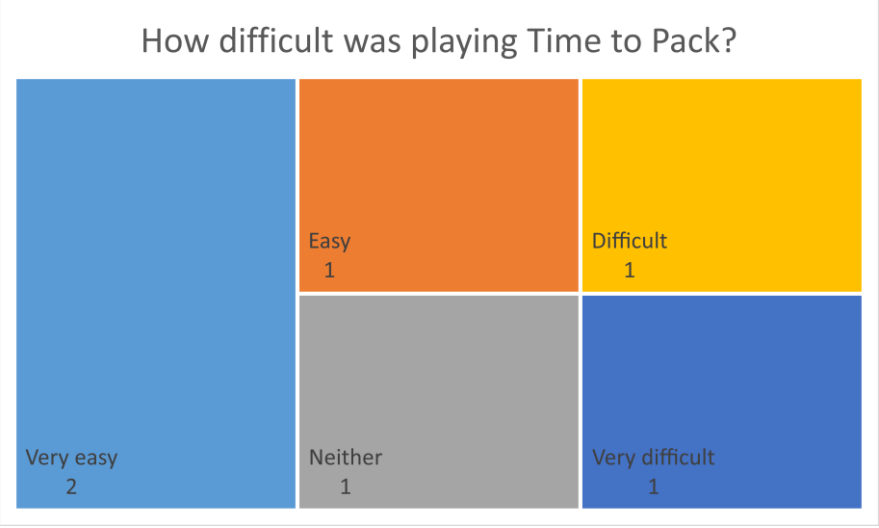

Figure 4-12 - How difficult the participants found Time to Pack

4.3 Discussions

Even though the primary purpose of the serious game is to assess cognition, it demonstrated a potential to entertain players while collecting valuable data. In general, the participants said to enjoy the concept of the game. The games' preferences were very diverse, as shown in Figure 4-13 and Figure 4-14. The satisfaction and difficulty related to the mini-games which were reported by the older adults are combined in Figures Figure 4-15 and Figure 4-16.

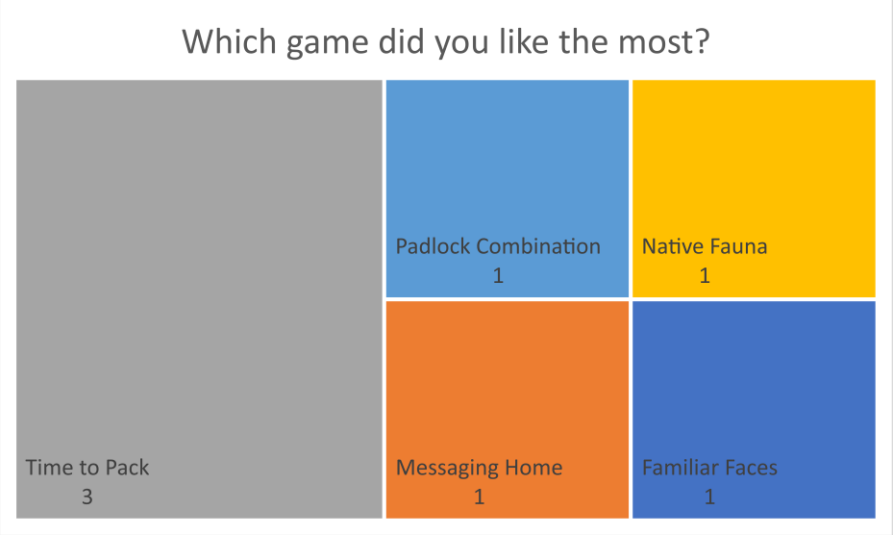

Figure 4-13 - Participants' preferred mini-game

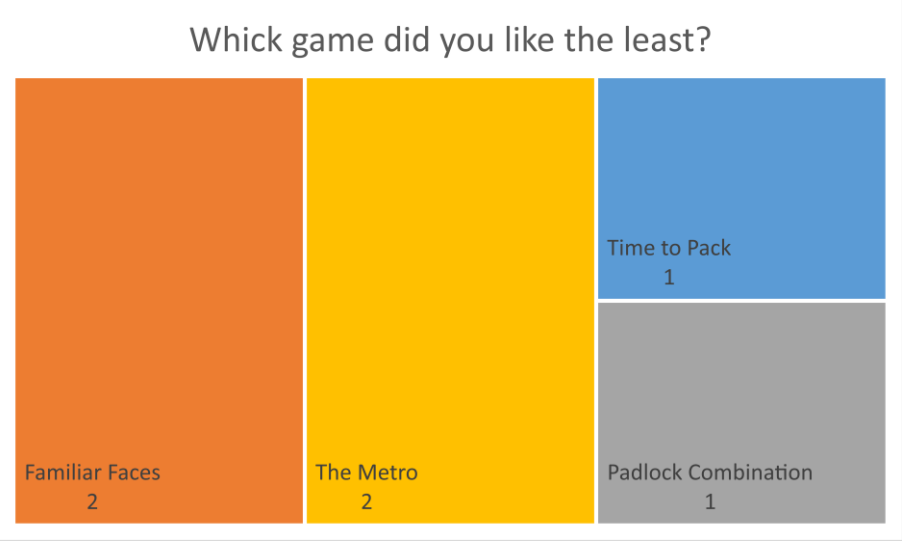

Figure 4-14 - Participants' least preferred mini-game

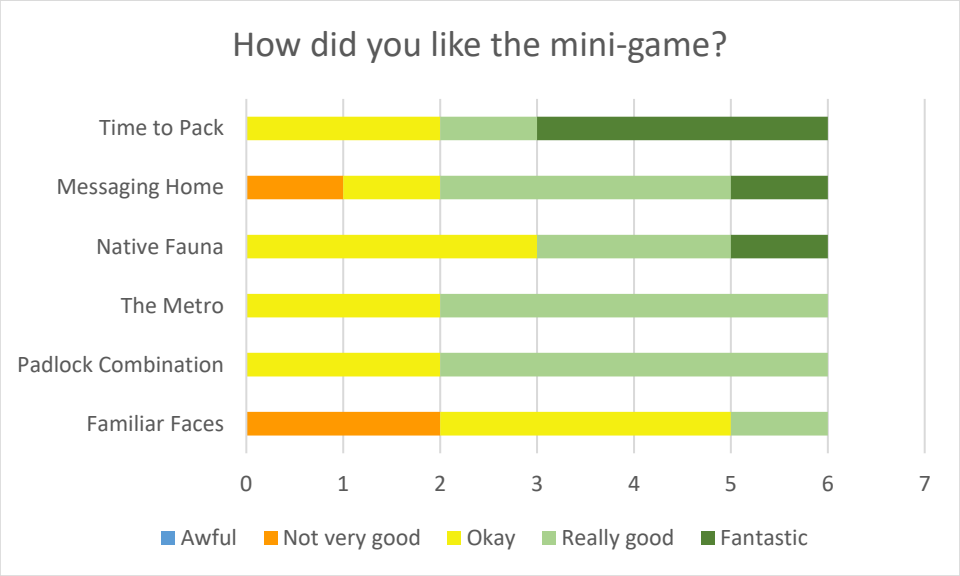

Figure 4-15 - How the participants liked the mini-games

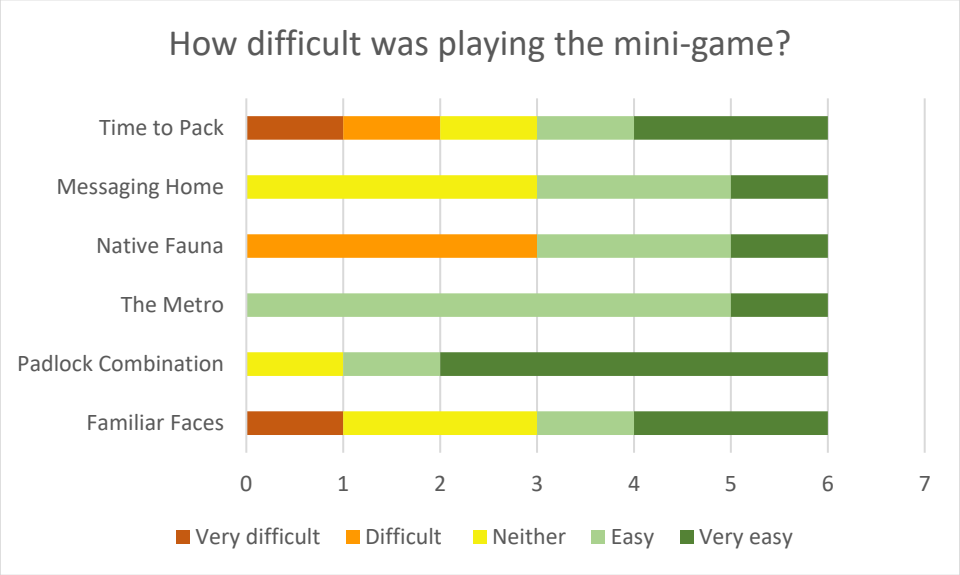

Figure 4-16 - How difficult the participants found the mini-games

The aged cohort looks receptive when the game involves cognitive skills, and they explained that the reason is that they like to exercise the brain. Likewise, they appeared to feel rewarded when they believe to have performed well in a cognitive exercise at their age. They often reported to like games they classified as easy and the reason for that is perhaps the feeling of fulfilment when completing the task. Three participants demonstrated enthusiasm at some point in the game and expressively said they were

having fun. P6 mentioned that playing CogWorldTravel is a better distraction than watching the TV. However, some aspects of the game were identified for refinement.

Firstly, the tutorials require improvement. In Chapter 3, one of the requirements defined for the serious game was that it shall include instructions that allow self-administration. The mini-game tutorials were developed using the Unity built-in recorder package. Before the start of each mini-game, a combination of video and instructions were shown to the player. From the interviews with the older adults, it was observed that this approach used to develop the tutorials was confusing for them. In the first mini-game, none of them could differentiate the video from an actual game, even though the instructions were below the video and there was an arrow to go to the next screen, all of this within a frame. They all wanted to click on the video. Most of the participants got used to the idea of the video-based tutorial throughout the game. Only P2, who was the oldest participant, remained confused until the last mini-game and needed assistance to differentiate the tutorial and the actual game until the end. If CogWorldTravel intends to be a self-administered instrument, the tutorials should be re-designed, as the current approach was not clear. One possible way is the use of an interactive tutorial where the player has the opportunity to go through an unscored trial before starting the actual game. The video and the instructions could demonstrate what the player will do and fade away after the reasonable amount of time for reading that set of instructions. Then, the player could be invited to try it in the unscored trial. Only after learning what they need to do during the game, the player would start. As the participants that reported not understanding the tutorial also skipped it, this suggested approach should be clearer and prevent players from starting without understanding the game.

A second point flagged for improvement was the narrative of the story. While the story intended to create a bit of context for the activities, the participants demonstrated that the story is a crucial aspect in the design of the game and deserved more attention. They wanted to understand and visualize each activity in the context of the trip. In addition, in *Familiar Faces*, the thumbs up included as an immediate feedback to motivate the player can be replaced by a feedback where it is clearer that

the chosen person does not have the suitcase. In *Padlock Combination*, a reminder that the words can be formed by three or four letters should be displayed during the gameplay. In *The Metro*, a warning that the sequence will increase should be displayed so that the player knows what to expect. *Native Fauna* was designed to be a fast paced game as it would measure reaction time. This has been observed and mentioned by the participants as a negative aspect of the mini-game and reinforces the preference of older adults for slow paced games. The ideal pace for the mini-game needs to be further investigated so that the balance between reaction time measurement and comfortable gameplay can be reached. In *Messaging Home*, the quality of the images should be improved, which was already expected. This was limited by the availability of open source images that reliably represent the six basic emotions. Finally, *Time to Pack* should inform the player that they need to complete the suitcases as quick as possible. Although most participants did not report issues with the inputs required by this mini-game, the inputs could be simplified if a single click rotated the items and holding the mouse allowed to drag and drop. As part of the story refinement, the tetromino-shaped items could also be re-designed to resemble clothes or other equivalent personal belongings commonly packed for travelling.

In conclusion, CogWorldTravel was well accepted by the participants. After the implementation of the lessons learnt during this study, the game has the potential to be enjoyed by a number of older adults and provide a positive user experience during the cognitive assessment. Two requirements were expected to be verified during the pilot study: Requirement 01 and Requirement 02 (see Chapter 3, Table 3.1). As all participants needed at least some assistance during the game, Requirement 01 could not be satisfied. The re-design of the tutorials is needed before this requirement is compliant. As all participants completed the entire procedure, including listening to instructions, playing the game, and answering the interview questions in approximately 45 minutes, Requirement 02 can be considered as compliant.

5. The Validation with Experts

This chapter presents the validation process of CogWorldTravel which consisted of conducting semi-structured interviews with experts in the assessment of dementia. The interviews sought to assess which cognitive elements were involved in the game task. The results of this study were presented in the IEEE International Conference on Serious Games and Applications for Health – SeGAH 2022 and published in its conference proceedings (Oliveira 2022a).

5.1 Introduction

The evaluation of CogWorldTravel was twofold. While the pilot study aimed at investigating useability issues and validate whether the player could understand the game based on the tutorials or not, the semi-structure interviews with experts aims at investigating what cognitive aspects are involved in the mini-games. The requirements defined in Chapter 3 established that CogWorldTravel shall include at least one cognitive aspect of each major cognitive domain: complex attention, executive function, learning and memory, language, perceptual-motor, and social cognition. In this study, it will be validated if those requirements were met by the design.

The experts that participated in the semi-structured interviews were chosen by their profile descriptions on the websites of Australian Universities and Research Institutes. An invitation to participate in this research was sent directly to their institutional e-mail, to which they kindly responded and accepted. When they replied to the e-mail, they were provided with the participant information sheet for further details on the study and the consent form. After they had the chance to read the information sheet and returned the signed consent form, the semi-structured interview was scheduled. The interviews were conducted in a 1-hour one-to-one Zoom meeting, which was recorded and transcribed at a later moment.

During the interviews, each of the six mini-games were demonstrated, including a detailed explanation of how to play, the parameters being collected during gameplay,

the cognitive aspects that the mini-game intends to measure, and the rationale behind the design of that specific task. Other validated tests that inspired the mini-game were also presented for comparison purposes. Power Point slides were used to present the information (see Appendix B), which was alternated with the actual serious game for the demonstration. The experts were invited to share their opinion on whether each mini-game could provide a measure of the cognitive elements it intended. The questions used to guide the interviews were open-ended questions that would allow being adjusted to cover potential directions and are shown in Table 5.1. At the end of the interviews, questions related to the overall game experience were also included to guide further discussions.

Table 5.1 - Questions that Guided the Verification Process with Experts

Game	Questions
Familiar Faces	- Do you think it can measure recognition memory?
Padlock Combination	- Do you think it can measure expressive language, attention, or executive function?
The Metro	- Do you think it can measure working memory, memory, or attention?
Native Fauna	- Do you think it can measure processing speed, attention, concentration, or working memory?
Messaging Home	- Do you think it can measure social cognition?
Time to Pack	- Do you think it can measure perceptual-motor, planning abilities, or attention?
Overall	- Do you think the tasks included in this game are elder-friendly? - Do you think this game provides a measure of cognitive performance? - If I would perform a clinical trial with the game, do you think it could detect dementia? - Do you think it would be helpful to screen people remotely? - What improvements would you suggest?

At the end of each interview, the experts were de-identified. In order to keep their privacy, the experts will be identified here as E1, E2, E3, E4, and E5. The interview was transcribed and at the end of all interviews, the feedback from the five experts related to the same mini-game were combined into a single document for analysis. The

organization of the content by mini-game allowed to understand and compare their overall perspective.

The protocol for this study was approved by the Human Research Ethics Committee (HREC) of the University of Technology Sydney (UTS). The ethics approval number for this study is UTS HREC REF NO. ETH21-6304.

5.2 Results

Five experts participated in the semi-structured interviews. Their profile can be seen in Table 5.2. They all have a formal qualification in health sciences, affiliations with an Australian university and a Research Institute, and extensive research experience with dementia, older adults, and cognitive performance.

Table 5.2 - Profile of the Experts that Participated in the Study

Expert	Profile
E1	Psychologist, Adjunct Senior Research Fellow at a Sydney University, conjoint appointment at a Research Institution.
E2	Neuroscientist, Research Fellow at a Sydney University, conjoint appointment at a Research Institution.
E3	Senior Research Fellow at a Sydney University, Research Affiliate at a Research Institution.
E4	Clinical neuropsychologist, Research Leader at a Research Institution.
E5	Cognitive neuroscientist, Research Fellow at a Sydney University, conjoint appointment at a Research Institution.

The cognitive elements that were considered to be included in each task are summarized in Table 5.3, demonstrating that CogWorldTravel satisfied requirements 03 to 08 and has one aspect of each major cognitive domain at a minimum, and the feedback obtained from the experts for each mini-game will be described in the following.

Table 5.3 - Cognitive Elements Included in Each Game Task

Cognitive Domain	Element	Mini-Game					
		Familiar Faces	Padlock Combination	The Metro	Native Fauna	Messaging Home	Time To Pack
Complex Attention	Sustained Attention				X		
	Divided Attention						
	Selective Attention	X					
	Processing Speed				X		
Executive Function	Planning						X
	Decision Making						
	Working Memory	X	X				
	Inhibition				X		
	Mental flexibility						
Learning and Memory	Immediate Span			X			
	Recent Recall	X					
	Delayed Recall						
	Recognition Memory	X					
Language	Expressive Language		X				
	Grammar and Syntax						
	Receptive Language						
Perceptual-motor	Visual Perception						X
	Visuo-constructional						
	Perceptual-motor						X
	Praxis						
	Gnosis			X			
Social Cognition	Recognition of Emotions					X	
	Theory of Mind						

5.2.1 Mini-game 01: Familiar Faces

The experts confirmed that *Familiar Faces* provides a measure of:

- Recognition memory,
- Working memory, and
- Attention.

One strength of this mini-game identified by the experts is that it is not reliant on linguistics. Overall, the five experts enjoyed this game. E2 said this was her favourite game and was a smart way to replicate the original test.

The experts also provided insightful comments regarding the activity proposed in this mini-game. E4 explained it measures working memory because the player needs to keep things alive and active in mind. E1 anticipated that the recognition would not be fully encoded in long-term memory and recalled from there, given the average range of correct faces a normal person would probably achieve. The recognition would be held in short-term memory. If we wish to collect a measure of long-term memory, we would need to recall the faces at a later moment. E3 observed that the task's difficulty level would depend on how similar the faces would be in terms of ethnicity, gender, and age.

Opportunities for further investigation were also identified by the experts. E5 demonstrated a concern that involving faces could be complex and overlap with social cognition aspects. She said that potential biases could arise from using faces in the task. If different emotions are expressed in the faces, there could be a potential bias as people tend to remember more positive emotions. There could also be a bias for older faces compared to younger ones. If the game task aims at keeping the ability to recognize as consistent as possible, she would recommend analysing further the impact of using faces.

5.2.2 Mini-game 02: Padlock Combination

The experts confirmed that *Padlock Combination* provides a measure of:

- Executive function, and
- One component of language.

One strength identified by the experts is that it is quite similar to what older people might see in the newspaper. E5 highlighted that she was interested to know how people would go with this game in the community. She expects that people would be familiar with this task.

An open challenge identified by the experts is that this mini-game probably does not measure verbal fluency. E3 explained that the reason is that the words involved in the game may not be complex enough. Still, E1 said it could be a good compromise. While the game is not drawing on precisely the same aspects of language as in most fluency tests, those tasks are specific to language, and this game draws heavily on working memory because the player would be holding in memory the words already submitted to know that the next word to be produced is not one of those. In general, they agreed that the test could be used for some elements of language.

5.2.3 Mini-game 03: The Metro

The experts confirmed that *The Metro* provides a measure of:

- Immediate memory span,
- Visual scanning, and
- Visual awareness.

There was not a consensus regarding the measurement of working memory. One of the experts said that working memory is not expected to be measured in this mini-game, as the player does not encode and manipulate information. The first information would be forgotten as soon as the next span comes in. The player does not need to retain for any longer period. However, another expert said it is similar to traditional

tests used for working memory, and highlighted that there is a lot of debate about what working memory actually is.

One challenge identified by the experts was related to the interval between the highlighting of stations. E1 explained that the interval between the highlighting for when people are watching relates to the encoding of information. If it is very slow, people would have to hold it in working memory for longer before they can start repeating the sequence. If it is very fast, they get less chance to encode or capture that position in memory before the next one appears. He added that it is important to test it to make it the right difficulty so that nearly everyone can get a few correct, so we do not have a floor effect. If it is too easy, people will just go on forever on this task, and that will take too long to fail.

5.2.4 Mini-game 04: Native Fauna

The experts confirmed that *Native Fauna* provides a measure of:

- Processing speed,
- Inhibition, and
- Sustained attention.

Many insightful comments were provided by the experts regarding the activity proposed in *Native Fauna*. One of the experts emphasized the importance of clearly telling the participant that they need to respond as quickly as possible and reward them accordingly so that the task provides a sensitive measure of processing speed. Two experts explained that this task is related to inhibition as sometimes you need to respond, sometimes you need to stop responding. They compared this task with the strip and go/no go tasks. E4 said it is not just about maintaining attention but a sensitive measure of one aspect of executive function. She explained that for some people with a cognitive deficit, once they get to a response pattern, they have problems stopping that response.

A recommendation by the experts was to match the number of flamingos in the game with the number of *As* that appear in the letter *A* task from the MoCA, if we want

to make those tasks comparable. The MoCA task has 11 targets and 18 distractions. One of the experts explained that the MoCA checks whether you can respond at the right time and stop yourself from responding at the right time. If there are not enough flamingos in the game, the player might not have to control themselves so much. The game tests the ability to stop yourself from responding even though the screen is flashing at you.

5.2.5 Mini-game 05: Messaging Home

The experts confirmed that *Messaging Home* provides a measure of:

- Social cognition.

There was unanimity among the experts that this mini-game is a strength of CogWorldTravel. Even though social cognition is not included in the MoCA or the Mini-Mental State Examination (MMSE), the experts evaluated that it has value to be included and that this game does measure it. E2 said that if the goal of the whole game is to replace or complement one of the more standard cognitive function tests, the fact that this element is added can improve it.

A challenge identified by the experts is that we might have a high ceiling effect given that there are only six trials, one for each basic emotion. They suggested to test considering reaction time as a way to make the task more sensitive.

5.2.6 Mini-game 06: Time to Pack

The experts confirmed that *Time to Pack* provides a measure of:

- Perceptual-motor,
- Attention,
- Visuospatial, and
- Planning abilities.

There was a debate whether the player should be informed that they need to perform the task as quickly as possible or not. E5 suggested that informing the player

could provide a more sensitive measure, but at the same time, it could make the older adults feel pressured and anxious. In addition, the experts were concerned whether older adults would experience any problems using the mouse during this task, as they may need to rotate, drag, and drop items.

An open challenge identified in this mini-game is that it is a 2D task, and therefore could not test 3D visualization. The addition of the 3D element could increase the difficulty of the task.

5.3 Discussions

In general, the experts liked and encouraged the continuation of this research project. The following are quotes from the experts:

"[…] and I think they would also be more interesting than lots of the tests used at the moment".

"I really like the concept and how you tie everything together like a real-world experience".

One strength of CogWorldTravel detected during this study is that it does not rely heavily on language. The following are quotes from E1 and E2:

"I think they are great in the sense that they do not rely heavily on language. That is a real strength".

"I think for a lot of the cognitive tests, MMSE or MoCA, some of the problems they did have was the language component, whether someone with low literacy or someone who speaks a different language could really understand what they are meant to do. What you have here sort of overcomes that problem in a way".

The use of game elements was also positively seen by the experts, as explained by them in the following:

"I like that it is gamified because if you are trying to assess people remotely is less confronting than a normal kind of assessment where you are very strict on the way that

you are asking things, which can put people off a little bit, especially if they are concerned about their memory. Maybe it could take away the feeling of being tested".

In addition, the fact that CogWorldTravel involves the cognitive elements separately was seen as another strength. The following is a quote from E4:

"I like that the games are simple in design, which is a positive thing because they are not overwhelming. Each game is focused on what the task involves. I think it does have potential".

In terms of the overall perception of CogWorldTravel, all experts agreed that the serious game seems appropriate for older adults.

On the other hand, as an overall test of cognitive assessment, the experts mentioned that it is probably a bit shorter than a full neuropsychological battery, but it would be appropriate if our goal is to be an initial screen rather than a comprehensive assessment. Although the initial goal to include at least one element of each major cognitive domain was achieved, this study brought the understanding that the addition of other cognitive elements is essential. On a positive note, the design of CogWorldTravel allows new mini-games to be added without impacting existing ones. The following are quotes from the experts:

"Some of the domains are definitely covered in many elements of your study design. Perhaps there are a few also missing, for example, the abstraction, which is finding the similarity between two words, and delayed recall, which is one way to test the memory by recalling some information after a period".

"I think the assessment of executive function is really important. For clinicians, one of the challenges is often differentiating between clinical diagnoses. A big one for older people is: is this person on their way to dementia, or is it something related to depression? In many ways, those things look the same. The potential of gamification to assess executive functioning is really valuable, and I think that would be an area where it would be good to see strengthened. The task with the flamingos to think about that not so much as a processing speed task but as a kind of response/inhibition process. The other thing missing in executive functioning is cognitive flexibility – switching

attention and being flexible in your thinking. Another very common cognitive problem for older people that tends to be an early sign is naming difficulties. It would be good to incorporate something like that. In terms of memory functioning, it would be good to incorporate a measure of memory recall – without having cues available so you can organize your own retrieval of information".

"One thing that might be missing is a delayed recall memory task, which you could link into the memory tasks that you have but include a delayed stage. Maybe doing the memory task at the start, then having the 7th aspect of your game that looks at delayed memory in relation to that first memory task. I think it could be useful, particularly if you are thinking about dementia, to get that delayed, then you could look at more encoding and delayed recall".

The results from the evaluation with older adults suggest that CogWorldTravel is paving the way towards an alternative CSI, yet some improvements and further investigation were identified. The experts were open to the idea of the game and agreed that cognitive elements can be measured through the mini-games. The addition of new mini-games could assist clinicians to perform a more comprehensive assessment and allow them to differentiate between diagnoses. In general, this study endorses the value of serious games as a tool to screen cognition. The specific approach used in the design of CogWorldTravel, which consists of a set of mini-games to measure different cognitive aspects, enables flexibility in the use of the serious games. This means that new mini-games can be added incrementally without affecting existing mini-games. In addition, it enables the healthcare professional to recommend the whole set of mini-games, or make a selection among the mini-games for certain patients. The mini-games can measure cognitive aspects independently. This is aligned in a way with traditional CSI, such as the MoCA and the MMSE, which measures cognitive aspects through a set of tasks. Further investigation of the potential of CogWorldTravel as a CSI would require a clinical trial where the correlation between results obtained in each mini-game and results obtained in traditional tests could be investigated. In addition, a variety of parameters can be calculated to evaluate CogWorldTravel as a CSI to detect both early stages and moderate dementia.

6. CogWorldTravel Pilot: Lessons Learnt

This chapter integrates the findings from the pilot study with older adults and the semi-structured interview with the experts, which were described in Chapters 4 and 5, respectively. It also prepares the ground for the next iterations of CogWorldTravel.

6.1 Introduction

In Chapter 4, it was described the pilot study performed with older adults, from which lessons learnt were captured. Although CogWorldTravel was generally well accepted by the participants of the study, for every mini-game, at least one lesson was learnt that can be reflected as an improvement of the design. Likewise, in Chapter 5, it was described the semi-structured interviews performed with experts in the assessment of dementia. In those interviews, it was discussed what cognitive elements are required to play each mini-game and, therefore, a potential to measure those cognitive elements involved in the task. The general concept of CogWorldTravel was well accepted by the experts that provided feedback but, in the same way as the pilot study, every mini-game has considerations to be taken, and many lessons were learnt on how to improve the assessment of dementia. This chapter intends to capture the thoughts as a result of the integration of the lessons learnt from both studies, and outlines a series of design recommendations for the next iteration of the serious game CogWorldTravel. These recommendations are guidelines on how CogWorldTravel can take one more step towards an alternative CSI. The proposed design modifications will be described in the following and comprehend both modifications on existing mini-games and the augmentation of CogWorldTravel with new mini-games to test cognitive elements that were not addressed in its first iteration.

6.2 Proposed Design Modifications

This section will suggest design modifications to enhance the game design that was initially proposed, including suggestions to improve the tutorials and the six mini-games.

6.2.1 Design Modification for the Tutorials

The tutorials included in the first version of CogWorldTravel were based on a combination of video and instructions. The player would read the instructions, watch the quick video, and move to the next screen by pressing the arrow button until the "start" button would become available in the last screen. During the pilot study with older adults, two issues were identified in this approach. First, the participants were confused with the videos. At least when playing the first mini-game, all participants understood that they should perform the instructions by clicking on the video above the instructions. This demonstrated that the tutorials were not clear. The second issue was identified by observing the players going through the tutorials. Some participants clicked on the arrow to go to the next screen without reading or paying attention to the instructions being presented. They skipped the tutorials to start playing the game as soon as possible. The suggestion to overcome these two issues in a next iteration of CogWorldTravel is the replacement of the current tutorials by interactive tutorials where the player watches a video and reads the instruction, which is presented to the player for a reasonable amount of time and then fade away, and performs an unscored example of the game task before starting the actual game. This new tutorial would resolve both issues, as the player would not keep trying to click on the video or accidentally click on the arrow to move on without seeing the tutorial. The unscored trial would help them to learn the game before starting.

6.2.2 Design Modification for Mini-game 01: Familiar Faces

The pilot study did not demonstrate major issues in *Familiar Faces* but indicated that an improvement in the story of the game could be beneficial. In the initial version of *Familiar Faces*, the suitcase of the player is missing and they will help security to

identify people and go through as many people as possible without going through the same person twice. As an immediate feedback to motivate the player to keep going, thumbs-up appear every time they select a new person. Two concerns were raised during the pilot study and throughout the development of the research project in general. First, the situation where the suitcase is missing can be stressful for some older adults, especially if they have cognitive impairment. Second, the thumbs-up can mislead the player to think that they have found the suitcase.

In addition, the story of the mini-games demonstrated to be very significant to the participants of the study. In this context, it is suggested a change in the story of this mini-game in a future iteration of CogWorldTravel. One possible solution is proposing the player to buy souvenirs for their family and friends back home. However, because of luggage space constraint, they should only buy one gift to each dear person. They should select one person to buy a gift at a time and not buy to the same person twice. The immediate feedback could be replaced with motivating sentences, such as “She will love this gift” or “He will be glad you remembered him during your trip”.

The experts that participated on the semi-structured interviews mentioned that the use of faces in the mini-game may add bias, as people tend to remember more positive emotions and older faces when compared to negative emotions and younger faces. This was an interesting point of view, especially because the mini-game is inspired on the Warrington Recognition Memory Test for faces (Warrington 1984), which is a validated and well-accepted cognitive test. However, the Recognition Memory Test by Warrington consists of two tasks. One is the recognition of faces, like the one included in CogWorldTravel, and the other is the recognition of words, which could be added to CogWorldTravel as a new mini-game in a future iteration.

6.2.3 Design Modification for Mini-game 02: Padlock Combination

In *Padlock Combination*, the player needs to form words of three or four letters with a given set of four letters as an attempt to open the padlock. Some of the participants missed in the instructions that the words could be formed with three letters as well. The participants either did not read the tutorial carefully or forgot the rule after started

playing the game. This issue could be resolved by replacing the tutorials with the interactive approach. By giving the chance to the player of forming an unscored word of three letters, it is likely that they will remember this rule when playing the mini-game. Another solution that may help is to display a message at all times to remember that the words can be formed with three or four letters. Lastly, the last box of the padlock could be displayed in a different colour to highlight that it is optional and different from the others that are mandatory.

In addition to the above improvements, the experts evaluated that the language task involved in this mini-game is simpler than those of traditional tests. It is suggested that future iterations of CogWorldTravel include new mini-games that assess other components of language. In order to be comparable with the MoCA, CogWorldTravel should include one or more tasks that test naming skills and the formation of syntactically complex sentences.

6.2.4 Design Modification for Mini-game 03: The Metro

In *The Metro*, the stations are highlighted in the map and the player must repeat the sequence in the same order. The mini-game starts with a sequence of three stations and gradually increases by one station as the player progresses. However, the participants of the pilot study expected that the sequence would remain the same number of stations. When the sequence increased to four stations, the participants started clicking on the first station before the end of the sequence being highlighted. As a consequence, they missed the last stations of the sequence because they moved on to the next step of the activity ahead of time. Changing the tutorial to an interactive approach would most likely be beneficial to this issue. The interactive tutorial could start with one station, then increase to two stations and give the opportunity to the player to see the sequence being increased in the unscored trial. A message could also be displayed to inform the number of stations the player should expect to see. For example, “You will watch a sequence of 3 stations”.

As the experts mentioned in the semi-structured interview, this mini-game is very similar to the digit span test and measures the capacity to hold small amounts of

information in an active and accessible way. The time between two highlighted stations can impact the result of the test. The slower the stations are presented, the longer the person would need to keep the information. A future iteration of CogWorldTravel could make this parameter easily configurable by the healthcare professional in the settings screen so that different assessments could be performed and compared. In addition, some digit span tests provides the possibility of choosing if the patient should repeat the sequence in the same order or reversed. Next iterations of CogWorldTravel could offer the same feature.

6.2.5 Design Modification for Mini-game 04: Native Fauna

The mini-game *Native Fauna* was easily understood by the participants of the pilot study. They were requested to take photos of the flamingos and avoid the coconuts. However, because the coconut is very different from the flamingos in shape and colour, differentiating the target from the distraction was very easy for all participants. In a next version of CogWorldTravel, the distraction could be replaced with an image that shares more similarities with the flamingos so that the player is required to stop themselves from responding to the distractions.

The number of targets and distractions in *Native Fauna* were bounded by the time. The player should perform the activity for two minutes. However, one of the participants mentioned that the task was repetitive and one of the experts suggested to match the number of targets and distractions with the number of targets and distractions of the letter *A* task of the MoCA. While the current version of CogWorldTravel has approximately 36 targets and 14 distractions, the letter *A* task has 11 targets and 18 distractions. Adjusting those numbers would shorten the activity for the players, make it comparable with the validated cognitive test, and most likely make it less repetitive.

6.2.6 Design Modification for Mini-game 05: Messaging Home

In this task, the player is expected to click on facial expressions that support the feeling mentioned in the conversation. Only one older adult had issues understanding the task, which could be resolved by the redesign of the tutorials as well. Once they have the chance to practice before getting scored, it is less likely that players would not know what to do during gameplay. Although the task has been easily understood by all other participants of the pilot study, one player reported an expected issue, which was the quality of the images on which they should click. The images were black and white and small due to the unavailability of images that demonstrate proper facial expressions for the six basic emotions. In future iterations of CogWorldTravel, the replacement of those images is desirable. In addition, one of the experts raised the concern of a ceiling effect due to a small number of trials. One possible solution for this would be the addition of time for the player to respond.

6.2.7 Design Modification for Mini-game 06: Time to Pack

Time to Pack requires the player to place tetromino-blocks in a 2D grid that represents a suitcase. As discussed with the experts during the semi-structured interviews, in a next iteration, this task could include 3D challenges so that 3D visualization is tested. This would also increase the difficulty of the task.

As per the lessons learnt during the experiment with older adults, it would be beneficial if the blocks could represent real items. It means that the design could be improved to keep the desired shaped but resemble an item that one would pack in order to make the task more meaningful. Although most participants did not have issues to drag, drop, and rotate items, it would be easier if the items were rotated with a single click. The next iteration of CogWorldTravel could simplify the inputs required from the player by reducing the inputs to a single mouse button. A single click would rotate, while holding the same button would allow to hold the item and drag. The release of the button would drop the item. This change would also make easier once the game changes the platform and is played using a mobile device. Finally, this mini-

game needs to add instructions that the player needs to perform the task as quick as possible as the task is timed.

6.2.8 Adding New Mini-games

Traditional instruments measure cognitive abilities individually. Ideally, cognitive elements should only be involved in the task when this specific ability in being measured. For example, the experts mentioned that one strength of CogWorldTravel is that the game is not heavily relying on language. Table 5.3 summarized the cognitive elements included in CogWorldTravel and demonstrated that the overall goal of including at least one element of each major cognitive domains was achieved. The same table can be used as a reference to the addition of new mini-games to measure cognitive aspects currently not included in CogWorldTravel. While there is room to add a series of new mini-games to test multiple new cognitive elements, the next iterations of CogWorldTravel should prioritize the addition of mini-games to measure mental flexibility, abstraction, naming, and delayed recall.

A new mini-game for mental flexibility can be inspired by tests such as the Wisconsin Card Sorting Test (WCST) (Milner 1963), the Trail Making Test (TMT) (Butler et al. 1991), and the Verbal Fluency Test (VFT) (Lezak et al. 2004), which test one's ability to shift between two or more concepts. A test for abstraction usually assesses the ability to identify and interpret patterns. A new mini-game for abstraction can be inspired by the abstraction component of the MoCA (Nasreddine et al. 2005), which requires the individual to identify the similarity between a train and a bicycle and a watch and a ruler. Other popular tests available on the internet requires to identify the next item of a sequence of different shapes and figures. A new mini-game for naming could be inspired by naming tests such as the Graded Naming Test and the naming component of the MoCA, which show images and ask the individual to say what the image is. Naming is related to the ability to refer to objects, people, places, or ideas by proper names and is involved in crossword puzzles. Finally, a delayed recall game can be inspired by the memory component of the MoCA, which asks the individual to recall

some information after five minutes. A mini-game or a combination of mini-games can request the player to retrieve some information after a certain interval.

6.3 Conclusion

The pilot study with older adults and the semi-structured interviews with the experts provided insight into the design of the six mini-games and yielded a great amount of lessons learnt. All mini-games have the potential to measure some aspects of cognition, but all of them have room for improvement.

Given the importance that older adults have given to the story of the game, it should be enhanced. It was observed that the players wanted to understand the narrative and relate the mini-games to it. In addition, they enjoyed more the mini-games when they felt to perform well in a cognitive task. A few issues were identified in the tutorials and in the instructions of certain mini-games, which can be improved so that the players can perform better. The consulted experts indicated aspects of the existing mini-games for further investigation, such as the impact of using faces in *Familiar Faces* and the impact of the interval between stations highlighted in *The Metro*. In order to improve the assessment, the experts suggested modifications such as matching the numbers of targets and distractions with the MoCA, including time in *Messaging Home*, and including a 3D task in *Time to Pack*.

In addition to the lessons learnt through the six mini-games included in the first version of CogWorldTravel, it is recommended that new mini-games are added to test other cognitive elements. In the first iteration of CogWorldTravel, it was not expected that the previously referred Table 5.3 would be completely filled out by considering the cognitive elements involved in the six proposed mini-games. Instead, it was expected at least one aspect of each major cognitive domain to be involved, which was achieved and can be easily visualized in that Table. However, CogWorldTravel can still take one step further and include new cognitive elements. As discussed with the experts during the semi-structured interviews, the first version of CogWorldTravel is suitable for an initial screen. A comprehensive cognitive assessment would need the addition of new mini-games to test cognitive elements that were not considered at this stage.

According to the experts, in clinical settings, a comprehensive cognitive assessment can take hours to be performed. This means that, if a future iteration of CogWorldTravel is more ambitious and intends to provide a more comprehensive assessment, requirement 02 (i.e., the serious game shall be completed in up to 30 minutes) can be relaxed. The design recommendations outlined in this chapter prioritize the addition of mini-games to test mental flexibility, abstraction, naming, and delayed recall following the lessons learnt with the interviewed experts. An advantage about the initial design of CogWorldTravel is that it enables the addition of new mini-games without affecting the existing ones. It means that new mini-games can be added incrementally.

Finally, it was perceived that the participants of the pilot study have a preference for playing games in mobiles devices instead of computers. It is ideal that the next iteration of CogWorldTravel evolves to a mobile platform. Ideally, the player should be able to choose which platform suits them better.

7. Conclusions and Future Work

This concluding chapter summarizes the key findings of this research work, discusses how the research questions were addressed, their potential and limitations, and discusses future research directions.

7.1 Summary of key findings

In Chapter 1, an introduction to the research project has been presented and the research questions, aims, objectives, significance, and contributions were defined. It was outlined that there is an urgent need to improve diagnosis rates of dementia, and CSIs are the first step towards diagnosis. The most significant challenge for the proper use of traditional CSIs is the time required for administration in clinical settings, and this research project proposed to investigate further the use of serious games as alternative CSIs. The rationale for the use of serious games is the possibility of self-administration and an improved experience for the older adult. Self-administration enables the screening to be performed remotely, or more efficiently in clinical settings. This is aligned with a previous survey conducted with older adults that indicated their preference to be assessed at home. Even traditional tests, such as the MoCA, which has announced its upcoming solo version, are shifting towards self-administration.

In Chapter 2, a literature review was conducted to understand the achievements in the field up to this time. Existing commercial games and bespoke games have been investigated to assess cognitive performance. While commercial games are likely to be engaging, they do not necessarily satisfy the requirements of a CSI. On the other hand, bespoke games face the opposite challenge. While they offer the possibility of assessing multiple cognitive elements, keeping them engaging is challenging. Most previous work still had an exploratory approach and focused on whether it would be feasible to use the serious game for cognitive screening. At this stage, it is undeniable that significant correlations exist between in-game measurements and traditional methods of cognitive screening; however, little attention has been paid to the factors that contribute to an ideal game-based CSI. In this context, this research project

focused on investigating how to design and develop serious games that also satisfy the requirements of traditional CSIs.

In Chapter 3, the requirements of the serious game were defined based on the criteria of CSIs. It was proposed that the serious game shall sample all major cognitive domains: complex attention, executive function, learning and memory, language, perceptual-motor, and social cognition. In addition, considerations related to the duration and the administration of the tool were made. The design was particularly challenging because of the interdisciplinary nature of the research. In addition to being driven by the need to sample all major cognitive domains, it also tried to accommodate age-related changes in health, and be independent of culture, language, and education level as far as possible. CogWorldTravel's story revolved around travelling and included six mini-games: *Familiar Faces*, *Padlock Combination*, *The Metro*, *Native Fauna*, *Messaging Home*, and *Time to Pack*. All mini-games have foundations in previous research, validated cognitive screening methods, and the working definition of each cognitive domain.

The evaluation of CogWorldTravel was twofold. Firstly, a pilot study involving older adults has been conducted to investigate any useability issues, which was described in Chapter 4. Six older adults were invited to play the game and answer a few questions about their experience. In order to verify Requirement 01 and investigate whether older adults could play the game with minimal assistance or not, the study investigated the perception of the participants towards the tutorials. The combination of video and instructions used in the development of the tutorials demonstrated to be particularly problematic. All participants needed assistance at least in the first mini-games. While some participants got used to it after a few examples, others continued to require assistance to differentiate the video from the actual game until the end of the study. This means that Requirement 01, which states that the serious game shall allow self-administration, was not satisfied. An interactive approach where the player has the opportunity to learn before playing would be more suitable for the development of the tutorials. After being assisted during the tutorials, the participants did not have any

other major issues while playing the mini-games but minor improvements were identified for all mini-games.

A few participants highlighted that they were having fun at some point in the game, demonstrating a great acceptance of CogWorldTravel and satisfaction when solving cognitive tasks. As *Native Fauna* intends to measure processing speed, the task is fast-paced, which was mentioned by the participants, which confirms their preference for slow-paces games. The other five mini-games included slow-paced activities. In regards to the attempt to accommodate age-related changes, only one participant asked to make the buttons in *Padlock Combination* bigger and make the images in *Messaging Home* coloured. One major concern during the design phase game was whether the participants would be able to rotate the items in *Time to Pack*; however, two thirds of the participants did not report any issues. In general, these results show that CogWorldTravel has been accepted by the majority of participants.

In continuation to the evaluation of CogWorldTravel, Chapter 5 described semi-structured interviews with five experts in the assessment of dementia. This second stage of the evaluation process aimed at investigating what cognitive aspects were involved in each mini-game and the overall perception of the experts towards the serious game. This provided an understanding of whether the serious game satisfies Requirements 03 to 08. According to the consulted experts, *Familiar Faces* has the potential to measure recognition memory, attention, and working memory. *Padlock Combination* has the potential to measure executive function and a component of language. *The Metro* has the potential to measure immediate memory span, visual scanning, and visual awareness. *Native Fauna* has the potential to measure processing speed, sustained attention, and inhibition. *Messaging Home* has the potential to measure recognition of emotions. Finally, *Time to Pack* has the potential to measure perceptual-motor, attention, and planning abilities. Therefore, CogWorldTravel has the potential to provide a measure of at least one aspect of each major cognitive domain, which is in accordance with the requirement of an ideal CSI to sample all major cognitive domains. The outcome from the requirements verification is summarized in Table 7.1.

Table 7.1 - Requirements Verification Matrix

ID	Requirement	Comments	Result
01	The serious game shall include instructions that allow self-administration.	The participants had issues to differentiate the tutorials from the actual game and required assistance. The tutorials need improvement.	Fail
02	The serious game shall be completed in up to 30 minutes.	The six mini-games can be completed in less than 30 minutes.	Pass
03	The serious game shall sample at least one cognitive aspect of Complex Attention.	This is sampled by *Familiar Faces* and *Native Fauna*.	Pass
04	The serious game shall sample at least one cognitive aspect of Executive Function.	This is sampled by *Familiar Faces, Padlock Combination, Native Fauna,* and *Time to Pack*.	Pass
05	The serious game shall sample at least one cognitive aspect of Learning and Memory.	This is sampled by *Familiar Faces* and *The Metro*.	Pass
06	The serious game shall sample at least one cognitive aspect of Language.	This is sampled by *Padlock Combination*.	Pass
07	The serious game shall sample at least one cognitive aspect of Perceptual-motor.	This is sampled by *The Metro* and *Time to Pack*.	Pass
08	The serious game shall sample at least one cognitive aspect of Social Cognition.	This is sampled by *Messaging Home*.	Pass

In addition, the experts emphasized that the game does not rely heavily on language, which was a desideratum of the design. The design choices aimed at involving language only in the occasion of measuring this specific skill. Likewise, we

attempt to design game tasks that people with any level of education could perform reasonably fairly. Recognition of faces, recognition of emotions, assembly of items, memorizing highlighted stations in a metro map, and taking photos of an animal as quickly as possible are activities that did not seem to be highly influenced by education or even culture.

The results from the studies with older adults and experts in the assessment of dementia were integrated In Chapter 6, and design recommendations for the next iteration of CogWorldTravel were outlined.

The key contributions of this research project can be summarized as follows:

- A comprehensive literature review in the topic of serious game for cognitive screening that may inform future works.
- General guidelines on the design of serious games for cognitive screening that may assist other researchers.
- The design of CogWorldTravel as a serious game that is paving the way towards an alternative CSI.
- Many lessons learnt throughout the evaluation process of CogWorldTravel that may inform future work.

Finally, the answers to the research questions defined in Chapter 1 are summarized in the following:

What features should a game have to be used as a CSI for dementia?

There is no doubt that games can be used to screen cognition. However, games that were not designed for such purpose do not necessarily satisfy the criteria of a CSI and cannot be considered a proper instrument. As explained in Chapter 3 and summarized in the analytical framework in Section 3.4, an ideal game-based cognitive screening instrument should:

- Assess all major cognitive domains,
- Be age-friendly, and

- Gamify.

By incorporating these three characteristics, the serious game will be in accordance with the same criteria of traditional CSIs, accommodate age-related changes, and provide a less intimidating experience for older adults.

What is the overall perception of older adults and experts towards CogWorldTravel?

The overall perception of older adults was investigated in the pilot study and the overall perception of the experts was investigated in the semi-structured interviews. The studies have been explained in Chapters 4 and 5.

In general, the participants that represented the aged cohort enjoyed the game and they were receptive to a game that involves cognitive skills. Some of them highlighted that they were having fun while playing; however, they were confused with the approach used for the development of the tutorials, which involved demonstrations through videos and instructions.

The experts were also receptive to the idea of assessing cognition using a game-based CSI. One experts even said that CogWorldTravel is more interesting than lots of tests used at the moment. They have agreed that CogWorldTravel involves at least one cognitive element of each major cognitive domain, but assessed that it is more suitable for an initial screening rather than a thorough assessment. In order to provide a more comprehensive assessment, the addition of new mini-games is still needed. One strength of CogWorldTravel detected by the experts is that it does not heavily rely on language skills.

What cognitive elements are involved in CogWorldTravel?

As explained in Chapter 5, the cognitive elements involved in CogWorldTravel were validated through semi-structured interviews with experts in the assessment of dementia, which are listed below:

- **Complex attention:** selective attention and sustained attention.

- **Executive function:** working memory and inhibition.
- **Learning and memory:** immediate span, recent recall, and recognition memory.
- **Language:** expressive language.
- **Perceptual-motor:** visual perception and perceptual-motor.
- **Social cognition:** recognition of emotions.

What are the lessons learnt from CogWorldTravel?

The evaluation of CogWorldTravel was conducted in two stages, both of them yielded a number of lessons learnt, which were presented in Chapter 6. The lessons learnt were translated into design recommendations for future iterations of CogWorldTravel and are summarized in the following:

- Tutorials to be re-designed using an interactive approach,
- *Familiar Faces* to have its story refined,
- *Padlock Combination* to display a reminder that words can be formed by three letters,
- *The Metro* to inform the number of stations the player should expect to see,
- *Native Fauna* to include distractions that are more similar to the target and match the amount of targets and distractions with the MoCA,
- *Messaging Home* to have images replaced by higher quality images and timed activity,
- *Time to Pack* to re-design tetrominoes and include instructions that the player needs to perform the activity as quick as possible,
- New mini-games to be added to address missing cognitive elements.

7.2 Limitations and Future Work

This section describes the limitations identified throughout the development of this research project and provides future work directions.

CogWorldTravel was designed based on well-researched, validated medical instruments and also based on the description of the cognitive domains that was obtained from the relevant medical material. In addition, the validation of the design involved feedback from experts in the assessment of dementia; this research focused on technical trials of the game design and implementation. The full validation of CogWorldTravel as a game-based CSI and the definition of its utility parameters will require a clinical trial that is outside the scope of this PhD research. A clinical trials is the common procedure to evaluate cognitive screening tests and new ways to detect cognitive disorders, which can be conducted in future works. The study of the design performed in this research project provides an indication about the performance of CogWorldTravel as a game-based CSI. The clinical trial would require healthy and demented individuals to volunteer to play CogWorldTravel so that sensitivity and specificity when screening for dementia could be determined. Only after the determination of those parameters, CogWorldTravel could be incorporated in clinical practice and used as a medical tool.

In this research project, the design of CogWorldTravel aimed at sampling all major cognitive domains and, thus, at least one cognitive element of each major cognitive domain has been included. However, each major cognitive domain involves multiple cognitive elements. The current design of CogWorldTravel was considered suitable for an initial screening. A more comprehensive cognitive assessment would require the addition of other cognitive elements, which is possible through the addition of new mini-games in future studies. The experts that were consulted in this research project recommended the addition of new mini-games to involve cognitive flexibility, abstraction, naming, delayed recall, and a more complex task for expressive language. Although the addition of new mini-games was not possible within this research project due to time and budget constraints, the way in which CogWorldTravel has been designed offers the flexibility to add new mini-games without impacting the existing ones. The architectural concept of CogWorldTravel is modular, where each mini-game is a module that provides a measurement for certain cognitive elements. New modules can be added, others can be modified, and the order in which the mini-games are played can be rearranged, if required. This concept may offer the opportunity for

healthcare professionals to create personalized assessments for individuals. The individual may be requested to play the entire collection of mini-games or a personalized selection that is in accordance with their health condition. The healthcare professional may also request an initial set to be played and, if concerns are raised, request further assessment.

In conclusion, a step towards the use of game-based cognitive screening instruments has been taken and CogWorldTravel is paving the way towards becoming an alternative instrument. In addition, this PhD research collected many lessons learnt and guidelines that will inform other researchers in the same field. When these game-based instruments are ready to be incorporated into clinical practices, there will be an uncomplicated, playful, and consistent way of screening for dementia that could increase the number of people being tested. This is urgently required to address the existing dementia underdiagnosis global issue and prepare for the increase in the number of people with dementia due to the ageing of the population in the years yet to come.

8. References

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Appendix A – Form: Pilot Study with Older Adults

Interview Guide
Researcher: ☒ F ☐ B
Participant ID: 01 Female
Age: ☐ 60-65 ☐ 66 – 70 ☐ 71-75 ☐ 76-80 ☐ 80+
Studies: ☐ Primary ☐ High ☐ Vocational ☐ Bachelor's ☐ Master's ☐ PhD
Familiar Faces
Could you understand the game by seeing the tutorial? ☐Yes ☐No
How did you like this game? ☐1 – Awful ☐2 – Not very good ☐3 – Okay ☐4 – Really good ☐5 – Fantastic
How difficult was playing this game? ☐1 – Very Difficult ☐2 – Difficult ☐3 – Neither ☐4 – Easy ☐5 – Very easy
Did you have any issues playing this game?
Any other comments / perception from the researchers:
Performance: Correct Hits: Time Since Start:
Padlock Combination
Could you understand the game by seeing the tutorial? ☐Yes ☐No
How did you like this game? ☐1 – Awful ☐2 – Not very good ☐3 – Okay

☐4 – Really good ☐5 – Fantastic
How difficult was playing this game? ☐1 – Very Difficult ☐2 – Difficult ☐3 – Neither ☐4 – Easy ☐5 – Very easy
Did you have any issues playing this game? No.
Any other comments / perception from the researchers:
Performance:
The Metro
Could you understand the game by seeing the tutorial? ☐Yes ☐No
How did you like this game? ☐1 – Awful ☐2 – Not very good ☐3 – Okay ☐4 – Really good ☐5 – Fantastic
How difficult was playing this game? ☐1 – Very Difficult ☐2 – Difficult ☐3 – Neither ☐4 – Easy ☐5 – Very easy
Did you have any issues playing this game?
Any other comments / perception from the researchers:
Performance: Max achieved: Successes Since Start:
Native Fauna
Could you understand the game by seeing the tutorial? ☐Yes ☐No
How did you like this game? ☐1 – Awful ☐2 – Not very good ☐3 – Okay ☐4 – Really good ☐5 – Fantastic
How difficult was playing this game? ☐1 – Very Difficult ☐2 – Difficult

☐3 – Neither ☐4 – Easy ☐5 – Very easy
Did you have any issues playing this game?
Any other comments / perception from the researchers:
Performance: Average reaction time: correct photos taken (target): wrong photos taken (distraction): missed targets:
Messaging Home
Could you understand the game by seeing the tutorial? ☐Yes ☐No
How did you like this game? ☐1 – Awful ☐2 – Not very good ☐3 – Okay ☐4 – Really good ☐5 – Fantastic
How difficult was playing this game? ☐1 – Very Difficult ☐2 – Difficult ☐3 – Neither ☐4 – Easy ☐5 – Very easy
Did you have any issues playing this game?
Any other comments / perception from the researchers:
Performance: Correct Faces out of 6:
Time to Pack
Could you understand the game by seeing the tutorial? ☐Yes ☐No
How did you like this game? ☐1 – Awful ☐2 – Not very good ☐3 – Okay ☐4 – Really good ☐5 – Fantastic
How difficult was playing this game? ☐1 – Very Difficult ☐2 – Difficult ☐3 – Neither ☐4 – Easy ☐5 – Very easy
Did you have any issues playing this game?

Any other comments / perception from the researchers:
Performance: Completed Suitcases:
Overall
Which game did you like the most? ☐Familiar Faces ☐Padlock Combination ☐The Metro ☐Native Fauna ☐Messaging Home ☐Time to Pack
And the least? ☐Familiar Faces ☐Padlock Combination ☐The Metro ☐Native Fauna ☐Messaging Home ☐Time to Pack
What did you like?
What did not you like so much?
What would you keep?
What would you change?

Appendix B – Slides: Semi-structured Interviews with the Experts

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

Introductions

Fernanda Oliveira
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Serious games for the elderly

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

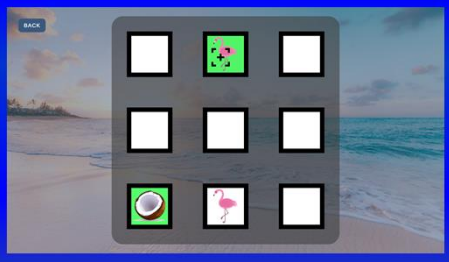
Research Overview

- ❑Design and develop a game-based cognitive test
  - ❑Provide a measure of cognitive performance
  - ❑Elder-friendly design
  - ❑Suitable for self-administration (not self-assessment)

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

CogWorldTravel Explained

❑Native Fauna



- ❖ Inspired by the Letter A task (from the MoCA – provides a measure of attention, concentration, and working memory).
- ❖ Cognitive domains involved:
- Complex Attention
- ❖ Data collected during gameplay:
- Processing speed (average reaction time)
- Number of correct photos taken
- Number of wrong photos taken (coconut)
- Missed flamingos

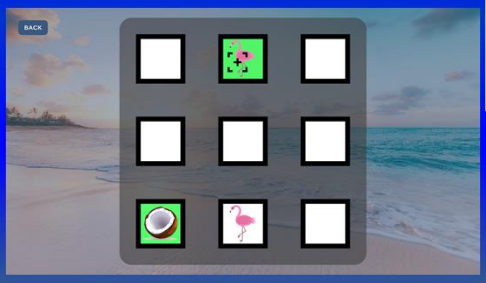
Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

Feedback

❑Native Fauna



Complex attention (sustained attention, divided attention, selective attention, processing speed)	*Major:* Has increased difficulty in environments with multiple stimuli (TV, radio, conversation); is easily distracted by competing events in the environment. Is unable to attend unless input is restricted and simplified. Has difficulty holding new information in mind, such as recalling phone numbers or addresses just given, or reporting what was just said. Is unable to perform mental calculations. All thinking takes longer than usual, and components to be processed must be simplified to one or a few. *Mild:* Normal tasks take longer than previously. Begins to find errors in routine tasks; finds work needs more double-checking than previously. Thinking is easier when not competing with other things (radio, TV, other conversations, cell phone, driving).	*Sustained attention:* Maintenance of attention over time (e.g., pressing a button every time a tone is heard, and over a period of time). *Selective attention:* Maintenance of attention despite competing stimuli and/or distractors: hearing numbers and letters read and asked to count only letters. *Divided attention:* Attending to two tasks within the same time period: rapidly tapping while learning a story being read. Processing speed can be quantified on any task by timing it (e.g., time to put together a design of blocks; time to match symbols with numbers, speed in responding, such as counting speed or serial 3 speed).

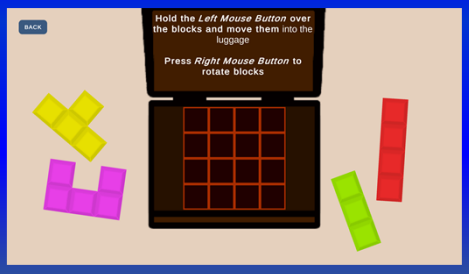
Executive function (planning, decision making, working memory, responding to feedback/error correction, overriding habits/inhibition, mental flexibility)	*Major:* Abandons complex projects. Needs to focus on one task at a time. Needs to rely on others to plan instrumental activities of daily living or make decisions. *Mild:* Increased effort required to complete multistage projects. Has increased difficulty multitasking or difficulty resuming a task interrupted by a visitor or phone call. May complain of increased fatigue from the extra effort required to organize, plan, and make decisions. May report that large social gatherings are more taxing or less enjoyable because of increased effort required to follow shifting conversations.	*Planning:* Ability to find the exit to a maze; interpret a sequential picture or object arrangement. *Decision making:* Performance of tasks that assess process of deciding in the face of competing alternatives (e.g., simulated gambling). *Working memory:* Ability to hold information for a brief period and to manipulate it (e.g., adding up a list of numbers or repeating a series of numbers or words backward). *Feedback/error utilization:* Ability to benefit from feedback to infer the rules for solving a problem. *Overriding habits/inhibition:* Ability to choose a more complex and effortful solution to be correct (e.g., looking away from the direction indicated by an arrow; naming the color of a word's font rather than naming the word). *Mental/cognitive flexibility:* Ability to shift between two concepts, tasks, or response rules (e.g., from number to letter, from verbal to key-press response, from adding numbers to ordering numbers, from ordering objects by size to ordering by color).

- Do you think Native Fauna can provide a measure of processing speed (considered as efficient as complex psychological tests)?
- Do you think it can provide a measure of attention, concentration, and working memory (letter A task)?
- Do you have any other feedback?

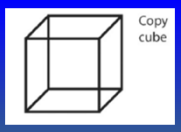
GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

CogWorldTravel Explained

❑Time to Pack



- ❖ Inspired by Tetris (involves rapid visual-spatial problem-solving and motor coordination skills). Visuospatial abilities are evaluated using a clock drawing task and a 3-D cube copy in the Montreal Cognitive Assessment.
- ❖ Cognitive domains involved:
  - Perceptual-motor
  - Executive function
  - Attention
- ❖ Data collected during gameplay:
  - Number of suitcases completed within two minutes.



GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

Feedback

❑Time to Pack

- Do you think Time to Pack can provide a measure of perceptual-motor?
- Do you think it can provide a measure of planning abilities?
- Do you think it can provide a measure of attention?

Perceptual-motor (includes abilities subsumed under the terms *visual perception, visuoconstructional, perceptual-motor, praxis,* and *gnosis*)	*Major:* Has significant difficulties with previously familiar activities (using tools, driving motor vehicle), navigating in familiar environments; is often more confused at dusk, when shadows and lowering levels of light change perceptions. *Mild:* May need to rely more on maps or others for directions. Uses notes and follows others to get to a new place. May find self lost or turned around when not concentrating on task. Is less precise in parking. Needs to expend greater effort for spatial tasks such as carpentry, assembly, sewing, or knitting.	*Visual perception:* Line bisection tasks can be used to detect basic visual defect or attentional neglect. Motor-free perceptual tasks (including facial recognition) require the identification and/or matching of figures—best when tasks cannot be verbally mediated (e.g., figures are not objects); some require the decision of whether a figure can be "real" or not based on dimensionality. *Visuoconstructional:* Assembly of items requiring hand-eye coordination, such as drawing, copying, and block assembly. *Perceptual-motor:* Integrating perception with purposeful movement (e.g., inserting blocks into a form board without visual cues; rapidly inserting pegs into a slotted board). *Praxis:* Integrity of learned movements, such as ability to imitate gestures (wave goodbye) or pantomime use of objects to command ("Show me how you would use a hammer"). *Gnosis:* Perceptual integrity of awareness and recognition, such as recognition of faces and colors.
Executive function (planning, decision making, working memory, responding to feedback/error correction, overriding habits/inhibition, mental flexibility)	*Major:* Abandons complex projects. Needs to focus on one task at a time. Needs to rely on others to plan instrumental activities of daily living or make decisions. *Mild:* Increased effort required to complete multistage projects. Has increased difficulty multitasking or difficulty resuming a task interrupted by a visitor or phone call. May complain of increased fatigue from the extra effort required to organize, plan, and make decisions. May report that large social gatherings are more taxing or less enjoyable because of increased effort required to follow shifting conversations.	*Planning:* Ability to find the exit to a maze; interpret a sequential picture or object arrangement. *Decision making:* Performance of tasks that assess process of deciding in the face of competing alternatives (e.g., simulated gambling). *Working memory:* Ability to hold information for a brief period and to manipulate it (e.g., adding up a list of numbers or repeating a series of numbers or words backward). *Feedback/error utilization:* Ability to benefit from feedback to infer the rules for solving a problem. *Overriding habits/inhibition:* Ability to choose a more complex and effortful solution to be correct (e.g., looking away from the direction indicated by an arrow; naming the color of a word's font rather than naming the word). *Mental/cognitive flexibility:* Ability to shift between two concepts, tasks, or response rules (e.g., from number to letter, from verbal to key-press response, from adding numbers to ordering numbers, from ordering objects by size to ordering by color).
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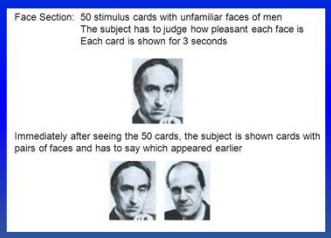
GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

CogWorldTravel Explained

❑Familiar Faces

- ❖ Inspired by The Warrington Recognition Memory Test
- ❖ Cognitive domains involved:
- Learning and memory
- Attention
- ❖ Data collected during gameplay:
- Number of faces achieved before repeating the same face



GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

Feedback

❑Familiar Faces

Learning and memory (immediate memory, recent memory [including free recall, cued recall, and recognition memory], very-long-term memory [semantic; autobiographical], implicit learning)	*Major:* Repeats self in conversation, often within the same conversation. Cannot keep track of short list of items when shopping or of plans for the day. Requires frequent reminders to orient to task at hand. *Mild:* Has difficulty recalling recent events, and relies increasingly on list making or calendar. Needs occasional reminders or re-reading to keep track of characters in a movie or novel. Occasionally may repeat self over a few weeks to the same person. Loses track of whether bills have already been paid. **Note:** Except in severe forms of major neurocognitive disorder, semantic, autobiographical, and implicit memory are relatively preserved, compared with recent memory.	*Immediate memory span:* Ability to repeat a list of words or digits. **Note:** Immediate memory sometimes subsumed under "working memory" (see "Executive Function"). *Recent memory:* Assesses the process of encoding new information (e.g., word lists, a short story, or diagrams). The aspects of recent memory that can be tested include 1) free recall (the person is asked to recall as many words, diagrams, or elements of a story as possible); 2) cued recall (examiner aids recall by providing semantic cues such as "List all the food items on the list" or "Name all of the children from the story"); and 3) recognition memory (examiner asks about specific items—e.g., "Was 'apple' on the list?" or "Did you see this diagram or figure?"). Other aspects of memory that can be assessed include semantic memory (memory for facts), autobiographical memory (memory for personal events or people), and implicit (procedural) learning (unconscious learning of skills).
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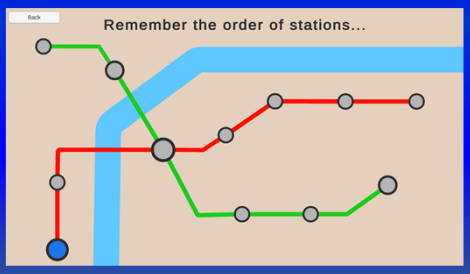
- Do you think Familiar Faces can provide a measure of recognition memory?
- Do you think it can provide a measure of attention?

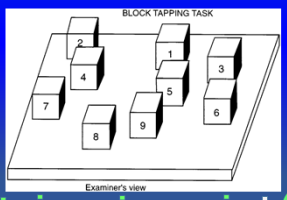
GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

CogWorldTravel Explained

❑The Metro



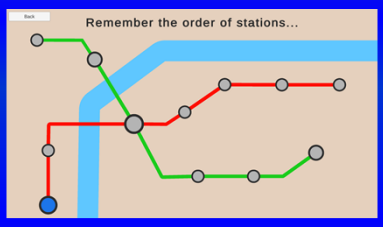
- ❖ Inspired by The Corsi Blocks Test - an effective measure of visuospatial short-term and working memory, as it requires memorization of relative positions in space in a temporal order.
- ❖ Cognitive domains involved:
- Learning and memory
- Executive function
- Attention
- ❖ Data collected during gameplay:
- Maximum length achieved and the total number of correct sequences repeated



GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

Feedback

❑The Metro



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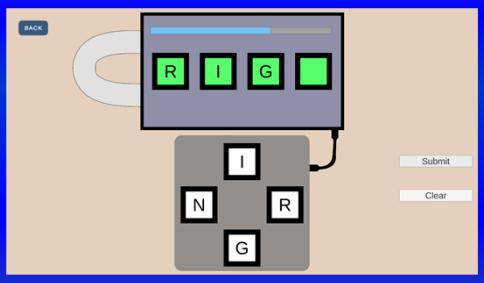
- Do you think The Metro can provide a measure of working memory?
- Do you think it can provide a measure of memory?
- Do you think it can provide a measure of attention?

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

CogWorldTravel Explained

❑Padlock Combination



- ❖ Inspired by the verbal fluency task contained in neuropsychological tests - An analysis of MoCA's items revealed that the fluency task reliably discriminates between demented patients, mild stages, and normal cognition.
- ❖ Cognitive domains involved:
- Language
- Attention
- Executive function
- ❖ Data collected during gameplay:
- Number of words generated within two minutes.

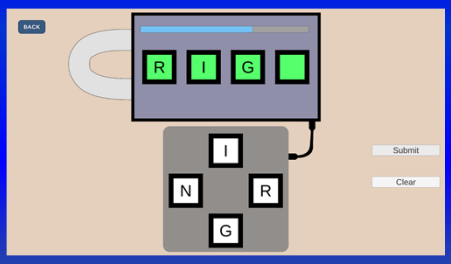
LANGUAGE	Repeat : I only know that John is the one to help today. [ ] The cat always hid under the couch when dogs were in the room. [ ]
	Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words)

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

Feedback

❑Padlock Combination

Language (expressive language [including naming, word finding, fluency, and grammar, and syntax] and receptive language)	*Major:* Has significant difficulties with expressive or receptive language. Often uses general-use phrases such as "that thing" and "you know what I mean," and prefers general pronouns rather than names. With severe impairment, may not even recall names of closer friends and family. Idiosyncratic word usage, grammatical errors, and spontaneity of output and economy of utterances occur. Stereotypy of speech occurs; echolalia and automatic speech typically precede mutism. *Mild:* Has noticeable word-finding difficulty. May substitute general for specific terms. May avoid use of specific names of acquaintances. Grammatical errors involve subtle omission or incorrect use of articles, prepositions, auxiliary verbs, etc.	*Expressive language:* Confrontational naming (identification of objects or pictures); fluency (e.g., name as many items as possible in a semantic [e.g., animals] or phonemic [e.g., words starting with "f"] category in 1 minute). *Grammar and syntax* (e.g., omission or incorrect use of articles, prepositions, auxiliary verbs): Errors observed during naming and fluency tests are compared with norms to assess frequency of errors and compare with normal slips of the tongue. *Receptive language:* Comprehension (word definition and object-pointing tasks involving animate and inanimate stimuli): performance of actions/activities according to verbal command.



- Do you think Padlock Combination can provide a measure of expressive language?
- Do you think it can provide a measure of attention or executive function?

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

CogWorldTravel Explained

❑Messaging Home

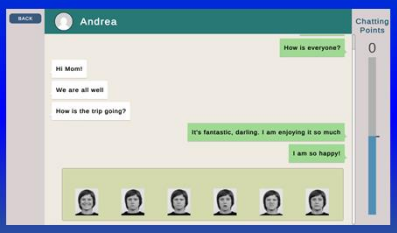
- ❖ Inspired by the Emotion Recognition Task - Social cognitive deficits play an important role in the development of behavioural changes seen in MCI and dementia patients.
- ❖ Cognitive domains involved:
  - Social Cognition
  - Language
- ❖ Data collected during gameplay:
  - Number of correct answers

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

Feedback

❑Messaging Home

Social cognition (recognition of emotions, theory of mind)	*Major:* Behavior clearly out of acceptable social range; shows insensitivity to social standards of modesty in dress or of political, religious, or sexual topics of conversation. Focuses excessively on a topic despite group's disinterest or direct feedback. Behavioral intention without regard to family or friends. Makes decisions without regard to safety (e.g., inappropriate clothing for weather or social setting). Typically, has little insight into these changes. *Mild:* Has subtle changes in behavior or attitude, often described as a change in personality, such as less ability to recognize social cues or read facial expressions, decreased empathy, increased extraversion or introversion, decreased inhibition, or subtle or episodic apathy or restlessness.	*Recognition of emotions:* Identification of emotion in images of faces representing a variety of both positive and negative emotions. *Theory of mind:* Ability to consider another person's mental state (thoughts, desires, intentions) or experience—story cards with questions to elicit information about the mental state of the individuals portrayed, such as "Where will the girl look for the lost bag?" or "Why is the boy sad?"

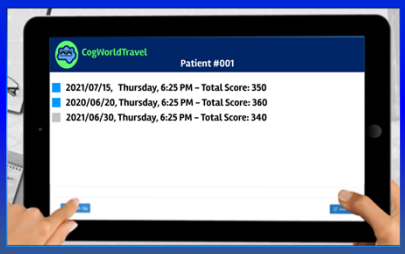


- Do you think Messaging Home can provide a measure of social cognition?
- Do you think it can provide a measure of language?

GAMES FOR THE COGNITIVE ASSESSMENT OF OLDER ADULTS

CogWorldTravel Explained

- Scores reporting:
  - Automatic scoring
  - Track the results overtime
  - Track total and partial measurements



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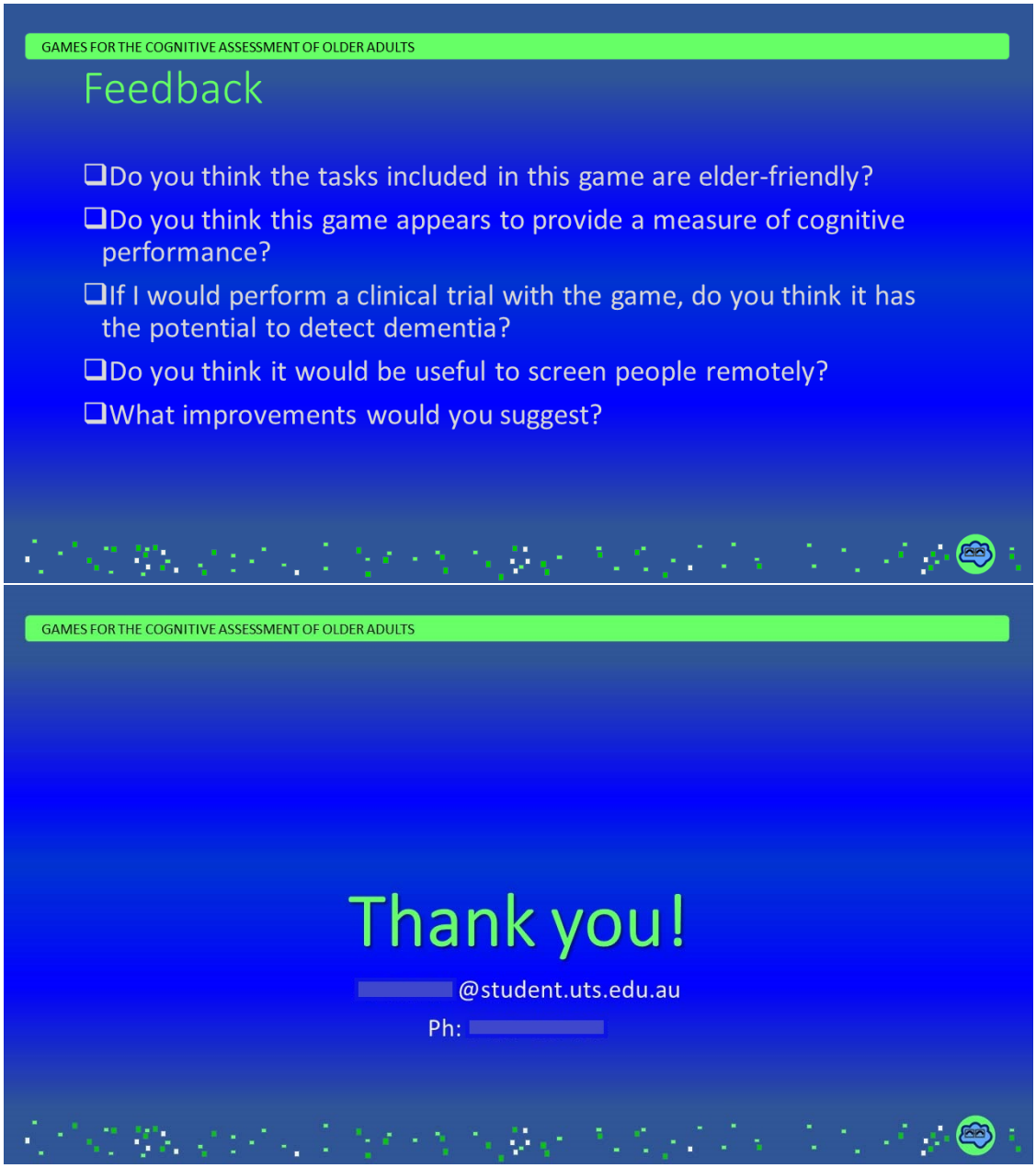
Learning and memory (immediate memory, recent memory [including free recall, cued recall, and recogni-	*Major:* Repeats self in conversation, often within the same conversation. Cannot keep track of short list of items when shopping or of plans for the day. Requires frequent reminders to orient to task at hand. *Mild:* Has difficulty recalling recent events, and relies increasingly on list making or calendar. Needs occasional reminders	*Immediate memory span:* Ability to repeat a list of words or digits. **Note:** Immediate memory sometimes subsumed under "working memory" (see "Executive Function"). *Recent memory:* Assesses the process of encoding new information (e.g., word lists, a short story, or diagrams). The aspects of recent memory that can be tested include 1) free recall (the person is asked to recall as many words, diagrams, or elements of a story as possible); 2) cued recall (examiner aids recall by providing semantic cues such as "List all the food items on the list" or "Name all of the children from the story"); and 3) recognition memory (examiner asks about specific items—e.g., "Was 'apple' on the list?" or "Did you see this diagram or figure?"). Other aspects of memory that can be assessed include semantic memory (memory for facts), autobiographical memory (memory for personal events or people), and implicit (procedural) learning (unconscious learning of skills).

Complex attention (sustained attention), divided attention, selective attention, processing speed)	*Major:* Has increased difficulty in environments with multiple stimuli (TV, radio, conversation); is easily distracted by competing events in the environment. Is unable to attend unless input is restricted and simplified. Has difficulty holding new information in mind, such as recalling phone numbers or addresses just given, or reporting what was just said. Is unable to perform mental calculations. All thinking takes longer than usual, and components to be processed must be simplified to one or a few. *Mild:* Normal tasks take longer than previously. Begins to find errors in routine tasks; finds work needs more double-checking than previously. Thinking is easier when not competing with other things (radio, TV, other conversations, cell phone, driving).	*Sustained attention:* Maintenance of attention over time (e.g., pressing a button every time a tone is heard, and over a period of time). *Selective attention:* Maintenance of attention despite competing stimuli and/or distractors: hearing numbers and letters read and asked to count only letters. *Divided attention:* Attending to two tasks within the same time period: rapidly tapping while learning a story being read. Processing speed can be quantified on any task by timing it (e.g., time to put together a design of blocks); time to match symbols with numbers; speed in responding, such as counting speed or serial 3 speed).

Language (expressive language [including naming, word finding, fluency, and grammar, and syntax] and receptive language)	*Major:* Has significant difficulties with expressive or receptive language. Often uses general-use phrases such as "that thing" and "you know what I mean," and prefers general pronouns rather than names. With severe impairment, may not even recall names of closer friends and family. Idiosyncratic word usage, grammatical errors, and spontaneity of output and economy of utterances occur. Stereotypy of speech occurs; echolalia and automatic speech typically precede mutism. *Mild:* Has noticeable word-finding difficulty. May substitute general for specific terms. May avoid use of specific names of acquaintances. Grammatical errors involve subtle omission or incorrect use of articles, prepositions, auxiliary verbs, etc.	*Expressive language:* Confrontational n or pictures); fluency (e.g., name as semantic [e.g., animals] or phonem category in 1 minute). *Grammar and syntax* (e.g., omission o ositions, auxiliary verbs): Errors ob ency tests are compared with norm and compare with normal slips of t *Receptive language:* Comprehension (pointing tasks involving animate a mance of actions/activities accordi

Perceptual-motor (includes abilities subsumed under the terms *visual perception, visuoconstructional, perceptual-motor, praxis,* and *gnosis*)	*Major:* Has significant difficulties with previously familiar activities (using tools, driving motor vehicle), navigating in familiar environments; is often more confused at dusk, when shadows and lowering levels of light change perceptions. *Mild:* May need to rely more on maps or others for directions. Uses notes and follows others to get to a new place. May find self lost or turned around when not concentrating on task. Is less precise in parking. Needs to expend greater effort for spatial tasks such as carpentry, assembly, sewing, or knitting.	*Visual perception:* Line bisection tasks can be used to detect basic visual defect or attentional neglect. Motor-free perceptual tasks (including facial recognition) require the identification and/or matching of figures—best when tasks cannot be verbally mediated (e.g., figures are not objects); some require the decision of whether a figure can be "real" or not based on dimensionality. *Visuoconstructional:* Assembly of items requiring hand-eye coordination, such as drawing, copying, and block assembly. *Perceptual-motor:* Integrating perception with purposeful movement (e.g., inserting blocks into a form board without visual cues; rapidly inserting pegs into a slotted board). *Praxis:* Integrity of learned movements, such as ability to imitate gestures (wave goodbye) or pantomime use of objects to command ("Show me how you would use a hammer"). *Gnosis:* Perceptual integrity of awareness and recognition, such as recognition of faces and colors.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Feedback
Do you think the tasks included in this game are elder-friendly?
Do you think this game appears to provide a measure of cognitive performance?
If I would perform a clinical trial with the game, do you think it has the potential to detect dementia?
Do you think it would be useful to screen people remotely?
What improvements would you suggest?
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Thank you!
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