A Framework and Serious Game to Support those with Mild Cognitive Impairment

By

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For my grandmother, Foon,

who is unable to read and write

but will be the first to play the game

I designed for you.

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This thesis was possible only with the kind support and help of many individuals and I would hereby like to extend my sincere gratitude to them.

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STATEMENT OF ORIGINALITY

I hereby certify that I am the sole author of this thesis and that no part of this thesis has been published/submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Sum Yuet Joyce Lau

Don't forget to play ...

ABSTRACT

Cognitive decline is common in the elderly. As a result, a range of cognitive rehabilitation games have been proposed to supplement or replace traditional rehabilitative training by offering benefits such as improved engagement. This research project focuses on mild cognitive impairment (MCI), an initial stage of cognitive decline that does not affect functioning in daily life, but which may progress towards more serious cognitive deteriorations, notably dementia. Unfortunately, while a variety of serious game frameworks and rehabilitative serious games have been proposed, there is a distinct lack of those which support the distinctive characteristics of MCI patients. Consequently, to optimise the advantages of serious games for MCI, the research proposes the *MCI-GaTE* (MCI-Game Therapy Experience) framework that may be used to develop serious games as effective cognitive and physical rehabilitation tools. The framework is derived from a combination of a survey of related research literature in the area, analysis of resident profiles from a nursing home, and in-depth interviews with occupational therapists (OTs) who work with MCI patients on a daily basis to help them overcome the disabling effects so that they can carry out everyday tasks. The conceptual framework comprises four sectors that may be used to guide game design and development: an *MCI player profile* that represents the capabilities of a player with MCI, *core gaming elements* that support gameful and playful activities, *therapeutic elements* that support cognitive and physical rehabilitation through tasks and scenarios according to the player's abilities, and *motivational elements* to enhance the player's attitude towards the serious tasks. Together, they provide tailored support for rehabilitation needs and may also serve as a set of comprehensive and established criteria by which an MCI serious game may be evaluated. To demonstrate the use of *MCI-GaTE*, an immersive and gesture-based serious game, *A-go!*, is designed that exploits the framework to enable MCI-diagnosed players to undertake a series of tailored therapeutic tasks supported by an assigned OT. To this end, a goal-directed design approach is employed, whereby personas, scenarios and journey maps are developed that satisfy the goals of both the MCI player and their OT, and enable the derivation of functional requirements leading to a visual design. *A-go!* is realised as a responsive and interactive high-fidelity prototype that supports gesture recognition and 3D game objects from a first-person perspective to facilitate immersion without the need for additional worn devices, such as headsets, which would prove impractical for the

targeted elderly players. Evaluation with OTs revealed that the immersive game potentially offers more effective and tailored support to MCI patients than traditional methods, contributing new possibilities for enhancing MCI rehabilitative training, while a comparative assessment of *MCI-GaTE* demonstrated that it provides a comprehensive approach not currently offered by state-of-the-art rehabilitative frameworks.

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2D	Two-dimension
3D	Three-dimension
2DVE	2D virtual environment
3DVE	3D virtual environment
AD	Alzheimer's Disease
ADHD	Attention deficit hyperactivity disorder
ADL	Activities of daily living
a-MCI	amnestic MCI
GNH	GRACE nursing home
IADL	Instrumental activities of daily living
MCI	Mild cognitive impairment
MCI-GaTE	MCI-Game Therapy Experience
na-MCI	non-amnestic MCI
NUI	Natural user interface
OT	Occupational therapist
PD	Parkinson's Disease
PM	Prospective memory
RO	Reality orientation
UI	User interface
UX	User experience

WM	Working memory

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1 Chapter One – Introduction

Gaming has become a significant sector of industry as digital games have become more in-demand and popular among vast majorities of players of all ages and conditions. According to *2020 Essential Facts About the Video Game Industry, a report from The Entertainment Software Association (ESA)*, over 214 million video game players play video games at least an hour each week across the United States [1]. The survey shows that digital games are not limited to youngsters but are also increasingly played by the elderly (65+) who have been playing them for almost a decade. To date, digital games are not purely for entertainment and instead offer numerous advantages which can be harnessed for various serious contexts, namely a "serious game". The serious contexts include game-for-change, game-based learning, educational computer games, edutainment, advertainment, corporate games, health games, military games, and political games [2]. Serious games are used in various applications across different sectors and play a significant role in the game market. Through the interactivity of novel serious games, players are able to learn skills and build up knowledge blocks [3]. In other words, a serious game facilitates "learning" through interactive ways. There is no denying the attractiveness and potential of games in promoting learning and behaviour change through psychological means [3]. There are different aspects of gaming which have been studied and developed including leisure, education, healthcare and business [4]. These aspects of gaming have been a worthwhile research topic for several decades. Serious games may be characterised along a continuum, ranging from games for purpose through to experiential environments with minimal or no gaming characteristics for experience [5]. Serious games for rehabilitation may extend anywhere along this continuum by assisting in physical or cognitive functioning at home or in a healthcare setting, using various interaction technologies, 2D or 3D game interfaces, and game genres. They may be single or multiplayer, adaptable, and facilitate progress monitoring and performance feedback [6]. In this thesis, a serious game is proposed for healthcare.

According to the World Health Organisation (WHO), dementia is one of the main causes of dependence and disability in older adults, and there are approximately 35.6 million people living with dementia around the world in 2010 [7]. Since dementia is strongly age-dependent, this number is expected to escalate rapidly by doubling every 20 years, and combined with the longstanding ageing problem worldwide, a higher rate of decline in cognitive function in the elderly is being increasingly witnessed in populations worldwide [8]. Concerns of deteriorating cognitive ability in the elderly continue to progress to an irreversible stage, namely dementia. It is envisaged that mild cognitive impairment (MCI) is a potential area to be taken into consideration in improving cognitive function and addressing the prevalence of dementia worldwide through an appropriate training method, since it exists at an early stage of cognitive decline. MCI exists mostly in the elderly population (65+) and is characterised by the quality of cognitive functions not meeting expectations with respect to age and education level, however performance is effectively normal in daily activities [9]. In amnestic MCI (a-MCI) [10], [11], memory loss is predominant and there is a high risk of progression to Alzheimer's disease (AD), whereas in non-amnestic MCI (na-MCI), other symptoms are prominent and there may be progression to other forms of dementia [12]. The pathological changes caused by AD are irreversible and contribute to both cognitive and physical decline [13] accounting for 60%-80% of dementia cases [14]. The interplay between cognitive and physical deteriorations affect an individual's ability to perform basic activities of daily living (ADLs) which are progressively compromised over time, affecting balance, mobility and gait [15]–[18] in late-stage dementia. Nevertheless, the deteriorations of cognitive function can be slowed or delayed if the symptoms appear at early stages, as with a diagnosis of MCI, and are given appropriate intervention, typically via a rehabilitation programme that includes a wide range of brain training targeted at various cognitive spheres. Hence, the rationale of proposing a serious game focusing on MCI is that an early stage of dementia manifested with memory complaints could be mitigated if the game is used as treatment with suitable frequency. As will be discussed in Chapter 2, many researchers have examined the efficacy of interventions, involving errorless learning, vanishing cues and computer-assisted approaches, for patients with cognitive impairment undergoing a period of programmes, typically 4 to 6 weeks. Therefore, a suitably designed game may serve as an effective method in assisting with memory capability in elderly patients.

Digital cognitive training may potentially benefit those with cognitive dysfunctions more than traditional training due to enhanced motivation and engagement, which overcome the tediousness of traditional training [19]. Moreover, digital games are starting to show potential for mitigating issues caused by cognitive impairment, e.g. playing a 3D video game (*Super Mario 64*) [20] has been found to increase the grey matter in an elderly player's hippocampus, where the spatial memory process occurs, through the spatial environment, motor coordination and learning process of the game. It claims that the amount of grey matter in the hippocampus is one of the biomarkers to identify neuropsychological diseases including MCI (the focus of this research project) and AD, both of which affect memory functioning. The game promotes a 3D environment for consolidating the elderly's cognitive map, a process in the hippocampus which supports them in learning the game and consequently in increasing the amount of grey matter. Thus, the proposed game (*Super Mario 64*) in the study can support cognitive functioning in the elderly through the increase of grey matter in the hippocampus. The study in turn encourages this research project to seek an innovative way to deliver a solution to those with MCI through gaming technology.

As the review in this thesis will show, current studies exhibit a significant amount of computerized or digital cognitive training for aiding those with cognitive dysfunctions. These studies demonstrate that digital forms of training can potentially benefit those with cognitive dysfunctions more than the traditional paper-and-pen training. However, despite how they may be labelled, most of these digital applications are not "games" as such, but remain computer-based serious tasks, lacking in means, such as gameful elements, to motivate and engage the elderly whilst they undergo the training. Moreover, existing approaches to gameful cognitive rehabilitation merely attempt to incorporate gameful elements within serious contexts to improve the monotonous traditional training. For the elderly, much of this has endeavoured to use touch-based tablet devices to stimulate various cognitive functions while minimising cognitive load, although augmented, virtual and mixed realities are increasingly being used [21]. Additionally, the literature e.g. [21] also shows that an involvement of appropriate physical interaction may support cognitive functions in the elderly, especially in the memory aspect. However, the large body of research on MCI rehabilitation has focused on exergaming interventions [22]. Approaches that combine both physical and cognitive training with a gameful approach are rare, and there are no studies tackling the MCI group in this way. Consequently, this research proposes a serious game for MCI that is optimized with respect to its gameful approach and its integration of physical interaction.

This chapter presents an overview of the project formed of the aim and objectives, research methodology, a list of research contributions, and a chapter-by-chapter outline of the thesis.

1.1 Aim and Objectives

As mentioned earlier, the current literature has provided digitized training platforms and serious games in various contexts, to improve or enhance the effectiveness of traditional methods. However, no particular framework introduces a serious game with a comprehensive methodology tailored to those with MCI, from the holistic literature and investigation of standardised clinical methods through to nursing home resident profiles and interviews with OTs. MCI serious games and cognitive-related digital training have regularly been published in the literature over the past decade. However, most of the research reviewed involves very limited aspects in achieving an optimal solution and thereby lacks integral impact on MCI serious games. The clinical protocols and underlying rationales were generally formulated in terms of MCI player profile and therapeutic elements to uncover the techniques used in conventional assessments targeting MCI players to greatly reduce the impediment to developing user-centred serious games. These user criteria extend the literature for serious game developers to understand the prerequisites and specificity of the MCI player to adapt to the therapeutic content during the game. The core gaming and motivational elements derived from the thematic processing of recent studies undertaken in Chapter 2 are reported as having positive effects on cognitively impaired patients. A major advantage of those elements is that they may extend current approaches in serving those with MCI by permitting gamefulness and playfulness to intersect with physio-cognitive utility throughout the game therapy in a novel way.

Having identified the current research implications and limitations, the main aim of this research is to develop a serious game framework for MCI, *MCI-GaTE* (MCI-Game Therapy Experience), that integrates physical interaction with a tailored and gamified form of cognitive rehabilitation for elderly players with MCI. The framework accommodates the range of the MCI player's cognitive and physical abilities through a player profile, commonly-used therapeutic contexts and tasks, and notions of playfulness and gamefulness for facilitating motivation and engagement. In this way, serious games designed using *MCI-GaTE* may be used as effective rehabilitative tools to support those diagnosed with MCI. The framework also serves as comprehensive criteria against which serious games may be evaluated to determine their pertinence and sufficiency for MCI players. The framework is derived from primary and secondary research processes to iterate themes for establishing a player profile and therapeutic, core gaming, and motivational elements within the framework, specifically: (i) research literature covering gameful cognitive and physical rehabilitation and playful experiences; (ii) resident profile data from a nursing home; and (iii) in-depth interviews with occupational therapists (OTs). The aim is further subdivided into main objectives which can be classified as follows:

i. To identify effective means by which those with MCI can undergo cognitive training via a literature review and data analysis of:

    a. Appropriate reported medical studies;

    b. Existing playful and gameful approaches that are most suitable for intervention in those with MCI;

    and

    c. Resident profiles from a nursing home and primary data from the interviews.

ii. To construct a serious game framework for MCI players based on Objective i.

iii. To design a serious game prototype that uses the framework from Objective ii.

iv. To test and evaluate usability and utility with reference to healthcare specialists and comparison against existing frameworks in order to establish the validity and effectiveness of the research outputs.

The aforementioned research implications have led to the main research question posed by this research, which is as follows:

Whereas Objectives i and ii concern the holistic literature research findings and data analysis presented in *MCI-GaTE*, the research hypotheses are constructed in accordance with *MCI-GaTE* to refine the research direction and surmise the research findings precisely. Thus, they are presented in Chapter 4, once the framework has been fully derived and evidence in support of them is argued in Chapter 7.

1.2 Research Methodology

This section explains several research methods that are employed in the research project. The acquired data from the research methodology, as shown in Figure 1-1, is to be analysed for use in proposing the serious game framework as well as in proceeding towards the defined research scope.

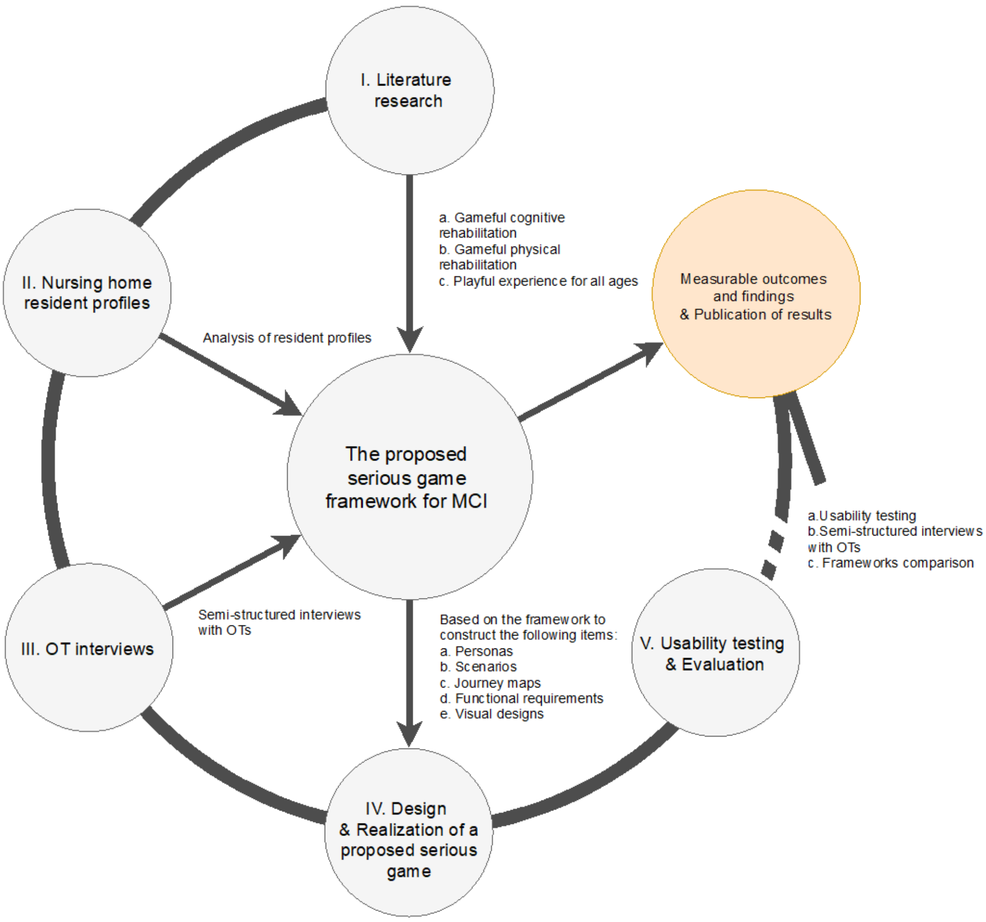


Figure 1-1 Research methodology

Literature research: It aims to compile and analyse secondary data collected from journals, articles, websites, books and other literature papers which are relevant to the research topic. The literature data comes from three defined fields as follows: (i) gameful cognitive rehabilitation, (ii) gameful physical rehabilitation, and (iii) playful experience for all ages. The results of the use of this method are summarized and documented in Chapter 2 for establishing an initial serious game framework. The literature research gathers the first data set from the year 2009 to 2019, to construct an initial *MCI-GaTE*.

Nursing home resident profiles: It includes resident information, diagnosis, capabilities and assessment tools that have been recorded and documented as patients' profiles by the specialists or occupational therapists. The resident profile data will be analysed and shown statistically and the potential influencing factors will be identified through a thematic approach in order to expand the initial serious game framework in Chapter 3.

OT interviews: The initial serious game framework will be shown to the OTs prior to the interview to define the research scope. The obtained responses will be analysed and compared in the creation of the serious game framework and proposed in Chapter 4.

Design and realisation of a proposed serious game: Based on *MCI-GaTE* that is presented in Chapter 4, the personas, scenarios and journey maps will be designed, and considered as user models to determine the functional requirements and generate the visual designs for the realisation stage. The creation of *A-go!*, an interactive, immersive, gesture-based, high-fidelity serious game prototype, aims at supporting clinical rehabilitation as gaming technologies can be potentially altered in accordance with the player's capabilities in order to improve the adaptability of the player to new circumstances. It will serve as an alternative method to test out the suggested theories as well as the underlying challenges.

Usability testing and evaluation: In order to ensure that the serious game system with proposed methods can be employed as one of the intervention means for those with MCI, a combination of usability testing, semi-structured interviews with OTs and comparison against existing frameworks will be conducted.

These research methods aid the production of the data results and findings for proposing *MCI-GaTE*. During the design and realisation stages, the framework will serve as the research scope for defining the requirement.

All research obtained prior ethical approval according to the ethical processes put in place by Brunel University London, which is committed to the UK Concordat on Research Integrity.

1.3 Research Contributions

The original contributions of this research can be considered as follows, correlating with the research aim and objectives detailed in Section 1.1:

(i) *MCI-GaTE* (MCI-Game Therapy Experience) serious game framework

The data analysis of literature, nursing home resident profiles and in-depth semi-structured interviews with OTs resulted in the identification of serious game elements, organised as *MCI player profile*, *therapeutic elements*, *core gaming elements* and *motivational elements.* This proposed multi-layered *MCI-GaTE* may offer an optimised training tool for MCI patients and act as design criteria to facilitate a comprehensive serious game specifically tailored to MCI players. The novelty of *MCI-GaTE* contributes to serious game literature through the evaluation of existing frameworks and healthcare specialists' validation. The significance of the findings (from state-of-the-art literature, nursing home and interview data) comprised a range of robust interaction and gaming approaches tailored to MCI players. The current literature (discussed in Section 7.4) does not suggest any MCI-related serious game framework addressing both physical and cognitive conditions in MCI players through gamefulness and playfulness, which this research addresses. Thus, the proposed work bridges serious game technology with the MCI context via a goal-directed approach, through an approach not currently offered.

(ii) *A-go!* as an interactive high-fidelity serious game

The design of *A-go!* is a proof-of-concept immersive, gesture-based serious game that was produced using *MCI-GaTE*. It provides UX&UI to visually present the techniques identified from personas, scenarios and journey maps. The demonstration stage of *A-go!* contains all designated hand gestures which can potentially discern the MCI players. The flexibility of *A-go!* can drastically reduce the intervention costs as there is no geographical limitation. For example, a virtual scene can enable a player to reminisce about past scenarios and contexts. *A-go!* promotes a range of game themes that allows the MCI player to select those which are most desirable within the scope of their rehabilitation. Taken together, this thesis will demonstrate that the proposed serious game and framework potentially offers more effective support to MCI patients than traditional methods, i.e. paper-and-pen training tools, and motivates and engages the MCI player to proactively undertake the intervention.

(iii) *Empirical Findings*

Two main empirical findings are presented in this research, which are the nursing home resident data and OT interview data. Four criteria were derived from these findings (MCI player profile, core gaming, therapeutic and motivational elements) which could lead to development of a wider range of serious games for MCI players, including the involvement of lower limbs, various culturally relevant game contents, and collaborative training environments. The MCI player profile consists of upper limb functioning tasks involving hands, arms and shoulders, whilst lower limb functioning tasks involve lower limb balancing. As the primary focus of the current research is on upper limbs, with lower limbs being secondary, several functioning tasks are not incorporate into the serious game. Therefore, further research investigating the lower limb functioning tasks could expand the current game to facilitate a fully body game-based therapy with an optimal amount of lower limb tasks. Additionally, since this research is limited to Hong Kong Chinese culture, further research could explore incorporate reminiscence-based therapeutic content for other cultures. The findings obtained from interview (evaluated in Chapter 4) have shown that the presence of the OT during the intervention can motivate the player to engage with the game. This implies that the collaborative training environment may increase the interactivity between the player and OT to further improve the player's engagement and interests. Thus, the resident and interview data can be used as a reference point for constructing a new goal-directed approach and application.

1.4 Thesis Outline

Chapter Two – Literature Survey on Serious Game in Healthcare and Initial *MCI-GaTE* presents a literature survey on serious game in healthcare in three significant areas: (i)Gameful Cognitive Rehabilitation, (ii)Gameful Physical Rehabilitation, (iii)Playful

Experience for All Ages and the initial serious game framework. It discusses and compares the existing methodologies in respect of the notions of playfulness and gamefulness in order to narrow down the research scope by selecting potential themes as a starting point.

Chapter Three – Data Analysis of Resident Profiles from GNH and Initial *MCI-GaTE* provides the use of GRACE nursing home (GNH) resident profile data for further constructing the initial framework that has been structured upon the literature survey results through the data analysis. The results are primarily utilised for deriving key elements, encompassing the MCI player's background and capabilities, within the *MCI Player Profile* sector of the framework, and will be used in the subsequent design modelling stage.

Chapter Four – Data Analysis of Interview and Final *MCI-GaTE* presents the primary data collected from the interviews with occupational therapists to finalize *MCI*-GaTE. Potential themes from the data are identified using a thematic approach and used to provide additional elements for the framework. The research hypotheses are constructed based on the findings and *MCI-GaTE.* Each of the four sectors of the framework is discussed in turn and considered in relation to the results presented in the previous chapters. *MCI-GaTE* will be adopted as a reference to design the serious game in the next chapter.

Chapter Five – Design of *A-go!*: a Serious Game based on *MCI-GaTE* reports the use of the primary and secondary data from Chapter 2 to Chapter 4 in designing the personas, scenarios and journey maps for the design modelling. These are followed by a list of functional requirements and an explanation of the game's visual designs with UX&UI sketches, in order to illustrate user interactions with the game.

Chapter Six – Realisation of *A-go!* as an Interactive High-fidelity Prototype presents the development of the design from the previous chapter into a digital prototype. A suite of themes derived from *MCI-GaTE* are selected and embedded in *A-go!* highlighting a significant level of acquisitions for producing a set of game themes for MCI player. Relevant MCI player profile criteria, therapeutic, core gaming and motivational elements from the framework are principally selected and integrated into the game environment and discussed.

Chapter Seven – Serious Game Usability Testing and Evaluation details the process of usability testing and evaluation of *A-go!* via thorough interviews with OTs and comparison of current state-of-the-art frameworks with *MCI-GaTE* in order to justify the effectiveness and usefulness of *MCI-GaTE*.

Chapter Eight – Conclusion presents the summary of the research findings, taking into consideration research limitations, and discusses future works based on the research outputs of this research project.

2 Chapter Two – Literature Survey on Serious Game in Healthcare and Initial *MCI-GaTE*

The literature survey examines the current existing gaming technologies in healthcare and underlines the techniques of using optimal paradigms, in terms of three main significant research fields: (i)Gameful Cognitive Rehabilitation, (ii)Gameful Physical Rehabilitation and (iii)Playful Experience for All Ages. The literature research gathers the first data set from the year 2009 to 2019, to construct an initial serious game framework for MCI (*MCI-GaTE*). The sections are ordered as follows: Section 2.1 provides an introduction by briefly overviewing the literature survey methodology and existing literature studies in serious games and MCI; Section 2.2 details the use of the thematic approach to analyse the gathered literature; Section 2.3 explores the potential materials from the existing serious games in physical and cognitive rehabilitation as well as playful activities; Section 2.4 presents a summary of the themes and uses them to construct the initial serious game framework; and Section 2.5 summarizes this chapter, as well as discusses how the findings may be built upon.

2.1 Introduction

In the past decade, clinical research has undertaken a systematic investigation on cognitive impairment training with the aid of digital experience, to find out the potential and efficacy of serious games for the elderly with cognitive impairment. In serious game technology, researchers are intended to employ all sorts of beneficial approaches to provide a personalised platform for the cognitive-impaired elderly to adapt to a technological environment associated with the usability and accessibility of the system. Researchers attempt to integrate the notions of gamefulness and playfulness into serious contexts to elicit the elderly's motivation and engagement in rehabilitation.

The diverse gamified rehabilitation areas that address both serious training context and novel technological platforms offers a meaningful and engaging experience for the target players while reaching the optimal training effective imposed by the prominent gameful and playful techniques. To strive for a balance between the MCI patients' constraints and fun experience, this chapter will commence to investigate the current literature on serious games targeting cognitive and physical rehabilitation, so as to pinpoint and assemble the potential themes for the first part of *MCI-GaTE*.

The following section begins by surveying the data in multiple databases and identifying key topics associated with the serious game and MCI, in order to outline the scope of the research.

2.1.1 Literature Survey Methodology

Table 2-1 below presents the research data gathering criteria for this PhD research program. Reliable written works from research fields with a high degree of influence or which are most likely to contribute to the accomplishment of the research aim and objectives were reviewed from reputable electronic databases (i.e. Medical studies: Elsevier, SpringerLink, PubMed Central, Wiley Online Library, Emerald Insight, ACM Digital Library; and Game-based studies IEEE Xplore, ScienceDirect, ACM Digital Library, ResearchGate). Furthermore, paper selection was carried out based on the inclusion and exclusion criteria (C1) shown in the table. Non-peer-reviewed literature, such as online blogs and magazines, were excluded. The selection of written works comes from a ten-year period (2009-2019) (C2) deemed appropriate for including all relevant works while excluding those that may be deemed to be outdated. The taxonomy in this research arises from [23], such that rehabilitation for dementia associated with the concept of games are classified as cognitive, physical and social-emotional. Considering the aim and objectives that have been identified in Section 1.1, this research is focusing on the effect of the interplay between cognitive and physical rehabilitation to aid individuals during the rehabilitation, and thus social-emotional factors are secondary to the research scope. However, game design principles and features may be embedded into the rehabilitation through the process of gamification first proposed by Walz and Deterding [24]. Therefore, the proposed serious game framework in this research also covers the interrelated domains of gamefulness and playfulness identified by Walz and Deterding. The literature discussed in this chapter considers the impact of gamefulness and playfulness on various health issues, since serious games are found to be an effective means to maintain player motivation at a high level and yield positive outcomes.

Restrictive selection criteria are crucial for identifying the population of themes and producing pertinent conditions for a serious game framework appropriate for those with MCI. Sections 2.1.2 and 2.1.3 overview serious games and MCI prior to the critical literature review.

Table 2-1 Criteria for literature survey

Title	C1: Inclusion and exclusion criteria	C2: Period of publication	C3: Influence on the research	C4: Number of literature
(i) **Gameful Cognitive Rehabilitation**	• Inclusion: Visualisation of the user interface, game architecture and framework • Exclusion: non-gameful rehabilitation, traditional cognitive rehabilitation	2009-2019	High	14
(ii) **Gameful Physical Rehabilitation**	• Inclusion: Visualisation of the user interface, game architecture and framework • Exclusion: non-gameful rehabilitation, exercise, traditional physical rehabilitation	2014-2019	Medium	11
(iii) **Playful Experience for All Ages**	• Inclusion: Visualisation of the user interface, architecture and framework • Exclusion: serious games, digital experiences with purpose	2009-2019	Low	6

Based on these criteria for the literature survey, papers were selected and reviewed from each of the three main research fields that are directly relevant to this research, resulting in three areas to review: (i)Gameful Cognitive Rehabilitation, (ii)Gameful Physical Rehabilitation and (iii)Playful Experience for All Ages. The categorisation of influence on the research topic is ranked in C3 based on the significance of the literature to the research question, whereas C4 states the number of literatures selected for the literature survey according to the level of influence on the research to derive themes for *MCI-GaTE.*

Before delving into those papers, a brief overview of two main areas is given: serious games and mild cognitive impairment (MCI).

2.1.2 Overview and Theoretical Background of Serious Game

Nowadays, games are not just limited to providing "pure entertainment", but offer advantages in other areas, such as in healthcare, education, corporate business, politics etc. A game with purposes and benefits, namely a "serious game", is intended to deliver the intuitiveness, motivations and engagement to users whereby they can experience the context in an interactive way. Jesse Schell defines "game" as a thing to play [25]. It consists of different goals and conflicts, which can involve two or more players in the contest with rules in order to bring a disequilibrial result and arouse the self-initiative of the players. Moreover, "endogenous meaning" is the value within the game that its designs can make the experience more influential and enhance the players' motivations. Games also provide players a sense of immersion and engagement, so as to allow them to have an active role in playing the game. Typically, various studies [25]–[29], have presented a combination of aspects shown in Table 2-2 to achieve what may be considered good quality games. [25], [27] and [29] highlight the fundamental key ingredients in making games, whilst [26] and [28] respectively consider the essential characteristic of successful game design for various user types (this section only focuses on the general user type) and collaborative environment. All information outlined and compared in the table serves to provide an overview of common aspects in designing games, whereas Sections 2.3.1 to 2.3.3 will consider several common aspects shown in Table 2-2, but whose usefulness will be further justified in terms of their pertinence to MCI. This is in order to filter out unnecessary common aspects.

Numerous studies have attempted to promote serious games in healthcare through gamifying various rehabilitative contexts with the deployment of game-based technologies. The researchers propose various methodologies to enhance the elderly's motivation and engagement through playfulness and gamefulness during the game-based rehabilitation. Playfulness refers to an attitude towards an activity in psychological, physical and emotional ways [30]. It can elicit a level of emotion and intrinsic motivation in people to particular things in the absence of purpose and goal. Walz and Deterding [24] have proposed the definition of gamification as "the use of game design elements in non-game contexts" and explored the phenomena of "gamefulness" and "playfulness" with using games and toys respectively and illustrated as in Figure 2-1. Each of these two areas is purely focused on its own levels of experience and behaviour where "gamefulness" is strictly distinguished from "playfulness".

The proposed serious game in this research is associated with the concept of gamification as defined by Walz and Deterding, but goes beyond this, such that it seeks to gamify rehabilitative training by determining the context of intervention studies for those with MCI along with the identification of useful gameful elements derived from a body of validated studies in Sections 2.3.1 to 2.3.3. Therefore, the serious game is intended to incorporate the gameful elements utilised in existing literature in order to provide specific purpose and benefit to its players.

Table 2-2 Common aspects in games

Common aspects in games	Description (sourced from the respective frameworks)	Framework				
		The Art of Game Design [25]	Lu-Lu [26]	Rules of Play (Game) [27]	Gamification Mechanics and Elements (General user type) [28]	MDA [29]
(i) **Aesthetics**	Aesthetics is the appearance or the "look" of the game that stimulates the player's five senses while the player is playing the game. It directly affects the gaming experience of the player emotionally, visually and affects the quality of immersion.	X				X
(ii) **Artificial**	"Games maintain a boundary from so-called "real life" in both time and space. Although games obviously occur within the real world, artificiality is one of their defining features."			X		

(iii) **Challenge**	For setting the challenge to the player, the difficulty and the appropriateness of level should be considered. Each level should be balanced and not overestimate or underestimate the ability of the player.	X				
(iv) **Conflict**	“All games embody a contest of powers. The contest can take many forms, from cooperation to competition, from solo conflict with a game system to multiplayer social conflict. Conflict is central to games.”			X		
(v) **Control**	Through controlling game objects, the sense of superiority and freedom of the player is enhanced.	X				
(vi) **Consequences**	The users may lose a life, points or items if they do something wrong in the game.				X	

(vii) **Curiosity/Mystery Box**	A sense of curiosity is driven by the content of the game whereby it should be well-designed in a complex and abstract form that is not fully unveiled for the player to explore and assimilate the information in the game. The mysterious situation may lead the player to discover new directions.	X			X	
(viii) **Dynamics**	“Dynamics describes the run-time behaviour of the mechanics acting on player inputs and each other’s outputs over time.”					X
(ix) **Decisiveness index**	“As a decision weight of the competence level and performance of each player, it can be a determining factor for each player’s decision in the process of creating the final collective decision.”		X			

(x) **Fantasy**	Fantasy is the processing of the game activity to improve the intrinsic motivation to the player. For instance, educational games can create an imaginative fantasy to narrow the gap between the player and the artefact.	X				
(xi) **Flow**	“Getting the perceived levels of challenge and skill just right can lead to a state of flow. Balance is the key.”				X	
(xii) **Investment**	“When people invest time, effort, emotions or money, they will value the outcomes all the more.”				X	
(xiii) **Leading**	“The leader of a team is the strongest and most proficient player in the team and, therefore, a player would occupy or vacate that position based on their performance.”		X			
(xiv) **Levelling**	“Increases the game difficulty as players progress to higher levels. Levelling provides a sense of accomplishment and reward.”		X			

(xv) **Loss Aversion**	"Fear of losing status, friends, points, achievements, possessions, progress etc can be a powerful reason for people to do things."				X	
(xvi) **Mechanics**	Mechanics refers to the flow and rules. It outlines the aim of the game and all the possibilities of the actions of the player, presenting the algorithms of the game components. Mechanics acts as an agent to support the story and allow it to be told.	X				X
(xvii) **Multiple stages**	"A game should include multiple stages to progress through, e.g., through characterisation, which they may change, upgrade and update as they progress."		X			
(xviii) **Mystery box**	"A little mystery may encourage people in new directions."				X	
(xix) **Narrative**	"Tell your story and let people tell theirs. Use gamification to strengthen understanding of your story by involving people."				X	

(xx)	**Non-optimal decision making**	“As part of encouraging the players to improve and to reduce non-optimal decision making, each team needs a leader, preferably one that evolves naturally during game play.”		X			
(xxi)	**On-boarding/Tutorials**	To allow the player to understand the functions of the system by offering tutorial or introduction.				X	
(xxii)	**Personalisation**	To include all players’ actions, preferences and behaviour that happen in the game.		X			
(xxiii)	**Players**	“A game is something that one or more participants actively play. Players interact with the system of a game in order to experience the play of the game.”			X		
(xxiv)	**Progress/Feedback**	“Progress and feedback come in many forms and have many mechanics available. All User Types need some sort of measure of progress or feedback, but some types work better than others.”				X	

(xxv) **Rules**	"Rules provide the structure out of which play emerges, by delimiting what the player can and cannot do."			X		
(xxvi) **Quantifiable outcome**	"Games have a quantifiable goal or outcome. At the conclusion of a game, a player has either won or lost or received some kind of numerical score. A quantifiable outcome is what usually distinguishes a game from less formal play activities."			X		
(xxvii) **Scarcity**	"Making something rare can make it all the more desirable."				X	
(xxviii) **Scoring**	"A scoring system should encourage players not only to continue playing but to guide each other into making better decisions."		X			
(xxix) **Signposting**	"Signpost next actions to help smooth early stages of a journey. Use "just in time" cues to help users who are stuck."				X	

(xxx) **Story**	Story allows the player to understand the context of the game via gamification and leads the player to fulfil the tasks based on a sequence of events.	X			X	
(xxxi) **Strategy**	"Make people think about what they are doing, why they are doing it and how it might affect the outcomes of the game."				X	
(xxxii) **System**	"A system is a set of things that affect one another within an environment to form a larger pattern that is different from any of the individual parts."			X		
(xxxiii) **Team matching**	"Team matching helps the players improve and progress and also avoid situations where some of the team members are significantly better than others as this would discourage less proficient players from engaging."		X			
(xxxiv) **Technology**	Technology supports the story, aesthetics and mechanics. It includes hardware and software.	X				

(xxxv) **Theme**	"Give your gamification a theme, often linked with narrative. Can be anything from company values to werewolves. Add a little fantasy, just make sure users can make sense of it."				X	
(xxxvi) **Time pressure**	"Reducing the amount of time people have to do things can focus them on the problem. It can also lead to different decisions."				X	

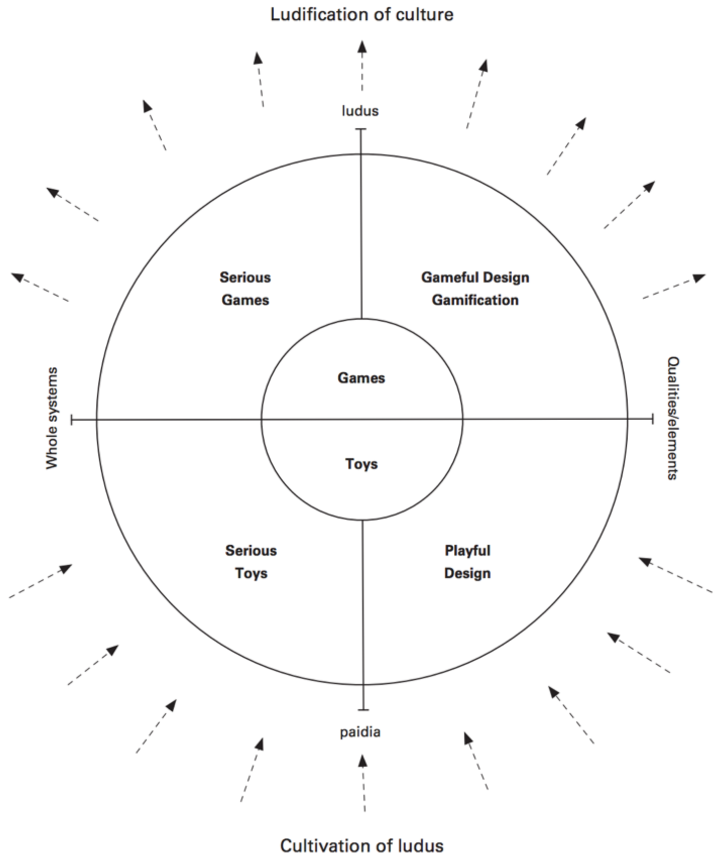


Figure 2-1 Gamification in ludification of culture [24]

In the scope of review, there is a great diversity of game-based rehabilitation studies that will be explored and evaluated. This aims to seek potential approaches to advance mild cognitive impairment training in terms of gaming technologies, for the elderly as well as to increase the quality of cognitive rehabilitation by maximizing useful materials in user interaction, gaming and design areas and by reducing the disadvantageous resources.

In Sections 2.3.1 to 2.3.3, three major categories are illustrated (i.e. gameful cognitive rehabilitation, gameful physical rehabilitation and playful experiences for all ages) with design interfaces, from which effective and feasible methods will be devised to achieve the research aims.

2.1.3 Overview and Theoretical Background of MCI

This section introduces the reader to background information relating to MCI, in particular the relevant cognitive functions and neuropsychological diagnostic methods to test for the characteristics which may possibly appear in individuals and to determine the implicit level of cognitive impairment. Several examples of digital training in medical studies will also be covered in order to introduce a set of methods that have given positive results in a clinical setting. Important terms related to MCI are defined and listed in Table 2-3.

Table 2-3 Definitions of terms

Term	Definition
Alzheimer's disease (AD)	"Alzheimer's disease is an irreversible, progressive brain disorder that slowly destroys memory and thinking skills and, eventually, the ability to carry out the simplest tasks" [14].
Amnestic MCI (a-MCI)	When the episodic memory performance does not meet the criteria of neuropsychological tests [11].
Cognitive function	Cognitive function is the overarching term for a whole set of brain-based skills we need to carry out tasks, of which can be divided in two subsets as basic cognitive function (e.g. attention, working memory, long-term memory, perception) or higher cognitive functions (e.g. speech and language, decision-making, executive control) [31].
Dementia	"Dementia is a syndrome due to disease of the brain – usually of a chronic or progressive nature – in which there is disturbance of multiple higher cortical functions, including memory, thinking, orientation, comprehension, calculation, learning capacity, language, and judgement. Consciousness is not clouded. The impairments of cognitive function are commonly accompanied, and occasionally preceded, by deterioration in emotional control, social behaviour, or motivation" [32].

Mild Cognitive Impairment (MCI)	1."Mild cognitive impairment is a syndrome defined as cognitive decline greater than that expected for an individual's age and education level but that does not interfere notably with activities of daily life"[12]. 2. "An intermediate stage of cognitive impairment that is often, but not always, a transitional phase from cognitive changes of normal ageing to those typically found in dementia"[11].
Non-amnestic MCI (na-MCI)	Rather than having a poor performance of memory function in neuropsychological tests, it slightly affects other cognitive functions, such as executive functions, use of language or visuospatial skills [11].

Mild cognitive impairment (MCI) is an intermediate stage of cognitive function between normal ageing to dementia and Alzheimer's Disease (AD) [10], [33]. Rather than being a single syndrome, MCI has been classified into various subtypes, which commonly fall into two classes: amnestic MCI (a-MCI) and non-amnestic (na-MCI), and four subdivided classes: single- and multi-domain a-MCI and na-MCI [34].

Two articles [10], [11] define a-MCI and na-MCI in terms of cognitive functions. The former happens when the episodic memory performance does not fulfil the criteria of neuropsychological tests and is revealed as memory impairment, while the latter refers to the poor performance of at least one other cognitive function, such as executive functions, use of language or visuospatial abilities, whilst memory remains intact in the neuropsychological tests.

In addition, criteria for the various types of MCI has been summarised in Figure 2-2 [11]. It outlines the diagnostic criteria of MCI from the Key Symposium in 2003, the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) and MCI due to AD.

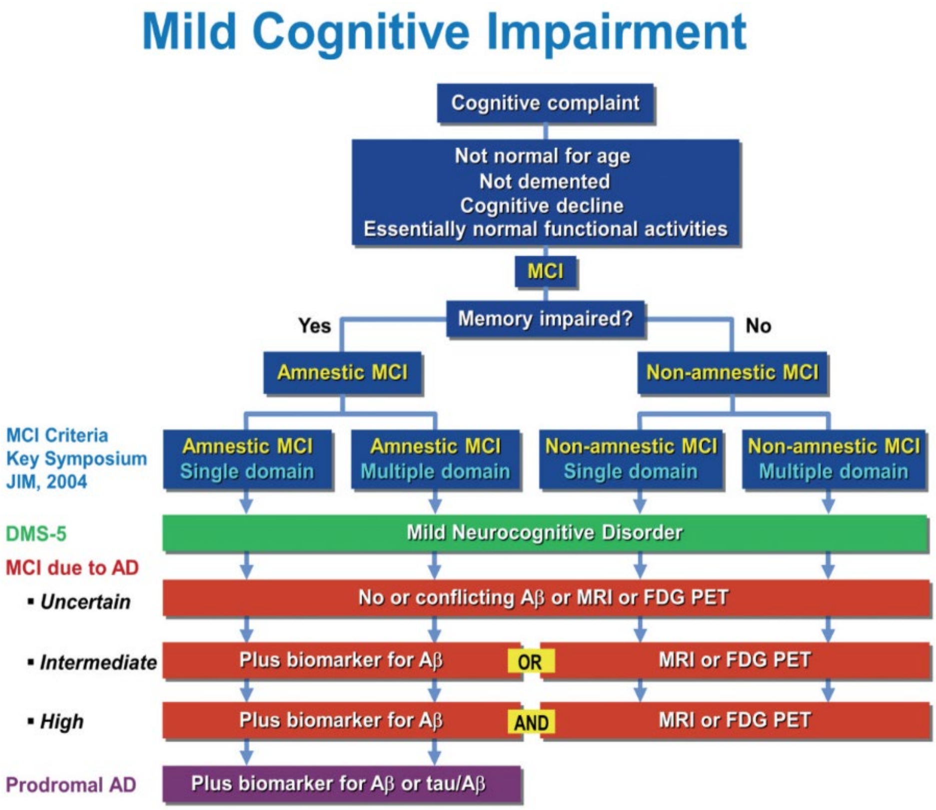


Figure 2-2 The criteria of MCI [11]

MCI occurs when the quality of cognitive functions in an individual does not meet the expectation with respect to age and education level but is adequate to perform normal daily activities [9]. The onset of MCI can be maintained at a certain level or reversed back to the normal state. After the symptoms of MCI are first identified, its state may progress to dementia. Furthermore, there is a great risk for a-MCI to progress to AD [12]. AD is a progressive neurodegenerative disease, where fragments (beta-amyloid plaques) and strands (neurofibrillary tangles) of protein accumulate on the outside and inside of neurons in the brain [14]. Although the precise biological changes that cause AD are yet to be fully understood, more studies are underway and the excessive build-up of protein in regions of the brain which are involved in learning, memory and emotional behaviours, is considered the hallmark pathology of AD [35]. It is believed that the beta-amyloid plaques impede communication between brain cells, whilst the abnormal formation of neurofibrillary tangles leads to failure of the transport system and cellular homeostasis in the brain [14]. Consequently, these changes to the brain contribute to synaptic dysfunction and eventually neuronal death in brain regions affected by AD. The pathological changes caused by AD are irreversible and clinical trials have revealed that 90% of a-MCI cases progress to include the clinical symptoms of AD. Nevertheless, the deterioration of cognitive function can be slowed or delayed if given appropriate intervention when the symptoms appear at early stage. A set of clinical neuropsychological diagnostic methods are listed and briefly introduced in Section 2.1.3.2 to assess the severity and map the progression of cognitive impairments.

2.1.3.1 Cognitive Functions

The transitional progression of cognitive function between that of normal ageing and AD has been clinically diagnosed as MCI [36]. MCI is strongly age-dependent and is expected to become more prevalent as the number of elderly escalates rapidly, especially once the baby boomer population begins to reach 65 years old and beyond, on top of the longstanding ageing problem worldwide. This section maps the progression from normal cognitive ageing (NCA) to age-related diseases including MCI and AD, in terms of cognitive functions. However, there is a misconception that AD is a consequence of ageing and people tend to wrongly attribute the signs of AD with the ageing process. Figure 2-3 presents the transition of cognitive functions from normal cognitive ageing to MCI and beyond, to probable AD and definite AD [37].

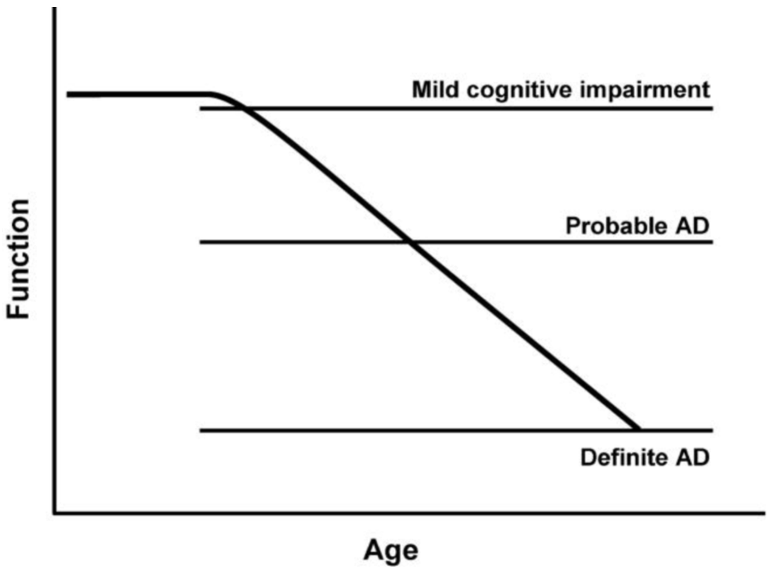


Figure 2-3 The transitional condition of cognitive function from normal ageing to MCI; and MCI to probable and definite Alzheimer's Disease (AD) [37]

Normal cognitive ageing (NCA) refers to the process where cognitive functions are altered over time in ageing brain. These functions include neurocognitive abilities relating to normal cognitive ageing, such as crystallized and fluid intelligence, and some other specific cognitive functions [38]. Crystallized intelligence is a memory-based ability that can remain stable by developing knowledge and skills, while fluid intelligence represents a set of inborn abilities including problem-solving and learning capacity that can reach the highest level at late 20's and gradually decline beyond that period [39].

As described and referenced in Figure 2-2 and Figure 2-3, MCI is an intermediate state of cognitive function between normal ageing and dementia, which mainly involves two subtypes: (i) amnestic MCI – memory impairment and (ii) non-amnestic MCI – decline in some cognitive domains other than memory, such as attention, use of language, executive function and visuospatial ability. Also, MCI has a high risk of progression towards Alzheimer's Disease (AD) and dementia. AD, being the most common irreversible cause of dementia [13] accounts for 60% to 80% of dementia cases [14] and involves cognitive and physical decline. The accumulation of AD pathology also contributes to other age-related functional declines such as motor decline. The interplay between cognitive and physical deteriorations affects a person's ability to perform basic activities of daily living (ADL). During the course of ongoing degeneration of brain tissues, not only are cognitive functions such as memory, communication and problem-solving skills impaired, but the change in mood and behaviour also lead to other issues. Furthermore, physical function and the ability to perform everyday activities are progressively compromised over time [14] alongside balance, mobility and gait problems [15]–[18] faced by people with late-stage dementia.

Different daily activities require a multitude of cognitive functions. Five main cognitive domains are listed below including attention, working memory, use of language, visuospatial skills and executive functions:

i. Attention

Attention refers to the ability to focus on certain stimuli. There are several types of attention which can be assessed in daily life situations: arousal, focused attention, sustained attention, selective attention, alternating attention and divided attention [40]. Among these types of attention, selective and divided attention are easily noticed to undergo decline in ageing people due to their complexity [38]. Selective attention is the ability to concentrate on certain stimuli or distractors in the given place, while divided attention is the ability to concentrate on several tasks at the same time.

ii. Working Memory

Memory is a very common cognitive activity thus its decline can be seen in older adults. A lot of activities involve working memory (WM) and long-term memory abilities. Research [41] claims that WM is one of the significant predictors for detecting the progression from MCI to AD. Generally, the cognitive system functions through a process which starts with attention and continues until decision making, and WM is required throughout the entire process. WM maintains short-term memory materials like auditory and visual information for future retrieval. WM load refers to the quantity of selected information in the central executive system, which varies from person to person. In addition, when a person encounters a new object and the brain compares a novel object with a familiar object, WM may be used momentarily.

iii. Use of Language

Language is one of the cognitive domains that work extensively with a wide range of cognitive systems including working memory, reasoning skill, auditory recognition, verbal abilities, executive functioning and relevant memory abilities [42]. With reference to crystallized and fluid intelligence that have been mentioned above, language learning is associated with these two cognitive abilities and remains stable in the normal ageing brain.

iv. Visuospatial skills

Visuospatial abilities refer to the capability of understanding two-dimensional (2D) and three-dimensional (3D) environments, while visual construction skills relate to the ability of assembling shattered objects. These cognitive skills embody the perception processing, relation among familiar objects like everyday objects and intuition in space [38].

v. Executive Functions

Executive functioning is the capacity for people to perform actions in daily life independently. The behaviours are well-organised and planned over a long period, and it includes problem solving and reasoning. These abilities may decline by age 70 and affect the ability to respond to different situations [38].

2.1.3.2 Neuropsychological Diagnostic Methods

Neuropsychological diagnostic methods are common medical resources for clinical specialists to detect or screen out the different levels of cognitive impairment in patients. It can be used before and after the assessment tools to indicate the efficiency of the rehabilitation. There are several popular methods which have been used in clinical settings and are discussed below as follows:

i. Trail Making Test (TMT), Parts A and B [43]

TMT Part A aims to test psychomotor speed while Part B assesses visuospatial, working memory, attention and executive functions. The task given in Part A is to link successive numbers from 1- 25, which are presented as 25 numbered circles individually and randomly scattered on the test paper. The task in Part B is to link alternating sequenced numbers 1-13 and letters A-L (i.e., 1-A-2-B-3-C…). The examinees are asked to draw one continuous line to connect the circles in their shortest time in both tasks. The performance in both tasks will be graded with respect to time (in seconds) and the number of errors made.

ii. ACE-III (Addenbrooke Cognitive Examination - III) [44]

ACE-III is another neuropsychological diagnostic method with sensitivities and specificities for testing cognitive impairment. It evaluates a variety of cognitive functions, such as attention, memory, verbal skills, language and visuospatial skills. The highest score of ACE-III test is 100 and it takes around 15 to 20 minutes to finish the examination and scoring. It is one of the traditional paper-pen assessment tools for cognitive impairment, for which the participant needs to have at least the basic educational level.

iii. Mini Mental State Examination (MMSE) [45]

MMSE is one of the general cognitive diagnostic methods that detects the mental status alterations in elderly. It aims for a quick assessment of orientation in time and place, attention, memory (i.e. verbal memory), use of language and visuospatial ability. In MMSE, each of the above cognitive functions is assessed in a set of tasks. Administration of MMSE takes around 5 to 10 minutes. [45] introduces a practical method for grading the cognitive state of patients for clinician as shown in Table 2-4. It presents the MMSE to map the progression and severity of cognitive impairments after the clinical diagnosis of AD has been made. However, it is not effective in identifying people with MCI and moderate to severe dementia.

Table 2-4 Interpretation of the Mini Mental State Examination (MMSE) [45]

Level of Impairment	Score	Formal Psychometric Assessment	Day-today functioning
Questionably significant	25-30	If clinical signs of cognitive impairment are present, formal assessment of cognitive functions may be valuable.	May have clinically significant but mild deficits. Likely to affect only most demanding ADL.
Mild	20-25	Formal assessment may be helpful to better determine pattern and extent of deficits.	Significant effect. May require some supervision, support and assistance.
Moderate	10-20	Formal assessment may be helpful if there are specific clinical indications.	Clear impairment. May require 24 hours supervision.
Severe	0-10	Patient not likely to be testable.	Marked impairment. Likely to require 24 hours supervision and assistance with ADL.

iv. Simple Reaction Time (SRT) Test [46]

In the simple reaction time (SRT) test, the examinee is asked to press the button as fast as possible once the visual stimulus (i.e. square) appears on the computer screen. It measures the attentiveness and processing speed of the participant. The test takes around 6 mins and records both time in mms and number of responses including correct and incorrect commission and omission. However, this test does not detect MCI as alertness is not a complex cognitive function, unlike selective and divided attention skills.

v. Go/No-Go Test [47]

Go/No-Go test measures the selective attention and cognitive inhibition processes, which is based on the go/no-go paradigm. One of the examples assigns the participant to perform the action with two fingers i.e. index and middle fingers. Before the test, the participant needs to learn all the responses: forming the "V" gesture with two fingers in response to one index finger; and showing one index finger in response to the "V" gesture. In the Go/No-Go testing, the previous pattern will remain unchanged except that the participant does not need to do anything while the examiner is showing one index finger. The task is to only respond to certain stimuli, but not to other stimuli.

2.1.3.3 Examples of Digital Cognitive Training in Medical Studies

This section covers several cognitive digital tests and training which involve a set of cognitive domains that have been exhibited above. Several researchers have adopted digital cognitive training in rehabilitation as a modified version of traditional training, i.e. digitised paper-and-pen training, which are presented in this section. They do not conform to a conventional definition nor do they contain most of the gameful elements which will be discussed in Section 2.3. A description of common techniques used for designing such digital cognitive training is summarised in Table 2-5. Considering digitised training which has been used in medical intervention helps to uncover limitations in terms of technological approach and to facilitate the identification of desirable features that could have been advanced in the proposed artefacts. This also serves to reinforce the research gap in terms a lack of suitable solutions, particularly with respect to interaction design and gameful approaches, which would enable the optimisation of game capability to support MCI. The therapeutic tasks in the following examples are typically altered from pen-and-paper method to an interactive platform without concerning the human-computer interaction to offer a better user-centred training to target users. However, the performance results are overall positive, which plausibly implied that the digitised therapy may improve the patients' cognitive functions. Thus, this section will further consolidate the research gap and direction leading to the investigation of gameful rehabilitative training that have been published in a body of literature.

Currently, the results of numerous research findings [48]–[50] deploying computerized platforms as means into cognitive training for those with memory impairment show generally positive feedback from the subjective user experience interviews. One of the studies [48] employs the tablet-based platform to present a new version of the traditional pen-and-paper test. The training took the form of a three-month (91 game days) Modified Trail Making Test, and the result revealed that most of the users with mild or medium level memory impairment improved their scores in the modified version. However, there was no score improvement in the traditional pen-and-paper Trail Making Test. Between the two tests, the user interface design on the modified version is designed differently from the traditional one. In the digital version, the player is asked to tap on the circle (i.e. numbered circle) to link it to the previous one until all the circles have been selected. The interaction feedback will instantly show on the tablet screen as either a change of the circle's transparency to indicate a correct answer, or a change of its colour to indicate an incorrect answer. In the traditional test, the users were only asked to connect those circles with a single line using a pen. There is no erasure of the drawing line and instant feedback like the digital version. The conclusion from this finding claimed that the improved score only showed in the modified test and not in the traditional test.

Existing cognitive training focuses mainly on the abilities of attention, executive function and reaction. Among the memory abilities, prospective memory (PM) function is one of the important cognitive spheres but there is only a small amount of developed game training for it. But PM is a significant ability that thoroughly affects everyone's everyday life situations because it is involved in real world conditions such as time and events. PM is divided into two types: event-based (E-B) and time-based (T-B). E-B and T-B training involves the execution and completion of specific E-B and T-B tasks at the right time respectively [51], [52]. The dysfunction of PM will affect daily routine. Furthermore, the deficiency of one memory ability and another cognitive function causes dementia [49]. To support PM function in a group of older people, a number of training activities [49], [53] depict daily life circumstances as a game, where players complete PM-related tasks.

With regards to memory training, the standardised diagnostic tests can only provide the test results to the participants when they have finished the task. However, participants do not require the correct answers after completing the training. To address corrections in computerized memory training, the study [49] tries to implement errorless learning technique to support the users in completing the memory training tasks. It suggested two types of memory training which combined the errorless technique and the spaced retrieval technique in a 7-week clinical study of PM training. The training was effective, and participants attained outstanding results in a set of measurements including MMSE. The accuracy of post-treatment was 90%. This study shows that the errorless learning approach is worth taking into consideration as it does not display mistakes during the cognitive training. By doing this, the MCI player can focus on the training with a sufficient amount of attention.

Apart from that, [50] proposes *Smart Thinker*, a desktop-based cognitive training, to address the cognitive problems and improve the cognitive performance in elderly. The Mini Mental State Examination (MMSE) is the chosen neuropsychological method to test the participants' cognitive skills before and after the digital training, which lasts for six weeks. The result reveals that *Smart Thinker* had improved the cognitive functioning in the participants.

The above examples of medical studies have been summarised as shown in Table 2-5. In the studies, touchscreen-based or desktop-based platforms were mostly exploited, so as to provide "point-and-click" direct manipulation during the training navigation. The ease of use in interaction and simple movements can narrow the gap between the user and the system.

Table 2-5 Examples of digital cognitive training

	Modified Trail Making Test*[48]*	**Errorless learning-based memory training [49]**	***Smart Thinker* [50]**
Cognitive Function	Attention and reaction speed	PM	Cognitive problems
Target User	Memory-impaired person	Elderly	Cognitive-impaired elderly
Interaction Technology	Touchscreen	Desktop	Desktop
Digital Training Approaches/ Elements	- Simple interaction, e.g. single tap - Erasure of the drawing line - Instant feedback	- Errorless learning technique - Spaced retrieval technique	

Diagnostic Method	- Traditional TMT - Modified TMT	- MMSE -Mattis Dementia Rating Scale (DRS) -Hong Kong List Learning Test (HKLLT) -Brief Assessment of Prospective Memory-Short Form (BAPM) - Modified Barthel Index (MBI) -Hong Kong Lawton Instrumental Activities of Daily Living Scale (HKLIADL)	MMSE
Performance Results	- No score improvement in the traditional TMT - Improved score in the modified TMT	- Outstanding results with 90% accuracy	-Had improved the cognitive functioning in the participants

The adoption of technologies in the medical studies constitute interactive platforms enabling the patients to perform the tasks. The instruments, however, are not specialized in aiding patients' physical needs. It may be plausibly explained that the performance results between the digitized and traditional methods vary. The results may be mistaken by the underlying factors caused by the physical performance and thus cause fallacy. This encourages the proposed serious game and framework in this research to take the technological aspect into account in considering the appropriate physical interactions. Furthermore, comparing the digital form of training to the traditional paper-and-pen test, the computer can also generate a bunch of everyday-life elements in the system while the traditional paper-and-pen has constraints in providing a close-to-reality experience to the user. Additionally, digital training can go beyond the simple translation of paper-and-pen based training and other types of basic approaches through the involvement of gameful and playful elements to arouse players' interest and enhance motivation in serious games. Collectively, the technological capacity in offering games and traditional constraints will be addressed starting from the selection of gameful elements to develop the optimised framework and serious game. In Section 2.3, serious games in healthcare include the notions of gamefulness and playfulness to further explain how these gameful elements have been used in numerous rehabilitations. These techniques will be harnessed to develop the *MCI-GaTE* through the thematic approach later on in this chapter. In the following section, the analytical method, i.e. thematic approach, for analysing the serious games in healthcare is introduced.

2.2 Analytical Method of Literature on Serious Games in Healthcare

Literature is selected from three main research fields from Table 2-1 (i.e. Gameful Cognitive Rehabilitation, Gameful Physical Rehabilitation, Playful Experiences for All Ages), which constitute the domains of the initial *MCI-GaTE* that is shown in Section 2.4 later on.

A thematic analysis is adopted to identify semantic and latent themes, where the former relates to general game principles (the conventional gaming elements), while the latter pertains to prominent gaming elements appropriate for physical and cognitive training [54]. Hence, papers are classified into two types (semantic and latent). The process focuses on exploring the probable gameful and playful techniques within these two types of research papers. The semantic papers cover the conventional gaming elements: scoring, rewards, feedback, progress, etc., and will provide the indispensable gaming elements in the framework of the proposed serious game. These gaming elements generally serve as the motivational techniques to sustain the player's attention and engagement. On the other hand, the latent papers will be analysed for prominent gaming elements which are applicable for physical and cognitive training. These include features like avatar-based, first-person view and distractors, that may be potentially apt for helping MCI patients. For example, the tangible walking game as reviewed in Section 2.3.1 gained slight improvements in working memory and suggests that the first-person avatar may be included in the proposed *MCI-GaTE* as a gameful feature to potentially improve working memory. By doing this, *MCI-GaTE* will be formed from two dimensions: (i) a number of fundamental conventional gaming elements in order to facilitate a basic game framework; and (ii)the prominent gaming elements which are directly suitable to support cognitive performance. It should be clarified that the purpose at this stage is theme identification for framework construction rather than determining when particular techniques would be best applied.

In the following section, literature covering recent healthcare games from the three research fields (i.e. Gameful Cognitive Rehabilitation, Gameful Physical Rehabilitation, Playful Experiences for All Ages) will be reviewed in order to construct *MCI-GaTE*. The data collected from the literature will be first analysed thematically, and presented by the concepts given by the notions of *gamefulness* and *playfulness*.

2.3 Literature Survey

The literature survey explores the techniques of gamefulness and playfulness which integrate with non-leisure contexts to promote the player's engagement and minimize the limitations of cognitive assessments, which can potentially increase the long-term motivation in players in order to facilitate active participation. Table 2-6 presents a list of definitions of themes that have been identified from the literature, which will be discussed in this section. The coding methods used here are guided by Saldana's cycle coding process [55] that will seek inputs regarding the gameful and playful elements, from which a set of new codes will then be generated as needed. Overall codes will be named as different categories (e.g. *playful activity, gameful cognitive rehabilitation* and *gameful physical rehabilitation*) by relating the codes, resulting in a three-level hierarchy as follows: *therapeutic elements*, *core gaming elements* and *motivational elements* categories as the first level, *gamefulness* and *playfulness* as the second level, and the codes as the third level. The selection of the codes will be discussed in Section 2.4.

Table 2-6 Definitions of identified themes from the literature survey for the initial *MCI-GaTE*

Themes for *MCI-GaTE*	Definition
2D/3D environment	Game space graphically represented in 2D or 3D
Achievements	Used as motivation, either alone or in conjunction with other gaming elements, such as pointsification to instantiate and visualise them to the player
Affection	A disposition or state of mind or body associated with a feeling
Autonomy: freedom of choice	Ability of players to make their own decisions
Avatar-based	Player's graphical representation within the game space
Behavioural flexibility	Control of the exploration of the gaming scenario
Competence: skills, challenges	Seeking attainable challenges that match and extend player skills and being sufficiently encouraged to proceed
Contextual awareness	Helps to elicit greater understanding of the game space and possible player behaviour within it in conjunction with other game feedback
Controllability	Interaction with and adjustment of game objects
Discoverability	Ability of players to locate something they need in order to complete a task
Distractors	Key for ensuring that the tasks are suitably challenging by hindering or preventing players from undertaking a task in a straightforward manner

Feedback	Provides guiding information to player which may serve to motivate, instruct, or similar
Flow	A zone between boredom and worry that sustains the motivation and enjoyment in the serious game
HUD design	Visualises and contextualises game features to the player using appropriate and readily understood visual cues
IADLs	Instrumental Activities of Daily Living - require more complex thinking skills, including organisational skills, than the fundamental skills required to independently care for oneself, such as shopping and meal preparation.
Immersion: player's experience	Being enveloped by the games' stimuli and experiences
Levels	Increase game complexity for the player
Lower limb tasks	Balancing tasks (i.e. sitting and standing balancing)
Main cognitive tasks	Tasks relating to the main cognitive functions of attention, language, visuospatial skills, executive functions (and working memory, which is considered separately below due to its importance to MCI)
Memory tasks	Cognitive tasks relating to short- and long-term memory
Metaphorical graphics	Assist a player in understanding their status, actions, and progress
Narratives	Provides context to the therapeutic elements to further aid the player in relating to real-life situations or reminiscing
Other physical tasks	Physical tasks involving parts of the body other than upper or lower limbs, such as face, mouth, neck, and breathing
Personalisation	Automatic customisation based on a prediction of the player
Player's perspectives	The role or point of view that the player has on the game, including first-person, third-person, top-down, isometric, flat, side-view, and text-based
Player's progress and rewards	Progress enables the player to understand their status within the context of the game, while rewards facilitate the extrinsic

	motivation through redeemable points or badges, which is similar to pointsification
Pointsification	Facilitates extrinsic motivation through redeemable points, badges, or similar, typically after the player has completed a level
Realism of graphical model	Degree with which figurative objects resemble real-life objects
Reality orientation	Broad-based therapeutic technique designed to increase cognitive stimulation by orienting an individual with dementia to the present
Real-time game objects	Player's physical movements are synchronised with the behaviour of their character or avatar within the game world
Relatedness: cooperation, social collaboration	How the player feels connected to others, to caring for and being cared for by those others, and to a feeling of belonging
Self-representation	The form of performance in gameplay in which the player's attitude is taken into account and can be utilised with elements of affection
Simplicity of game objects	Removal of complex objects
Tangible tools	Provide more natural, physical interaction affordances
Tutorial and guidance	Assists the player in understanding the gameplay and gamespace
Upper limb tasks	Those involving upper limbs, such as IADL-themed tasks

This section presents the literature survey within the three identified research fields as follows:

2.3.1 Gameful Cognitive Rehabilitation

In cognitive rehabilitation (neurorehabilitation), utilizing games with serious purposes is ubiquitous, but encouraging acceptance of rehabilitation among the elderly is lacking. Researchers have examined strategies for slowing down cognitive deterioration in patients and the use of digital therapeutic games may improve upon traditional rehabilitation, which is often tedious, and may increase long-term motivation in players to facilitate active participation.

Traditional neuropsychological assessments are not easy to administer and carry out and thus it is increasingly common to promote serious games as a solution in healthcare, typically as a screening tool or an alternative method for neuropsychological evaluations to overcome clinical limitations [56]–[58]. *MentalPlus*® [57] is a digital game proposed to assess cognitive functions including attention, memory and executive functioning, based on various scenarios. For example, in the selective attention training scenario, the player must respond quickly to click one of six buttons labelled with various animal heads to trigger a flying bird to drop the selected animal into a moving cage. The tutorial is given for the player to understand the functionality of 2D side-viewed virtual elements, including the flying bird as a carrier and animal heads as distractors as shown in Figure 2-4. These elements work to motivate players to continue training where the players can discern their utility from the metaphorical approach. *MentalPlus*® was compared with Telephone Interview Cognitive Status (TICS), one of the diagnostic tools in testing cognitive domains, and found to be useful for testing individual cognitive functions, such as attention and short-term memory, in players who have heart failure (HF) combined with cognitive impairment. Therefore, it can act as an alternative diagnostic tool for determining neuropsychological issues.

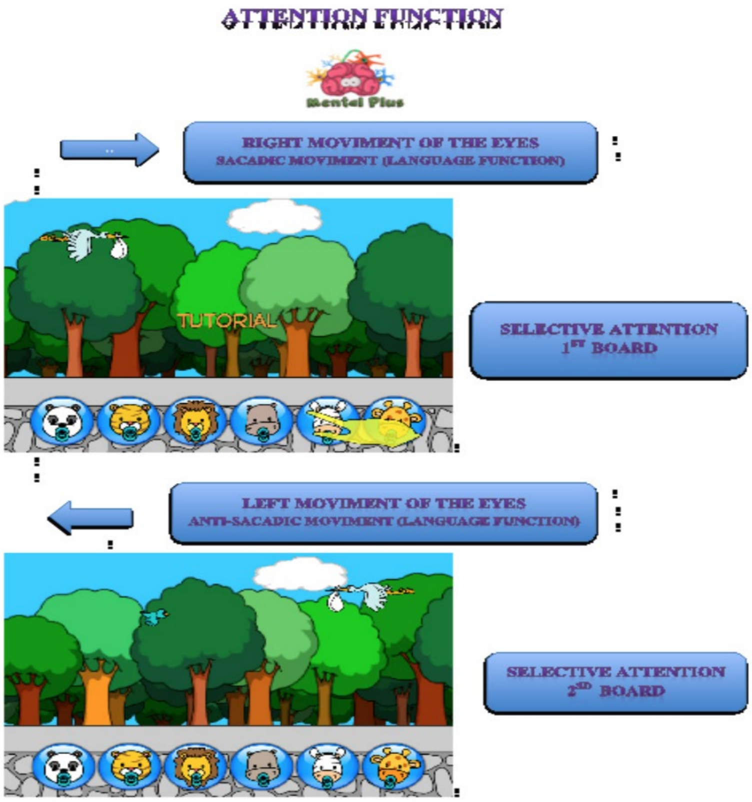


Figure 2-4 MentalPlus® digital game interface [57]

Similarly, *Episodix* [58] assesses cognitive functions and differentiates the mental quality between MCI, AD and healthy individuals, in particular episodic memory quality, through the use of three game scenarios focusing on: immediate and short-term memory, semantic and procedural memory, and long-term memory with yes/no recognition functioning. Developed in Unity and running on a touchscreen-based device, it allows the elderly to better adapt to the game. Rather than being a digital artefact for clinical service, the gamified design elements (aesthetics, progression and scoring as in Figure 2-5 and Figure 2-6) can be seen as a supportive way for the players to improve the training flow and behaviours. Several conventional gaming elements including player's progress, feedback and scores are displayed via HUD design, while the narratives guide the player to enter the therapeutic context (Figure 2-5).

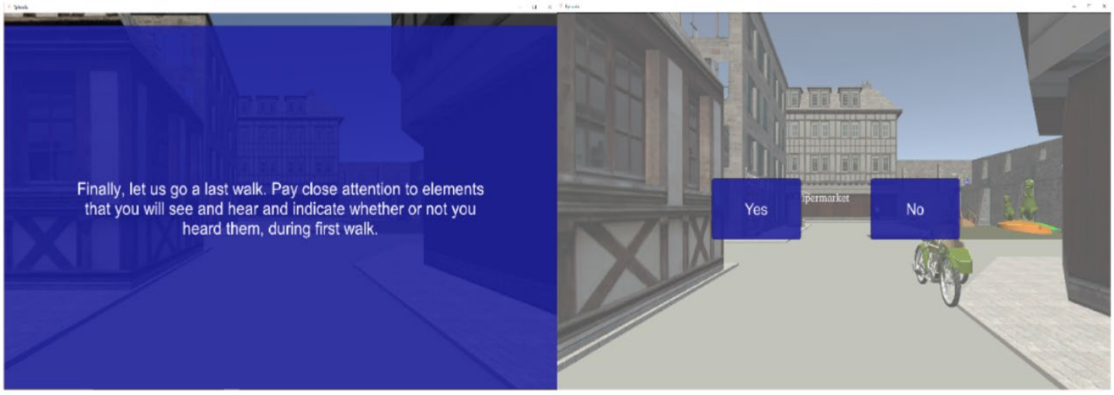


Figure 2-5 Episodix - Yes/No recognition phase [58]

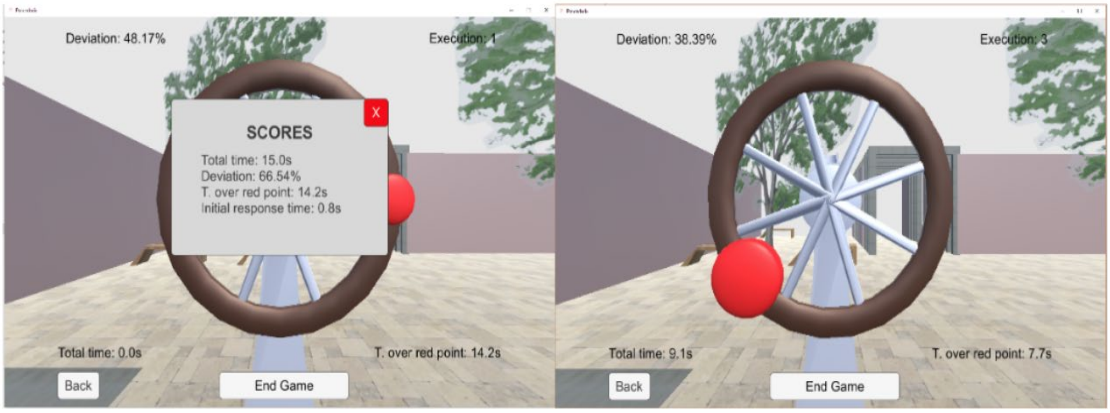


Figure 2-6 Episodix-Procedural memory game [58]

To date, the Preventive Neuro Health (PNH) system [19] is a gamified and personalised crowdsourcing-inspired tool for preventing cognitive decline in the elderly and those with early stage of dementia. It consists of 42 cognitive exercises focusing on six cognitive functions (attention, memory, executive functions, orientation, gnosis and praxis) and can be used independently without specialist monitoring and initial neuropsychological diagnosis. To sustain the motivation and improve performance, it adopts game design elements, such as metaphor to promote an unlocking feature for rewards based on earned points, and preferences and levels, to encourage users to participate, which have been organised in Figure 2-7. As shown in Figure 2-8, those features are driven by the Crowdsourcing-inspired gamification cycle.

The preferences in Figure 2-7 entail: (A)Reward, (B) Expertise, (C) Relationships, (D) Autonomy, (E) Altruism, (F) Influence; The stage comprises of: (G) Discovery, (H) On Boarding, (I) Mid-game and (J) End-game.

Game design element	Preferences	Stage
Tutorial (not binding first trial)	(B)	(G),(H)
Daily challenge (regular training)	(B)	(G),(H),(I),(J)
Random reward (surprising)	(A)	(H),(I)
Status (cognitive improvement)	(B),(D)	(G),(H),(I),(J)
Progress bar (tool unlocks)	(B),(D),(E),(F)	(G),(H),(I),(J)
Emotional assessment (exercises)	(E)	(G),(H),(I),(J)
Design assessment (exercises)	(E)	(H),(I),(J)
Avatar (profile customization)	(C),(D)	(H),(I),(J)
Voting (quality of exercise)	(F)	(H),(I),(J)
Access (performance stats)	(B),(D)	(H),(I),(J)
Mentoring (recommendations)	(C),(E)	(I),(J)
Access (not mandatory exercises)	(B),(D)	(I),(J)

Figure 2-7 Crowdsourcing-inspired gamification design [19]

Cycle	Description
Trigger	The system notifies (in a personalized way) to the user that has not yet overcome the daily challenge (set of cognitive training exercises) and today is active in calendar (user profile). Additionally, the system can also communicate the percentage of current users who have already succeeded the daily challenge in the community
Action	From dashboard, the user selects and performs the most appropriate exercises according to the cognitive domains that want to improve or their interests
Reward	When the user finishes each exercise, he/she receives a positive and personalized feedback: reinforcement, statics (successes, failures, abstentions, maximum time, and time spent), a cognitive update, and the contribution to the community purpose (unlocking functionalities)
Investment	The user perceives that the cognitive task has been carried out. If more exercises are missing to overcome the daily challenge, the trigger is launched again; else, the user is positively reinforced (the daily challenge is completed). Next, user is challenged to continue training by showing the remaining path to unlock the next crowdsourced achievement.

Figure 2-8 Crowdsourcing-inspired gamification cycle: daily challenge [19]

Undoubtedly, gameful features can maintain long-term player engagement in the cognitive programme and thus improve the cognitive performance of patients undertaking instrumental activities of daily living (IADL).

3D virtual environments (VEs) are common in neuropsychological rehabilitation [59]–[63] to provide high quality visualizations to the cognitively impaired which promote re-learning and reinforce IADL. Due to the nature of VE, it realistically emphasises ecological, economic and social values. The realism of 3DVE supports the patients in transferring the skills they have acquired in the virtual serious game to their real life. The 3D Neuropsychological Virtual Rehabilitation (NVR) simulation system [59] offers accessible means for individual cognitive rehabilitation. It assigns neuropsychological tasks in a VE with strong gaming elements. The game scene allows players to manipulate game objects and navigate the game space to complete cognitive tasks in first-person view. Scoring, time limit and feedback are provided as HUD design elements to visualise the player's status throughout the game, while narrative-based messages and statuses as illustrated in Figure 2-9 and Figure 2-10 in the game scene further facilitate involvement and realism.

Figure 2-9 Message statement [59]

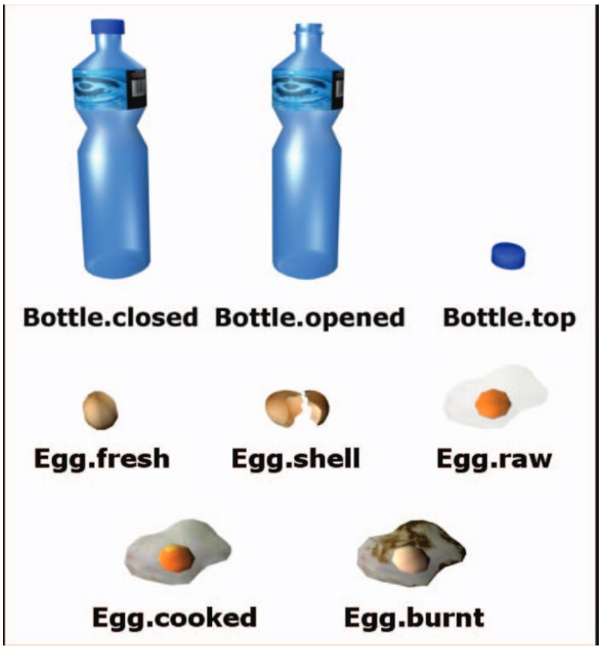


Figure 2-10 The different states of game objects [59]

Memory is greatly involved throughout multitasking when the cognitive impaired patients perform virtual IADL [60]. A touchscreen-based 3D multitasking game as shown in Figure 2-11, point-and-drag interaction enables a player to perform specific actions from the first-person view, such as filling a pot with water, to imitate a real-life cooking scenario. However, gameful features are not supported since the cooking scene is simply a virtual representation of a real kitchen setup which the player explores without any specific goal.

Figure 2-11 Cooking scenario [60]

Similarly, the VIRTRA-EL web platform [63] as shown in Figure 2-12 aims at preserving cognitive capacity in the elderly, such as memory, attention, planning management and reasoning, through realistic 3D rehabilitative settings. Game features are displayed statically, e.g. navigation arrows for camera movement within the first-person viewed game scene, a clock for orientation information, a map for displaying instant player's location, and a virtual currency. These reflect real-life situations (IADL-themed scenarios) for the elderly to raise awareness of the context and fulfil the tasks step-by-step with the guiding information.

Figure 2-12 The different scenarios [63]

Moreover, there is another 3DVE cognitive rehabilitation programme that focuses on the impairments from stroke [61]. The system utilises two types of navigation skills, allocentric and egocentric, as shown in Figure 2-13 and Figure 2-14 respectively, for stroke patients to orient themselves with their first-person vision so as to strengthen their spatial cognition. In the 3D geometrical game scene, a map as a visual cue and distant objects are used to help patients orient themselves readily. Both types of navigation training are gamified with the aid of earning coins, and this serves as a means to determine the difficulty level. Additionally, the game level will gradually get harder when 75% of the coins/scores is attained.

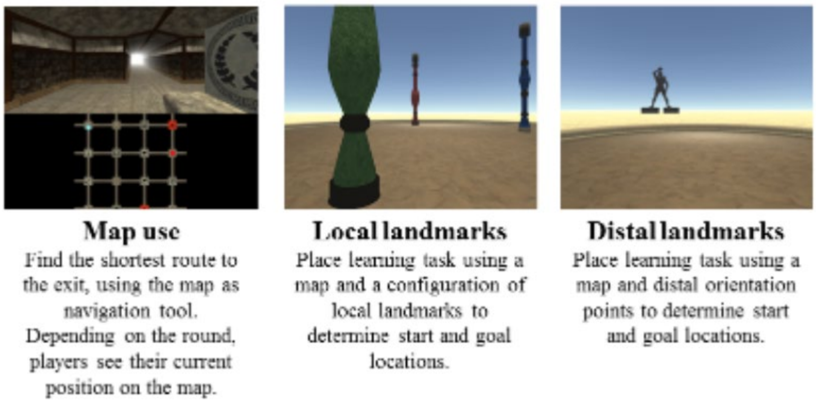


Figure 2-13 Allocentric training [61]

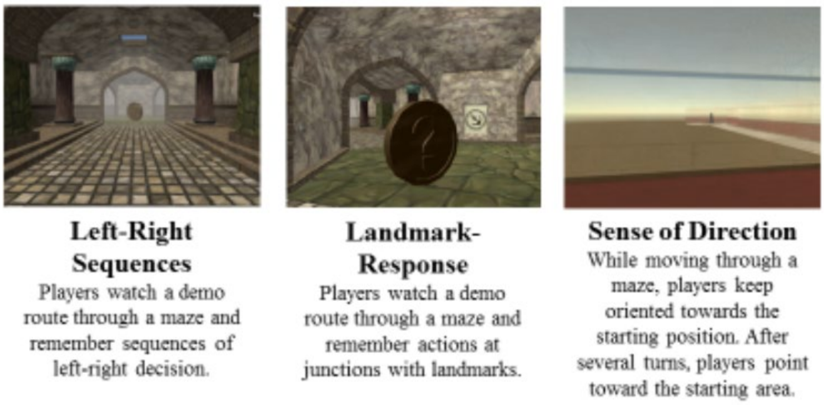


Figure 2-14 Egocentric training [61]

Not only can the 3D virtual environment work alongside gamified designs to increase the efficacy of cognitive rehabilitation, but state-of-the-art electroencephalogram (EEG)-based technology can also generate more accurate results for evaluation. A serious game for Attention Deficit Hyperactivity Disorder (ADHD) and Attention Deficit Disorder (ADD) [62] focuses on improving the task attention span for such patients. By using an EEG-based device, brain signals from the patients can control the game objects and select action buttons via a brain-computer interface (BCI) through a wireless EMOTIV device. It is a single-level serious game with one goal, which requires the player to take as many yellow cubes as possible within the time limit using two EEG actions to manipulate the avatar in the game scene: a 'push' state will be activated when the player wants the avatar to go straight while a 'neutral' state will be activated when the player is still. The quality of the gaming elements in the game are controlled to achieve the optimal condition for the patients to attempt the tasks. For example, the humanoid avatar as shown in Figure

2-15 uses grey to reduce distraction, while the realistic environment is mainly green with simple yellow cubes. Moreover, Figure 2-16 shows the action buttons which are available to players for selecting their option through their imagination. Another approach [64] uses EEGs to validate that game mechanics in commercial videogames are correlated with cognitive abilities, and the researcher envisages that these can potentially be incorporated into the design of a serious game in developing executive functions.

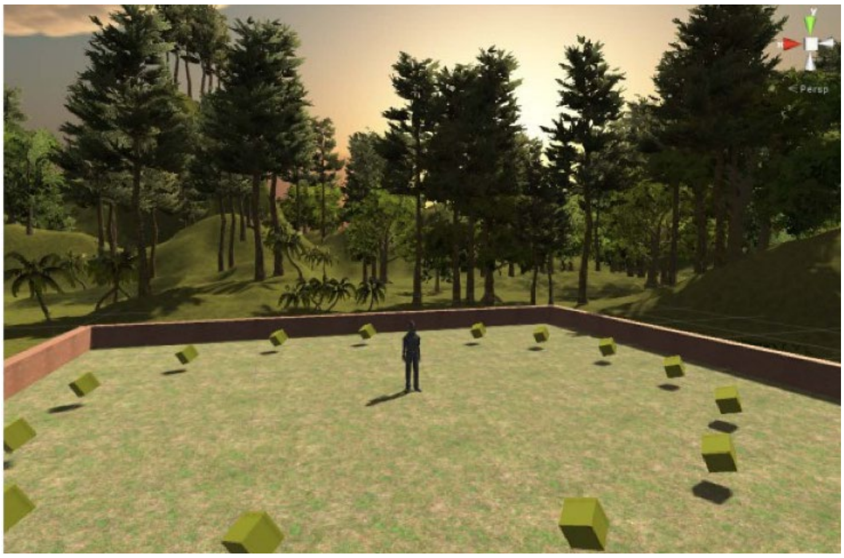


Figure 2-15 The EEG-based game scene [62]

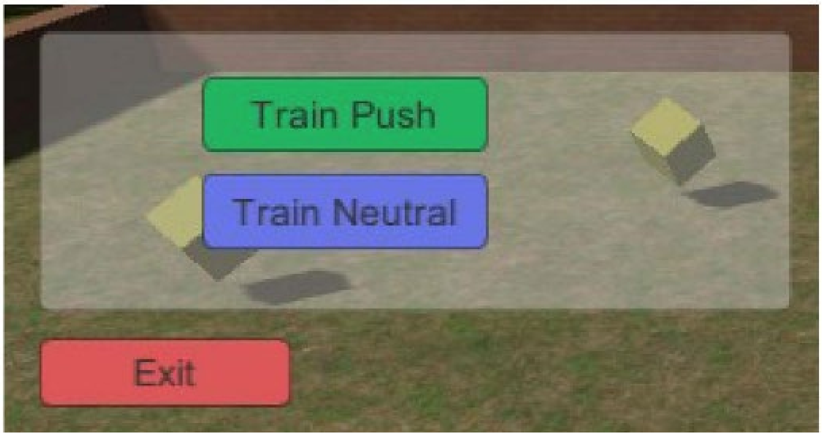


Figure 2-16 The action buttons [62]

Another attention-related serious game to be used in cognitive training is the iPad-based serious game *Decoder* as shown in Figure 2-17 [65], which is a cognitive game that aims to help visual sustained attention-impaired individuals, who lack a sufficient amount of attention to accomplish tasks. The game assigns a Signal Intelligence officer as a role for the player to identify criminal locations by undertaking numerical tasks. These are adjusted in real-time for the player, and selection of character and backstory provides further personalisation. The game was found to have positive effects on the target group by promoting enjoyment and task-related motivation. Several significant gaming elements can be highlighted throughout the game for enhancing training effectiveness: the game uses distractors to hinder the player, and rewards via letters which serve as mission clues to lead them to continue the training. Other conventional gaming elements, such as game levels and visual feedback, are also intended to improve the engagement and motivation of the player.

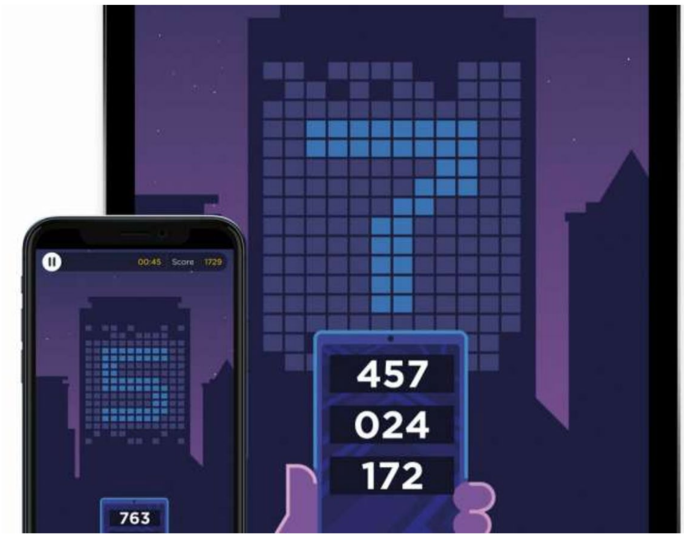


Figure 2-17 Decoder brain training game [65]

A current study [21] has highlighted that there are cognitive neuroscientific approaches for validating the serious game. The study validates the tangible walking game through testing the functions of attention, memory and emotional quality in senior players. In Figure 2-18, the picture shows the player in 3D gamespace using hand grip dynamometers and footboard to detect the physical changes in the hands, arms and legs, in order to control the first-person avatar in the game. The walking game involves two players, where the monitor displays two avatars simultaneously. As a competition, the players need to herd as many sheep as possible to the target place with the equipped devices. The results of the study revealed that the game can slightly improve the quality of working memory, although visual attention and emotional quality did not show large variations. It also claimed that physical activity, such as walking, can improve the cognitive quality in player. To surmise from this point, the first-person view avatar is a prominent gameful feature that may support the walking simulation to achieve a realistic sense of control and reach a better performance during training.

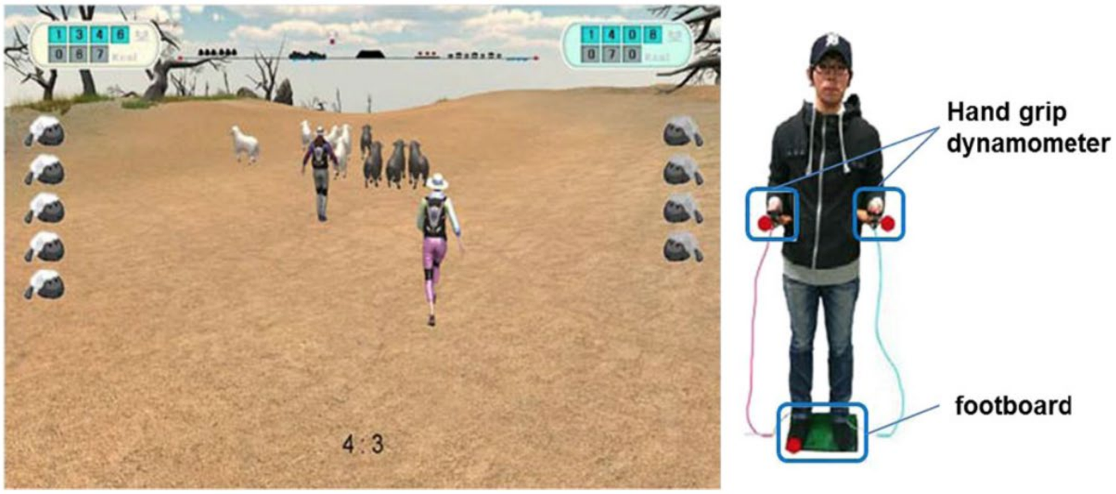


Figure 2-18 Tangible walking game [21]

In [66][67][68][69], 2D serious games are proposed to support those with neuropsychological dysfunctions. In [66], as shown in Figure 2-19, different IADL-themed scenarios, real-life daily routines, are created as therapeutic tasks beneficial to those with cerebral dysfunction. The flat design simplifies the appearance of the game objects which lowers the level of visual recognition required.

Figure 2-19 MyDailyRoutine's scenarios [66]

In [67], another 2D game, a touch-based whack-a-mole game, is proposed for assisting OTs in evaluating a patient's cognitive functions, focusing on hemi-spatial neglect, one of the perception abilities, through the use of a grey semi-transparent region as shown in Figure 2-20 over the playing area. After the training, a star rating as shown in Figure 2-21 for the patient is displayed according to the score and the OT is prompted to record notes.

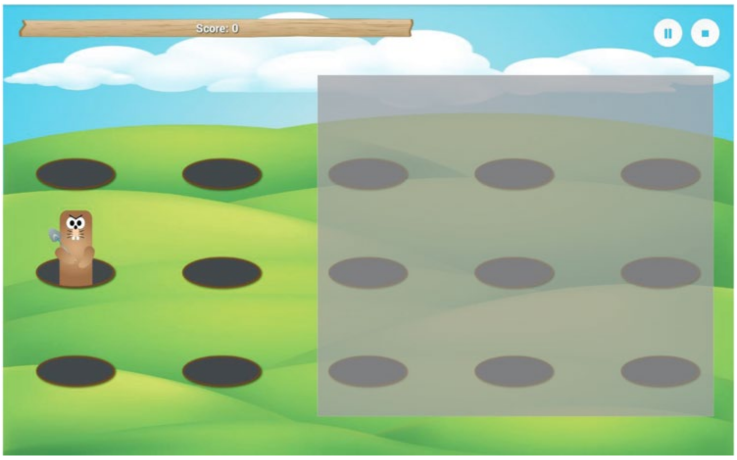


Figure 2-20 Whack-a-mole grey board [67]

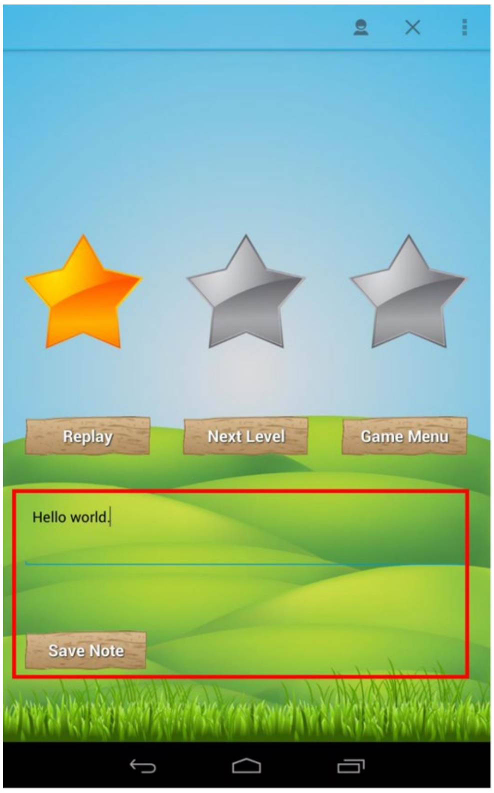


Figure 2-21 Whack-a-mole star rating and note [67]

Game of Gifts Purchase [68] is a shopping-based IADL game that uses characters with on-screen speech bubbles as shown in Figure 2-22 to explain the game scenarios to elderly MCI players. The gaudy user interface, however, may increase their cognitive load and cause them to lose interest in the game.

Figure 2-22 Game of gifts purchase's user interfaces [68]

Another study [69] attempts to improve prospective memory (PM) within the elderly by comparing traditional paper-and-pen tests with their digital versions in terms of the various elements provided by each. Digital training was found to beneficially provided realistic scenarios which contain distractors and model real-life situations, creating a sense of familiarity in users while undertaking the digital training. However, external cues in the environment, and the distractors which induce certain lifestyles and motivations, can affect performance in the PM tasks, while the level of attention in the task and its context can determine the efficacy of the PM training.

In the majority of the above approaches, 3DVEs tend to be favoured within the gaming scenarios to provide realistic adherence for cognitive impaired people. Compared with 2DVEs, the gaming specificities and project objectives in 3DVEs are relatively more suited to the target group. One study [70] has demonstrated that participants in 2DVEs and 3DVEs will carry different levels of cognitive load, with a 3DVE with sufficient visual cues offering advantages to participants with weak spatial ability. Cognitive rehabilitations that utilise a gameful approach may motivate MCI patients to attempt rehabilitation and the aforementioned examples mainly focus on cognitive functioning with light physical interaction for certain patients, one exception being the tangible walking game which combined both cognitive and physical tasks for those with neuropsychological issues. Thus, the extent to which physical tasks should be used to support the cognitive impaired person without creating excess cognitive load needs to be considered. Physical rehabilitation is considered further in Section 2.3.2. The interpreted data from the literature survey on gameful cognitive rehabilitation is summarised in Table 2-7 below in terms of themes for the proposed framework that are subsequently used to derive underlying elements, which will be presented in Section 2.4.

Table 2-7 Emergent themes for gameful cognitive rehabilitation

	Exemplifying Games													
Themes for *MCI-GaTE*	*MentalPlus®* [57]	*Episodix* [58]	PNH system [19]	NVR simulation [59]	ADHD/ADD serious game [62]	*Decoder* [65]	Whack-a-mole game [67]	Cooking game [60]	*VIRTRA-EL* [63]	Game of Gifts Purchase [68]	*MyDailyRoutine* [66]	PM serious game [69]	Allocentric & egocentric game [61]	Tangible walking game [21]
2D/3D environment	X			X	X		X	X	X		X		X	X
Avatar-based			X		X									X
Competence: skills, challenges			X											
Distractors	X					X						X		
Feedback		X	X	X		X			X				X	
HUD design		X	X	X		X			X				X	
IADLs				X				X	X	X	X			
Levels			X			X							X	
Main cognitive tasks	X	X	X	X	X	X	X	X	X					X
Memory tasks	X	X	X					X	X	X	X	X		X
Metaphorical graphics	X		X											

Narratives		X	X	X		X			X	X			X	
Personalisation			X			X								
Player’s perspectives	X			X	X		X	X	X		X		X	X
Player’s progress and rewards		X	X	X		X	X		X				X	
Pointsification		X	X	X		X	X		X				X	
Realism of graphical model				X	X			X	X				X	X
Reality orientation			X						X				X	
Relatedness: cooperation, social collaboration														X
Simplicity of game objects					X		X				X			
Tangible tools														X
Tutorial and guidance			X											

2.3.2 Gameful Physical Rehabilitation

Many physical rehabilitations explore the advantages of playing games and developing physical rehabilitation for the specific patient. Game-based physical rehabilitation so-called *exergames* have incorporated playful and gameful approaches in games for various physical rehabilitation contexts. Taking advantages of gamification, the training tasks are gamified with game design components to provide gameful experience for patients to anticipate and engage with the game. At the same time, playful design creates joyful and motivational digital experiences. In addition, gamefulness in physical games mostly employs gameful elements as motivators or distractors to facilitate engagement and attention of patients during the rehabilitation.

As reviewed in this section, there is a large body of studies utilize gameful elements to support physical rehabilitation (exergame) in various contexts, such as oral palsy and diabetes, to facilitate improved engagement and motivation in patients by motivating patients to interact with the real-time game objects and shift their attention away from the rehabilitation context. The gameful elements are designed according to the specific physical tasks the patients are required to fulfil.

According to Section 2.1.3.1, the degeneration of physical function and motor ability will affect the everyday performance of elderly with late-stage dementia. However, the overall daily activities of mild cognitive impaired (MCI) patients can be maintained as normal. Importantly, MCI is not characterized as dementia. Therefore, the following physical rehabilitation examples in this section are not differentiated for the MCI group.

In order to construct a gamified tool for particular group of people, *mHealth* [71] used a participatory design technique to identify various gameful design elements for a self-management and medical intervention app to help those with chronic physical illnesses. Its findings included an array of gameful elements and app design concepts as listed: (i)points, progress, and rewards, (ii)goals, challenges and competition, (iii)avatars and feedback, (iv)social features, (v)themes, stories and narratives and (vi)engaging visuals, sounds and texts, for improving the overall user experience.

Various studies [72]–[81] examine gamefulness and the selection of gaming technology based on the target users' individual limitations. For instance, *PhysioMate* [72] as shown in Figure 2-23 supports wheelchair users by using a *Microsoft Kinect* sensor to motion track their upper-limb movements, such as motor functionality, to facilitate synchronised interaction with the game objects, while [74] as in Figure 2-24 utilises VR-based gamified rehabilitation to help train upper limb movements through an avatar in the 3DVE. Both exergames require the patient in completing designated hand or arm movements and scores them accordingly.

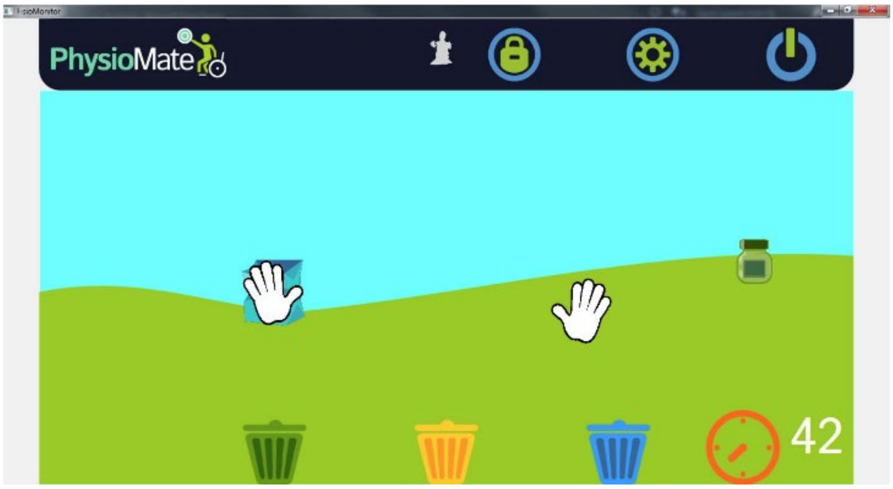


Figure 2-23 PhysioMate [72]

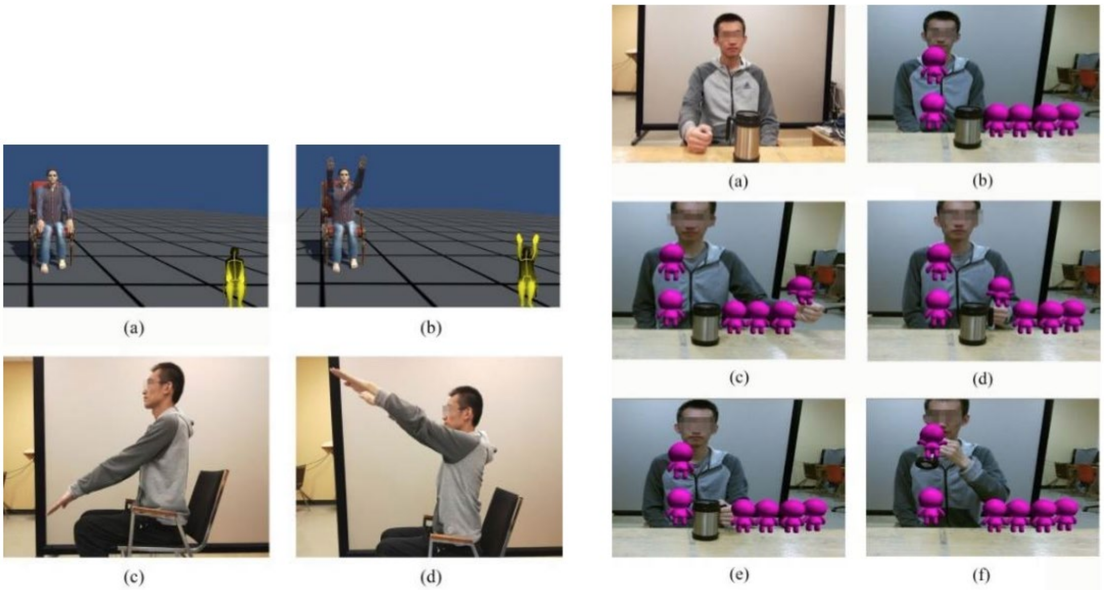


Figure 2-24 A VR-based user interface upper limb rehabilitation [74]

Similarly, another study [81] also takes a step towards exploiting the advantages of the natural user interface to develop a personalised game for patients with Parkinson's Disease (PD), which trains their fine motor skills naturally. It considers PD's physical capabilities, such as pinching, thumb opposition and grabbing hand movements, which are used to construct game scenes as shown in Figure 2-25 to Figure 2-27 respectively whose conventional gaming elements include scoring, graphical feedback and timer. It was evaluated according to immersion, flow, competence, positive affect, negative affect, tension and challenge, which serve as qualities leading to optimal motivation in players.

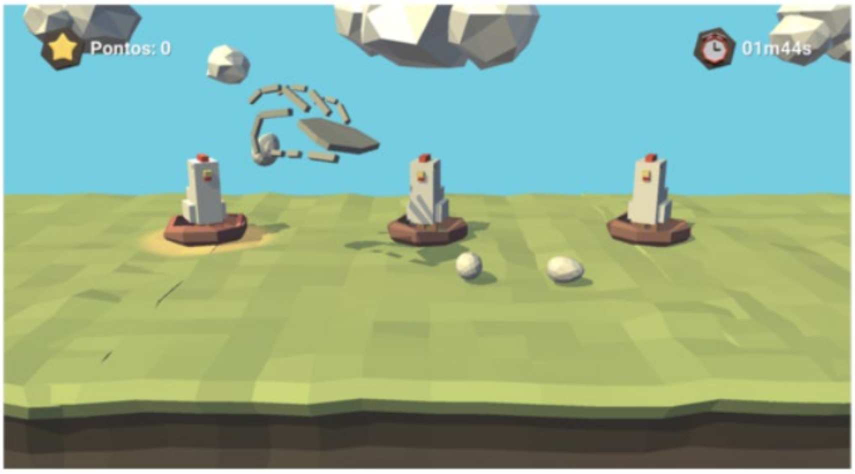


Figure 2-25 Game 1: Pinchicken [81]

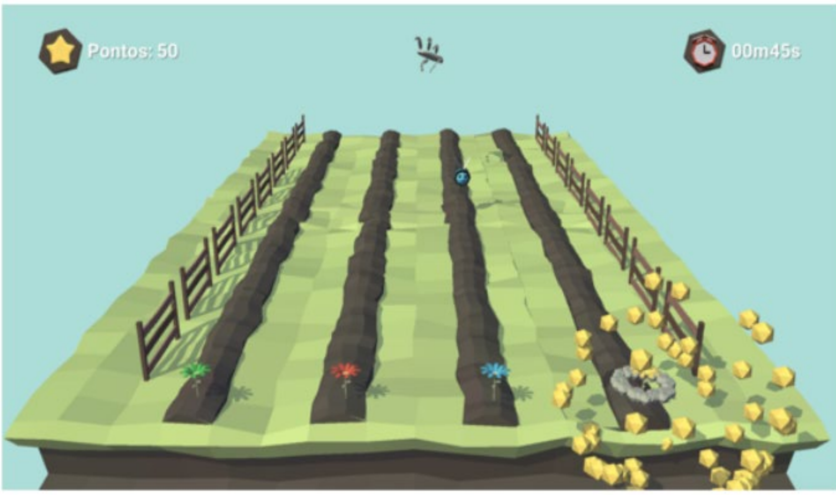


Figure 2-26 Game 2: Finger-Hero [81]

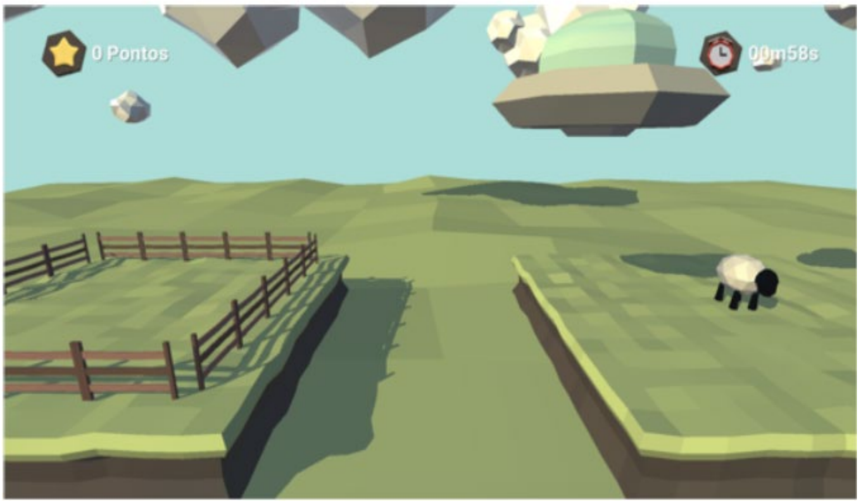


Figure 2-27 Game 3: Grabduzeedo [81]

The *Escape* game [73] for hand rehabilitation in Figure 2-28, and Fun-Knee [75] programs in Figure 2-29 take advantage of state-of-the-art interactive systems like *Leap Motion* and wearable sensors to expand the boundary of functionality for the patient to access the digital rehabilitation easily. Both exergames are highly supported by conventional gaming elements, such as scoring, timer and rewards, to motivate patients to engage with the game scene and complete the rehabilitation tasks.

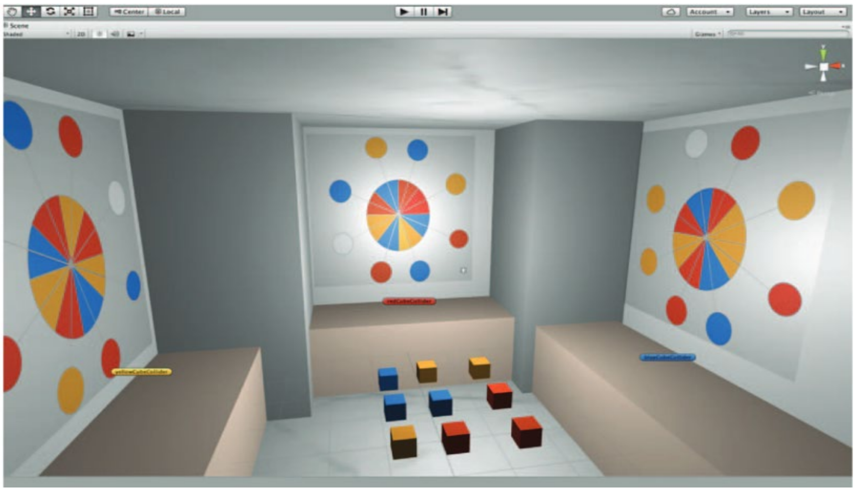


Figure 2-28 Escape game - hand rehabilitation [73]

Figure 2-29 Fun-Knee - Total Knee Replacement (TKR) post-surgical rehabilitation [75]

Gameful elements may increase the effect of rehabilitation through visual cues. They act as a communicator for patients to recognize and experience the flow of the game to achieve the rehabilitation tasks. To optimize the gaming experience in the psychological dimension, Csikszentmihalyi introduces "flow" as a state where the person behaves in conformity with the construct of flow, which is a zone between boredom and worry that sustains the motivation and enjoyment in an experience [82]. *Fun-Knee* is a successful example whereby the pain distraction element is incorporated as the distractor with the peak-end effect in order to reduce the pain and maintain the flow while patients are undergoing the Total Knee Replacement (TKR) rehabilitation process – a post-surgical knee therapy. This process utilizes two inclinometers to calculate the knee angle of the patients while they are performing the heel-slide movement, where the input data will be processed and displayed with gamified features. Pain is viewed as the foremost factor that affects the patient's cognitive function during the TKR rehabilitation process. Using gameful design elements, such as the number of fishes for keeping score and the fishes in the tank as a reward, the patient can be distracted from the pain while they are catching the fish, which enhances their motivation and engagement. The gameful design elements reward the patients for their correct responses. Moreover, the promise of reward and scoring features are key to arousing the patient's interest and increasing their motivation.

Several exergames [76]–[79] demonstrate that the combination of entertainment and therapeutic context can be highly beneficial to the quality of the rehabilitation process. These exergames offer gameful environments for specific physical issues in order to motivate patients. In [76], [77], [80], participants are required to perform tasks to improve their balance and postural skills for reducing the risk of falls, as well as the functioning skills of human limbs for strengthening the foot muscles. These rehabilitation games use sports games (soccer and Pong) as themes for patients to complete tasks by performing certain movements and interacting with virtual objects. They require a wide range of body movements and offer goals which can be adjusted to suit the participants' abilities. For example, in the *HitIt* – Fall Prevention serious game [76] as shown in Figure 2-30 is designed for the participants to move their head according to the soccer ball's position, while in the PONG game [77] as shown in Figure 2-31, ankle exercises for human lower limb rehabilitation are supported by blocking the ball from touching the scoring region. The *DoublePong* 3D platform game [80] as shown in Figure 2-32 enables patients to undergo rehabilitation with *AnkleBot*, a rehabilitation mechanism, for training the lower body and ankle with the requirements of using vertical and horizontal movements.

Figure 2-30 HitIt - Fall prevention serious games [76]

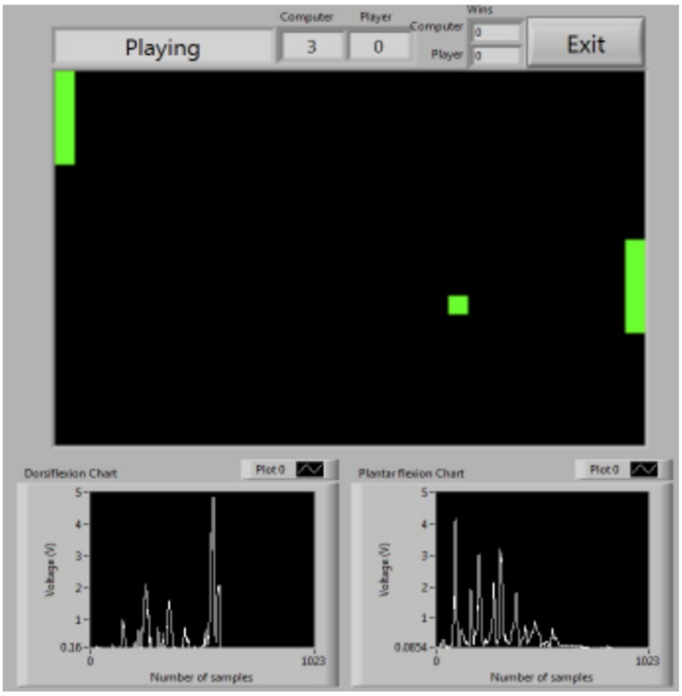


Figure 2-31 PONG game [77]

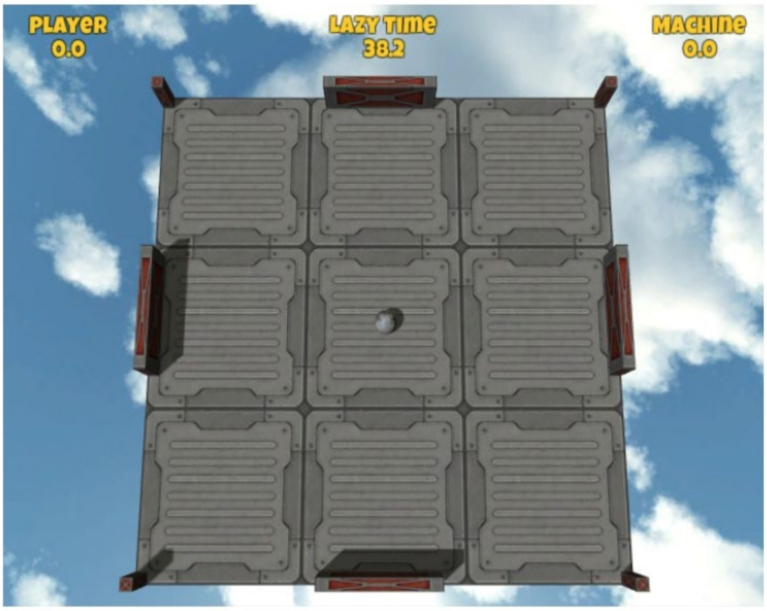
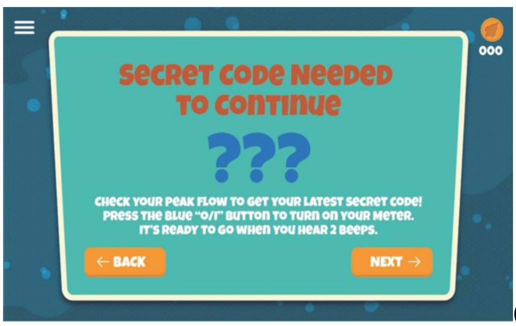


Figure 2-32 DoublePong [80]

The user interfaces are comparatively simpler, utilising target game objects to lead the player to control small parts of their body precisely to navigate virtual scenes. These games attempt to produce more subtasks with different gameful elements. For example, a Kinect-based oral rehabilitation system [78], as shown in Figure 2-33, helps the patient undergo a personalised oral rehabilitation by requiring the mouth and tongue movements to interact with specific real-time game objects, e.g. as virtual food is presented, the patient is asked to either bite or lick according to the type of food, so as to improve the score within a certain time frame.

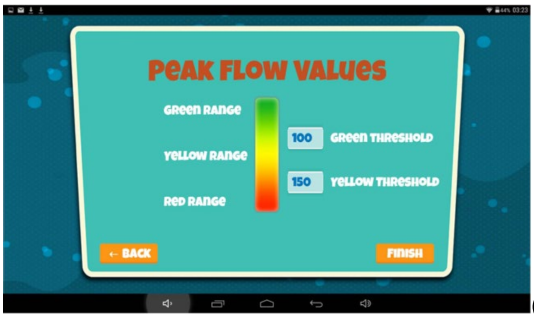
Figure 2-33 Oral rehabilitation game [78]

Additionally, game features can promote the entire rehabilitation package to the target patients while simultaneously accruing ecological benefits. In the case of the *ASPIRA* application [79], an embedded monitoring system checks indoor air quality to help asthmatic children, and the player is required to respond to prompts and alerts in order to achieve a healthy environment. The application adopts a "space" theme to help the player understand the procedure of the entire treatment process. Figure 2-34 demonstrates the UI of the system which improves and encourages the participant's intrinsic motivation in order to develop their self-management through gameful elements, e.g. the personalized avatar, alert function and accumulated prizes or achievement can help to maintain regular engagement.



(a)


(b)



(c)


(d)

Figure 2-34 ASPIRA game. (a)Alert for the required actions. (b)Identifying the cause of O2 alerts. (c)Provisioning process. (d)Morning questions [79]

These exergames implement motivators and distractors which help patients engage and focus on the serious game, and can also act as a tool to draw the attention of patients with cognitive impairment into memory training, which is crucial for completing MCI rehabilitation tasks.

Table 2-8 below presents the themes of gameful physical rehabilitation, which were obtained using the same process as in Section 2.3.1. All themes will also be further discussed when brainstorming for new ideas in Section 2.4.

Table 2-8 Emergent themes for gameful physical rehabilitation

	Exemplifying Games										
Themes for *MCI-GaTE*	*PhysioMate* [72]	*Escape* [73]	VR-based upper limb rehabilitation [74]	PD fine motor skills rehabilitation [81]	Fun-Knee™ [75]	*PONG* [77]	*DoublePong* [80]	*HitIt* [76]	*mHealth* [71]	Oral rehabilitation [78]	*ASPIRA* [79]
Achievements											X
Affection				X							
Avatar-based			X						X		X
Controllability	X	X	X		X					X	
Distractors					X	X	X	X		X	
Feedback	X	X		X	X				X		
Flow				X	X	X	X	X		X	
HUD design	X	X		X	X				X		
Immersion: player's experience				X	X	X	X	X		X	

Lower limb tasks					X	X	X	X			
Metaphorical graphics					X	X	X	X		X	
Narratives									X		
Other physical tasks									X	X	X
Personalisation	X	X	X	X	X					X	
Player’s progress and rewards	X	X		X	X				X		
Pointsification	X	X		X	X				X		
Real-time game objects					X	X	X	X		X	
Relatedness: cooperation, social collaboration									X		
Upper limb tasks	X	X	X	X							

2.3.3 Playful Experience for All Ages

The playful experience, namely playfulness, can improve a person's attitude towards an activity in psychological, physical and emotional ways [30]. The research in this thesis focuses on those with cognitive impairment who might lack self-motivation during rehabilitation. Thus, playfulness is explored as it may potentially enhance self-motivation in patients during rehabilitation (serious context) such as those with dementia, stroke or any physical or cognitive impairments. It is worth mentioning that this section focuses on exploring playful experiences specific to serious contexts, rather than all playful experiences since its purpose is to identify further potentially relevant themes for the framework.

Fast-changing modern technologies are one of the causes for the elderly being isolated from their social network and lowers their quality of social well-being. The inadequate accessibility to and lack of knowledge of information technology (IT) in the elderly [83] prompts researchers to explore the adaptive technologies and playful approaches to persuade the elderly to participate actively in social activities, which will help them to regain their confidence and motivation.

This project focuses on the group of people with mild cognitive impairment which can worsen into dementia, which is caused by Alzheimer's Disease (AD) [7]. One of the studies [84] indicates that people with dementia often have other related motivational and emotional disorders including depression, which affects the patients' behaviour toward different activities. The study provides a playful human-robot interactive (HRI) experience to patients to attempt to evoke motivational and positive feelings within them. The preliminary findings in the research reveals that playfulness can elicit a level of pleasure in a person's total well-being, but not in the group of people with motivational and emotional disorders. However, robotics technology is still in the development stage and there are many restrictions that prevent users from enjoying the playful experience to the fullest. In other words, the flexibility in playing is limited. Therefore, this section will explore the related studies [85]–[94] to give a general idea of how playfulness affects people's behaviour and psychology.

Play is a ubiquitous activity for all age groups [85]. The ambient play circumstances can persuade or seduce people to engage with the explorative, interactive and enjoyable experience involving the given playful elements [85], [86]. Recent studies [87]–[89] bring the inclusive playful experience to a wide range of people, such as those with cognitive, physical and developmental impairments who behave differently, so as to improve their social well-being and advance their enjoyment while playing. In [87], the behaviour and appearance of the robot *Iromec* is shown in Figure 2-35 as it provides play scenarios to children with various medical conditions, such as cognitive impairment and motor impairment, who may not be able to play normally. The play scenarios are supported by the user-centred design (UCD) approach, so as to conduct the ideation process to satisfy the user needs with auditory and visual elements and to predict their interactions with the design. Its freedom of utility of the product provides an adaptive personalised experience and facilitate their affection towards *Iromec*, which encompasses a variety of movements and actions to manipulate the robot. For example, an emotionless *Iromec* embedded with a task for children to take turns interacting with the robot and a mimic scenario to allow them to follow or discover the robot's movements caters for autistic children, while coordination and sensory stimulation caters for those with mental impairment, and physical interactions with the robot cater for those with motor impairments. Similarly, Modular Interactive Tile [88] allows people of all ages to freely enjoy the playful physical activities through moveable module tiles as shown in Figure 2-36 with a touchable surface and coloured lights as instant feedback which are the playful elements that the project intends to attract people with. The level of difficulty can be set by adjusting the number of tiles. Furthermore, the design of the Modular Interactive Tile can achieve the secondary goal of fall prevention [89], one of the common serious problems amongst the elderly.

Figure 2-35 Iromec, A robot companion [87]

Figure 2-36 Modular Interactive Tiles [88]

The player experience (PX) for the elderly in [90] as shown in Figure 2-37 applies skill balancing to playful elements, subject to manual and dynamic difficulty adjustment, facilitating intrinsic motivation, active behaviour and satisfaction. Manual adjustment was found to achieve a greater effect on the elderly than dynamic difficulty adjustment, and the elderly were motivated to challenge themselves through playing the game with playful elements that provided high flexibility of free movement with aid of Kinect in *Safari* Move, a zoo-themed game. Therefore, freedom of performance is important for eliciting active participation in players.

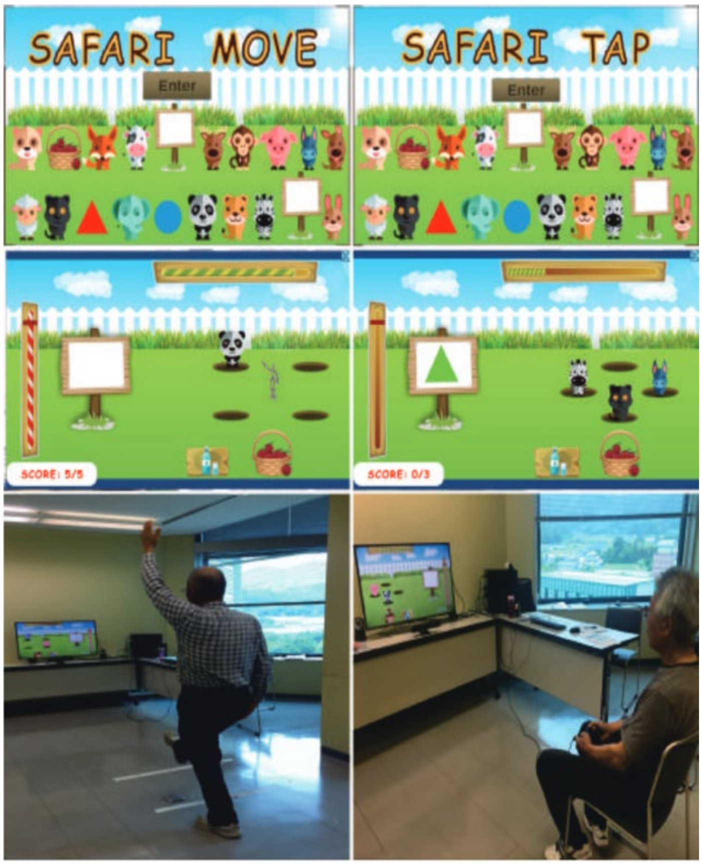


Figure 2-37 Skill balancing activity [90]

Multisensory Interactive Window in Figure 2-38 [92] is a tangible interactive installation for the elderly to enjoy the digital experience at home individually by looking through a virtual window. The system targets those who spend a lot of time at home and are unmotivated to do outdoor activities. Thus, it enables them to re-connect their social life with those who are far away, removing geographical limits.

Figure 2-38 Multisensory Interactive Window [92]

Aside from the above related work, recent research [93], [94] shows that playfulness can potentially enhance the learning experience. PlayCubes [93] in Figure 2-39 are dynamic objects for monitoring the constructional ability of children based on ActiveCuve (AC), a tangible user interface (TUI). It provides a playful virtual circumstance to children to mimic playing in the playground. Similarly, eShadow [94], as shown in Figure 2-40 uses the concept of the traditional puppet show to attract people to harness their personal expression and creativity. The digitial shadow theatre enables the player to participate and engage with the creative platform, so as to cultivate their social skills. It promotes active learning and provides an inclusive experience for children to enjoy.

Figure 2-39 PlayCubes [93]

Figure 2-40 eShadow [94]

In short, playfulness introduces inclusiveness, a sense of freedom and potentially collaborative experience to all age groups. The mixture of fun and play promotes an explorative, social and enjoyable experience to target players who actively interact. Importantly, playful interactions have great potential and influence to attract patients to participate in long-term physical and cognitive rehabilitation. By using playfulness as an attitude, active participation in cognitive rehabilitation is envisioned.

To summarise the playful elements from the above literature, a list of themes is once again compiled using the same method as in Sections 2.3.1 and 2.3.2 and summarised and defined each of the themes in Table 2-9 below. New potential elements will be further identified based on the listed themes and presented in the next section.

Table 2-9 Emergent themes for playful experience elements

	Exemplifying Games					
Themes for *MCI-GaTE*	*Iromec* [87]	Modular Interactive Tile [88]	PX for skill balancing [90]	Multisensory Interactive Window [92]	PlayCube [93]	eShadow [94]
2D/3D environment					X	
Affection	X	X	X			
Autonomy: freedom of choice	X	X	X	X	X	X
Behavioural flexibility	X	X	X			
Contextual awareness	X	X				
Controllability	X	X	X			
Discoverability	X					
Feedback	X	X				
Levels		X	X			
Lower limb tasks	X	X				

Narratives	X					X
Personalisation	X	X	X			
Relatedness: cooperation, social collaboration				X		
Self-presentation	X					X
Tangible tools	X	X		X	X	
Upper limb tasks	X	X				

2.4 The Initial *MCI-GaTE* with Literature Research Data

The literature data was first analysed thematically in the previous sections in order to congregate all the gameful and playful themes, which have been presented in Table 2-7, Table 2-8 and Table 2-9 in Section 2.3. This section presents an initial *MCI-GaTE*, as shown in Figure 2-41, developed based on the listed themes from the tables.

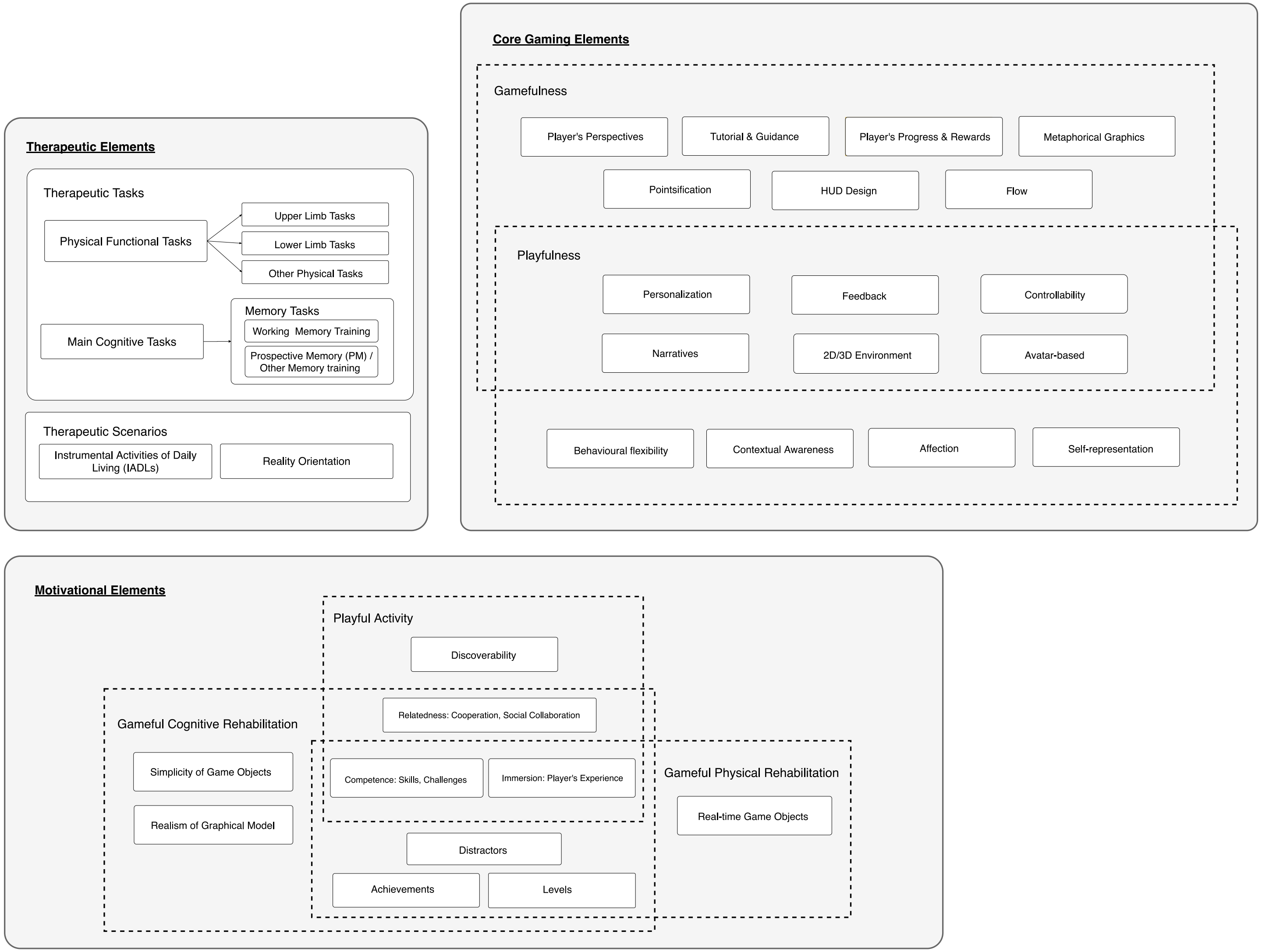


Figure 2-41 The initial *MCI-GaTE* with literature research data

The game framework considers three key aspects: (i)*Therapeutic Elements*, (ii)*Core Gaming Elements* and (iii)*Motivational Elements* which have been derived from the previously identified themes.

Therapeutic tasks and therapeutic scenarios are complementary in serious games and therefore are grouped together within the framework. Therapeutic tasks are provided to the player in accordance with therapeutic scenarios and both must be delivered within the game environment according to the MCI player's capabilities. In the MCI serious game, the therapeutic elements are selected as follows:

Numerous types of cognitive and physical rehabilitation were compiled from the related research literature as reported in Section 2.3 and were presented in Table 2-7 and Table 2-8. These are categorized as *physical functional tasks* and *main cognitive tasks* including working memory and prospective memory. *Upper limb tasks* are commonly employed for therapeutic use since the participants often utilize their upper limbs, i.e. both hands, to complete the specific tasks, such as *IADL-themed* tasks. All upper and lower limb tasks which were used in the literature were manageable for MCI patients. However, some therapeutic tasks utilized other parts of the body, i.e. *other physical tasks* (e.g. fall prevention and oral muscles tasks) which were not necessarily targeted at MCI patients. Additionally, working memory (WM) is the specific cognitive function used to identify the MCI group. In Section 2.1.3.1, it detailed the five cognitive domains and specific memory aspects along with the capability range for each domain that embodies the cognitive quality in therapeutic serious games for MCI patients.

The therapeutic scenario is created for the player to undertake the challenge of the tasks by mastering the orientation of the situation. For example, a supermarket simulation [63] presents a situation enabling a player to buy things using their perception. It allows the player to become aware of the context and therefore the scenario mostly provides visual cues to the player to integrate into their cognitive map. Many different scenarios can be used in a therapeutic way. In order to ensure that the therapeutic scenarios are tailored for MCI players, it incorporates those therapeutic scenarios within the framework which are commonly assigned to MCI patients, e.g. in nursing homes and other medical centres. This will be explored in Chapter 3, which presents data obtained from a residential nursing home, and Chapter 4, which presents the findings of interviews with OTs. The literature articles reviewed demonstrated that close-to-reality approaches, i.e. *IADLs* and

Reality Orientation, have a positive effect on those with cognitive impairment. To facilitate a serious game for MCI players, both approaches can be employed since they require more complex management skills which the MCI group is able to undertake. Thus, the scenarios can cover the actions for examining both MCI's mental and physical optimal capability level.

All core gaming elements within the framework were predominantly derived from the literature as per Table 2-7, Table 2-8 and Table 2-9, in terms of both gamefulness and playfulness. Within *gamefulness*, *player's perspectives*, *tutorial & guidance*, *player's progress & rewards*, and *metaphorical graphics* may be used to assist the MCI player in understanding their status within and the context of the serious game. These elements are responsible for generating the vision, steps, and personal progress of the player which conforms to their actions within the game. *Flow* is important for keeping the player motivated so that they can perform tasks with enjoyment, focus and understanding in order to be immersed in the game. Flow can also help to reinforce the concentration of MCI patients and cultivate long-term participation. *Pointsification* is used to facilitate extrinsic motivation, for example, through redeemable points or badges after the MCI player has completed a level in order to lead them to the next level. In order to ensure that such rewards appeal to the MCI player they should be closely related to their lifestyle, such as badges that relate to hypothetical roles they may adopt within a nursing home among their peers, e.g. "card game watchdog badge". *HUD design* serves to visualise and contextualise these gameful elements appropriately to the player in the form of appropriate visual cues that the MCI player is able to quickly understand in order to focus on the challenge.

Some elements exist as subsets of both gamefulness and playfulness. *Personalisation* enables the serious game to be adapted according to the MCI player profile. *Feedback* provides guiding information to the player which may serve to motivate, instruct, or similar. *Narratives* may be used to provide context to the therapeutic elements so as to further aid the player in relating to real-life situations or reminiscing. The *2D/3D environment* and *avatar-based* elements facilitate the construction of the game space and how the player exists within that game space.

The framework contains four elements that are expressly organised within *playfulness*: *behavioural flexibility*, *affection*, *contextual awareness* and *self-representation.* These elements are highly focused on stimulating the MCI player's preference for the activity. *Behavioural flexibility* enables control of the exploration of the gaming scenario, while *contextual awareness* may be used to help elicit greater understanding of the game space and possible player behaviour within it in conjunction with other game feedback. *Self-representation* is the form of performance in an activity in which the player's attitude is taken into account and can be utilised with elements of *affection* and the MCI player profile, so that the serious game can offer a competent and meaningful role for the player to engage with, which may be manifested through avatar-based playful scenarios that the MCI player would intrinsically be interested in.

Motivational elements within the framework are intended to enhance player attitude towards the serious tasks and to encourage the player to be more explorative. As well as general motivational elements, various *playful activity*, *gameful cognitive rehabilitation* and *gameful physical rehabilitation* elements were identified from the literature and presented in Table 2-7, Table 2-8 and Table 2-9.

Core to all motivated gameful and playful activity is the need to foster *competence: skills, challenges* and *immersion: player's experience* so that the player is psychologically immersed within the gameplay and sufficiently encouraged to proceed with skills and challenges that are 'just right' for them. The gameful cognitive rehabilitation motivators of *simplicity of game objects* and *realism of graphic model* enable the player to feel suitably engaged according to the requirements of the task and scenario and their own abilities. For physical rehabilitation, the use of *real-time game objects* is important so that the player's physical movements are synchronised with the behaviour of their character or avatar within the game world.

The use of *achievements* as motivation may be used in conjunction with other gaming elements, such as pointsification which would help to instantiate and visualise those achievements to the player. *Distractors* are key for ensuring that therapeutic tasks are suitably challenging. Together with levels may serve to help increase their complexity for the player, e.g. by hindering or preventing them from undertaking a task in a straightforward manner.

To sum up, gameful cognitive rehabilitation exploits technology to develop a therapeutic game, where it improves the tedious style of the traditional cognitive rehabilitation process. The core idea of using gamefulness in cognitive rehabilitation is to enhance the motivation and engagement in patients, which are crucial to improving the quality and experience of cognitive training. The notion of gamefulness in physical games employs gameful elements to act as motivators or distractors in order to improve the engagement and attention in patients during rehabilitation. The playful experience, namely playfulness, evokes a psychological, physical and emotional response in players towards an activity. This research focuses on the group of people with cognitive impairment who might lack the self-motivation to engage in rehabilitation actively. Promoting the secondary goal of playfulness can potentially increase their self-motivation.

Current medical research is lacking in digital means to provide an effective way to motivate the elderly to participate in rehabilitation as well as to acquire therapeutic purposes. The identified themes from the literature are to devise the initial *MCI-GaTE* for the elderly as illustrated in Figure 2-41, so as to optimize the advantages of the serious game in gamefulness and playfulness.

2.5 Conclusion

This chapter has presented the initial *MCI-GaTE* as shown in Figure 2-41. In Sections 2.1.2 and 2.1.3, it has given the overview and background information of MCI, in terms of five core cognitive functions, the clinical assessment for the test MCI group and some existing examples of computerized cognitive training including the relevant serious games. Overall, these examples do not extensively use playful and gameful experiences in the serious contexts and the advantages of gamefulness and playfulness can be further optimized. The thematic approach has been fully explained in Section 2.2. In Section 2.3, the gamefulness and playfulness approaches which have been used for a wide-ranging set of serious contexts were presented. The digital application attempted to promote active participation, motivation and engagement to specific patients through attractive and functional materials. In order to achieve active participation for those with MCI, a list of themes was summarized in tables and these themes were used for constructing the initial *MCI-GaTE* in Section 2.4. In the next chapter, the data from GNH will be presented primarily to select the materials for the *MCI Player Profile*.

3 Chapter Three – Data Analysis of Resident Profiles from GNH and Initial *MCI-GaTE*

This chapter presents the data collected from a nursing home in Hong Kong, Grace Nursing Home (GNH), for further constructing the initial serious game framework. The outline of the chapter is as follows: Section 3.1 introduces the aim of this chapter; Section 3.2 explains the data analysis of the themes selected for *MCI-GaTE* ; Section 3.3 details the entire process of obtaining the pertinent data from GNH; Section 3.4 identifies the target group and relevant documents for the research domain; Section 3.5 explains how the diagnostic documents can be used for inferring MCI patients' physical capabilities and neuropsychological qualities; Section 3.6 carries out the GNH data analysis for evaluating the underlying themes; Section 3.7 presents the identified themes, and how they have been integrated into the serious game framework and Section 3.8 sums up this chapter with findings.

3.1 Introduction

Prior to visiting the nursing home, ethical approval was obtained in accordance with the ethical process at Brunel University London, which is committed in the UK Concordat on Research Integrity. To provide a detailed understanding of the profile and background of elderly patients with MCI, and also uncover and refine further themes and elements for the framework from therapeutic settings, this chapter analyses resident patient records that were documented first-hand by specialists and OTs in a nursing home in Hong Kong, GRACE Healthcare Ltd. In this way, the capabilities and needs of the MCI group in the serious game environment can be determined. In collecting and analysing the data, it aimed to: (i) construct an MCI player profile within the framework comprising background information, cognitive and physical capabilities in order to support adaptation of the therapeutic serious game; (ii) identify therapeutic elements and approaches in support of MCI players; and (iii) compare across sources to identify consistent themes for the serious game framework.

3.2 Analytical Method of GNH Data

The purpose of this quantitative data is to provide a typical MCI patient (resident) basis for selecting the themes or materials of the game framework, which will be used in constructing the serious game in therapeutic settings objectively. This section focuses on gaining an insight into the target group's profile and background information. Moreover, it will examine and infer the capabilities and needs of the MCI group in the serious game environment based on the GNH data. The data collected were to seek inputs from GNH regarding use and experiences of conventional clinical setup. The resident profiles revealed the key assessments, in terms of player physical and cognitive capabilities, that incorporated the codes needed for generating the themes of *MCI player profile* and *therapeutic elements*. The In Vivo coding method [55] was widely used here, to ensure that the data were coded in accordance with, and rooted to, the clinical terminology, resulting in an hierarchy with categories *player background*, *player physical* and cognitive *capabilities* in *MCI player profile*, and *therapeutic scenarios* in *therapeutic elements.* The categories were then subdivided into further categories, such as *upper limbs* and *lower limbs*, in order to better structure and organize the MCI player profile. The selection of codes and categories are analysed and discussed in Section 3.7 to extend the initial *MCI-GaTE*.

3.3 Data Collection Procedure

The data collection was carried out in GRACE Healthcare Ltd. Hong Kong. The proposal of the research project together with the ethics approval was presented to the nursing home prior to visiting. Two branches of the nursing home were contacted through email and telephone to schedule a visit for data collection. The visits were held on two separate days at different locations. Throughout the data collection process, two senior OTs were assigned to introduce the nursing home settings and demonstrate the intervention routines for elderly. A variety of documents related to nursing home residents who are diagnosed with dementia was gathered by the OTs. The data set is collected first-hand and recorded by the specialists and occupational therapists in the nursing home. All participants' names have been removed for the sake of their privacy. The data set comprises of the diagnosis, duration of stay, results of various qualitative assessments which the participants had attempted. The data includes the participant records which have been collected and documented in original form. It includes several qualitative measurements and assessments that had been done by the participants in the presence of specialists or occupational therapists. Each data set has also listed out the basic background, i.e. educational background and social characteristics, of each participant. This collected data has been analysed and summarized in detailed assessment forms and individual care forms by the occupational therapists in the nursing home. The details of the data set are described in Section 3.6.

3.4 Subjects

The information was provided from two main documents: the assessment form (*n*=26) and the individual care plan (*n*=31).

The demographic information of the residents derived from the assessment forms is summarized in Table 3-1. It contains a total of 26 residents with dementia in the 72-100 age range though the average age was 85.65 (*SD*=6.32) years. All participants were residents in the nursing home and able to complete a set of relevant assessments. The participants were predominantly women (18 cases) while the men comprised of 8 cases. Sex cannot reflect the phenomenon attributing to dementia, which is further revealed in Section 3.6.2 (Figure 3-2). In the data set, all participants were diagnosed and categorized into three stages of dementia: mild (*n*=12), moderate (*n*=13) and severe (*n*=1). In terms of education, which reflects the understanding and learning capability of the residents, over 88% of them had no formal education, and the remaining 11.53% had primary school level as the highest education level. The consciousness level shows the long-term status of the residents, which may affect their engagement during the activity. 88.46% of them were at alert status, and 11.53% were at sleepy status. None of the residents were considered in the coma or drowsy statuses. The majority of residents' tolerance levels, which reflects their ability to undergo a sufficient duration of training, were classified as "need rest during activities" (*n*=18), and the remaining were either "easily tired, expended on minimal exertion" (*n*=4) or normal (*n*=4). One of the residents was unable to concentrate, seven others were attentive, and the remaining eighteen were easily distracted. It is worth mentioning that there was no other category for other demographic features provided, such as religion, ethnicity or blood type. Full access to such sensitive information was not required or granted.

An individual care plan is a supplementary document entailing the rehabilitative implementation and underlying factors affecting the resident's conditions in accordance with their assessment form results. It comprises an OT's full version of qualitative data analysis for each of the residents.

Table 3-1 Demographic data for residents according to assessment form (*n*=26)

Assessment Form (n=26)	*n*	%	*M*	*SD*
Sex				
Male	8	30.77		
Female	18	69.23		
Age (years)			85.65	6.31786235
Education				
No formal education	23	88.46		
Primary school	3	11.53		
Secondary school	0	0		
Post-secondary degree	0	0		
Dementia				
Mild	12	46.15		
Moderate	13	50		
Severe	1	3.85		
Consciousness				
Sleepy	3	11.53		
Alert	23	88.46		
Drowsy	0	0		
Coma	0	0		
Tolerance				
Need rest during activities	18	69.23		
Easily tired, expended on minimal exertion	4	15.38		
Normal	4	15.38		
Attention				
Unable to concentrate	1	3.85		
Easily distracted	18	69.23		
Attentive	7	26.92		

Note: *n* = number of residents; *%* = percentage of the count; *M*= mean; *SD* = standard deviation

3.5 Diagnosis

The samples of the collected data are from those with dementia. The diagnosis of dementia (i.e. Alzheimer's Disease) is made with the evidence of memory impairment and one cognitive domain deficit, which will affect daily life activity (in Section 2.1.3). In this case, those with mild dementia and memory impairment serve as the core MCI subjects, with the moderate and severe residents serving to indicate and infer further participant capabilities and treatment for MCI.

3.6 Preliminary Data Analysis

Across all the GNH sources, five themes from the data which will be used to develop those aspects of the serious game framework: (i) background information, (ii) cognitive capabilities, (iii) physical capabilities (upper limbs and lower limbs), (iv) therapeutic tasks and (v) therapeutic scenarios.

3.6.1 Participation

Generally, the assessment form includes the resident's major cognitive and physical issues whilst individual care plan is a supplementary document as mentioned earlier to detail the influencing factor and implementation for the patients. There is an inequality in the number of participants between (a)assessment form (n=26) as shown in Figure 3-1 and (b)individual care plan (n=31), as not all patients had a completed assessment form due to their inability to comply with all the required standards at the time. However, the individual care plan records all the background information as well as personalised tasks that the residents have undergone.

GRACE Nursing Home 頌恩護理院 (德田 Tak Tin)

職業治療評估表
Occupational Therapy Assessment Form
(Initial / Yearly)

Name 姓名 :	Sex 性別:	D.O.B. 出生日期:	File No. 檔案編號 :

Past Medical History 病歷記錄:

Social History 社交背景:

Educational Level 教育程度:

( ) No formal education失學 ( ) Primary小學 ( ) Secondary中學 ( ) Post-secondary大學

Conscious Level 清醒程度:

( ) Alert清醒 ( ) Sleepy渴睡 ( ) Drowsy昏睡 ( ) Coma昏迷

Attention 專注度:

( ) Attentive專注 ( ) Easily distracted分心 ( ) Unable to concentrate難以集中

Remarks 備註:

Hearing 聽力:

Hearing aid 助聽器: ( ) Yes ( ) No

( ) No difficulties沒難度 ( ) Minimal difficulties少許難度 ( ) Very difficult很困難

Vision 視力:

Glasses 眼鏡: ( ) Yes ( ) No

( ) Distant Objects遠 ( ) Nearby Objects近 ( ) Fine detail仔細 ( ) Blind失明

Physical Assessment 身體評估:

Sitting Balance 坐姿平衡:

Static 靜: ( )Good ( )Fair ( )Poor Dynamic 動: ( )Good ( )Fair ( )Poor

Standing Balance 站立平衡:

Static 靜: ( )Good ( )Fair ( )Poor Dynamic 動: ( )Good ( )Fair ( )Poor

Tolerance 能耐:

( ) Normal 正常
( ) Need rest during activities 要休息
( ) Easily tired / expended on minimal exertion 易倦

Hand function 手部功能:

( ) Fist 拳 ( ) Opposition 對指尖 ( ) Pinching夾 ( ) Grasp & release抓放 ( ) Co-ordination 協調

Functional tasks 活動:

( ) wringing towel 擰毛巾 ( ) Chopsticks 筷子 ( ) Buttoning 扣鈕 ( ) Tie Knots 綁帶

Major Problems 主要問題:

Treatment 治療方法:

Occupational Therapist 職業治療師: ______________________

Date of Assessment 評估日期 :______________________

Figure 3-1 An example of the assessment form

(a) Assessment Form (*n*=26)

The assessment forms indicated the general information for 26 of the 31 sampled residents, including their major cognitive and physical problems. The occupational therapist listed the percentage of patients who suffered from the various types of major problems. 26.9% of patients suffered from the five main cognitive problems: (i)attention, (ii)working memory, (iii)use of language, (iv)visuospatial skills and (v)executive functions, with 11.5% of them suffering from memory impairment. In addition, 92.3% of the patients suffered from physical problems. 53.8% of those with cognitive problems participated in cognitive training, whilst 7.7% of those with memory impairment took part in memory training. 26.9% of those with physical problems took part in physical training.

Regarding *background information*, residents predominantly had no formal education, and only three cases with moderate stage dementia had completed primary school. None of the cases had secondary school or post-secondary degree (Figure 3-3). 23 cases were assessed as alert when conscious, while three cases were sleepy. No cases were drowsy or in a coma (Figure 3-4). 69.2% of all cases had mediocre tolerance levels and needed to rest during activities (Figure 3-5). Almost all were either attentive or easily distracted, with only one resident unable to concentrate (Figure 3-6).

In respect of *physical capabilities*, three physical assessments were involved: hand functions, functional tasks and balancing. Hand functions and functional tasks required the residents to complete five tasks each using their upper limbs (Figure 3-7). 96.2% of those participating managed to complete four hand functions: fist, opposition, pinching and grasp and release, but only 69.2% could complete the co-ordination hand function. However, all mild cases were able to complete the four hand functions. Balance was assessed using sitting and standing tasks for examining the lower limbs (Figure 3-8 to Figure 3-10). As shown in Figure 3-8, while sitting, with good condition, 53.8% possessed static balance and 46.20% dynamic balance, whereas while standing, with good condition, only 11.5% and 7.70% possessed static and dynamic balance respectively. As can be seen, the cases in Figure 3-10 are inversely proportional to the cases in Figure 3-8.

(b) Individual Care Plan (*n*=31)

The Individual care plan is the detailed version of the assessment form. All 31 residents were fully recorded by their OT in terms of their cognitive and physical abilities, influencing factors, goals, and rehabilitation implementation. The main physical problems across all plans were recorded as: physical abilities/self-care, reduction of mobility, weak autonomous control ability, stiffness and contracture of limbs, and decreased amplitude of limb control ability. In terms of major cognitive problems, the cognitive abilities of most (26) residents were recorded as having deteriorated further due to ageing and extended hospitalisation, while 3 cases were due to being long-term bed ridden and a lack of social stimulation. Further to these, social and behaviour problems are influencing factors that should be considered when setting the goals for rehabilitation implementation. Common problems noted included restlessness, easily feeling annoyed, and being quiet or passive. Such problems may lead to a negative emotional state during activities. In order to improve the aforementioned physical and cognitive problems, six main rehabilitation implementations were recorded within the plans: rehabilitation exercises, cognitive training group, activities of daily living (ADLs), instrumental activities of daily living (ADLs), reminiscence activity, and reality orientation (RO).

3.6.2 Data Results

In this section, based on the data in Section 3.6.1, various topics are identified which relate to each of the five themes as follows: (i)background information, (ii)cognitive capabilities, (iii)physical capabilities (upper limbs and lower limbs), (iv)therapeutic tasks and (v)therapeutic scenarios. Each of these is used to construct a part of the serious game framework. Table 3-2 presents a list of definitions of themes that have been identified from the nursing home data, which will be discussed in section.

Table 3-2 Definitions of identified themes from the nursing home data for the initial *MCI-GaTE*

Themes for *MCI-GaTE*	Definition
ADLs	Activities of Daily Living - fundamental skills that are required to independently care for oneself such as eating, bathing, and mobility
Attention	Ability to focus on certain stimuli
Consciousness	A long-term status of the player that is closely related to engagement during an activity

Co-ordination	Cooperation of certain physical and/or cognitive capabilities to complete a task
Education	Player's educational background
Elbows: Pulling	Involving flexion and extension movements of the elbow that enable objects in front to be raised to a particular point
Executive functions	The capacity for people to perform actions in daily life independently
Fist	Wrapping the thumb across the other four fingers
Grasp and release	Involving hand grasp with a moderate power grip and wrist extension so that the fine motor muscles can be used to perform some functional tasks
Opposition	Using the thumb to touch the fingertips
Pinching	Exerting strength between the index finger and thumb, which requires control of the smaller or fine motor muscles of the hands
Reminiscence	Recalling the past
Shoulders: translating	Moving/shifting the whole upper limbs to perform activities
Sitting balancing	Ability to maintain a stable posture when seated
Standing balancing	Ability to maintain a stable straight posture supported by the legs
Tolerance	The patient's ability to undergo a sufficient duration of training
Use of language	Ability to verbally communicate normally and fully articulate oneself
Visuospatial skills	These skills refer to the patient's capability of understanding two-dimensional (2D) and three-dimensional (3D) environments, while visual construction skills relate to the ability of assembling shattered objects.
Working memory	The most used cognitive function that allows for the temporary storage of information
Working memory impairment	A deterioration in the ability to remember short-term information
Wrists: pressing/tapping/twisting	Involving flexion and extension movements of the wrist that enable objects in front to be raised to a particular point

Firstly, by integrating the aspects of education, tolerance, attention and consciousness which are extracted from the player background information in the assessment form, the type of player will be identified in accordance with these criteria as described in Figure 3-2 to Figure 3-6. When the background information is used to design the therapy, it is likely to produce an adaptive framework.

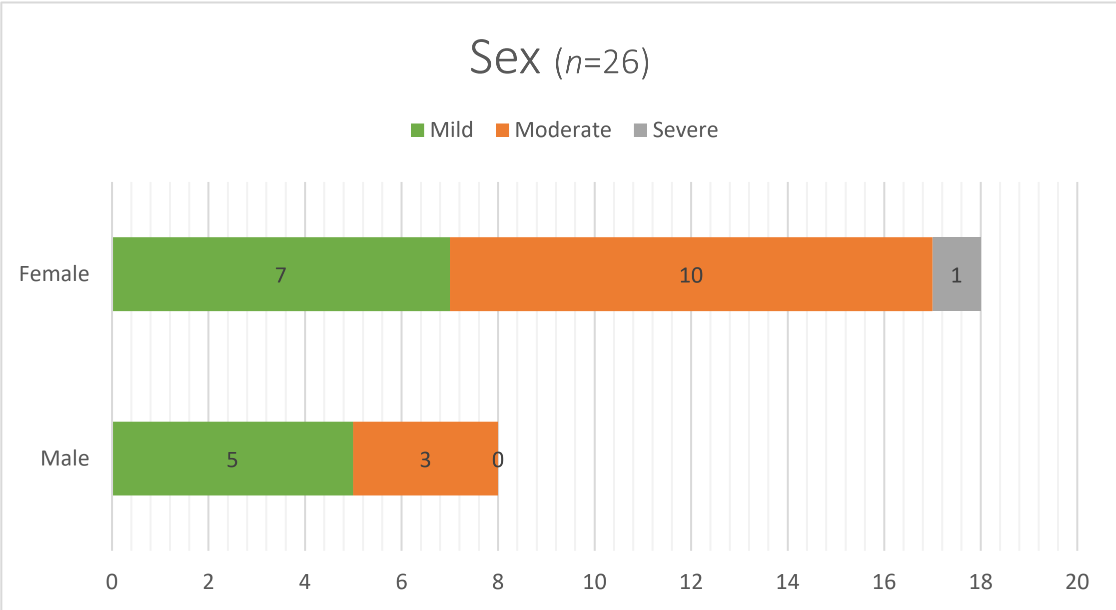


Figure 3-2 Sex

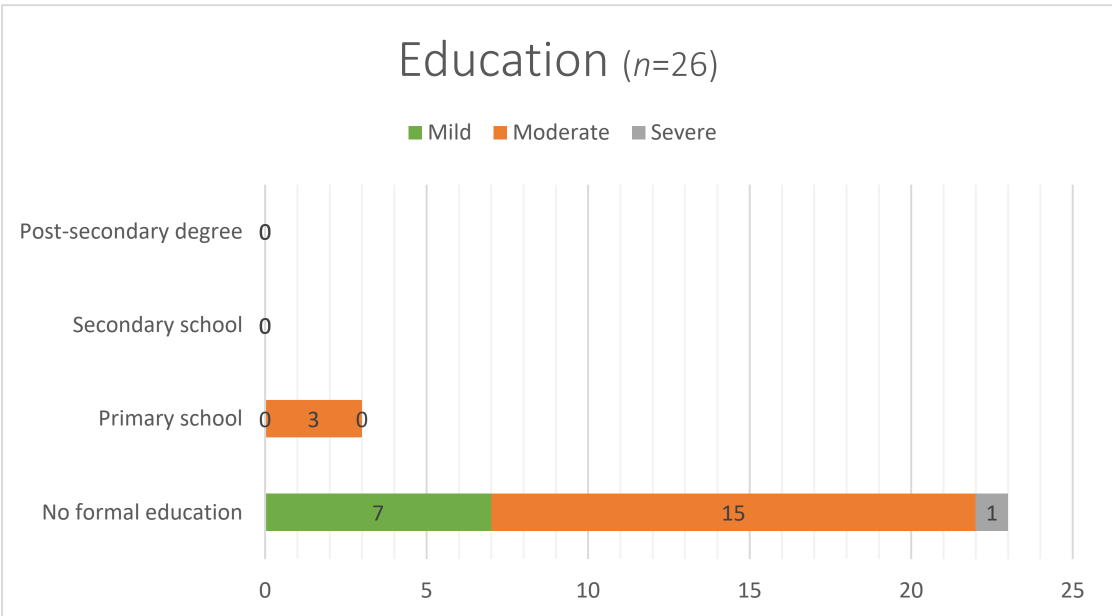


Figure 3-3 Education level

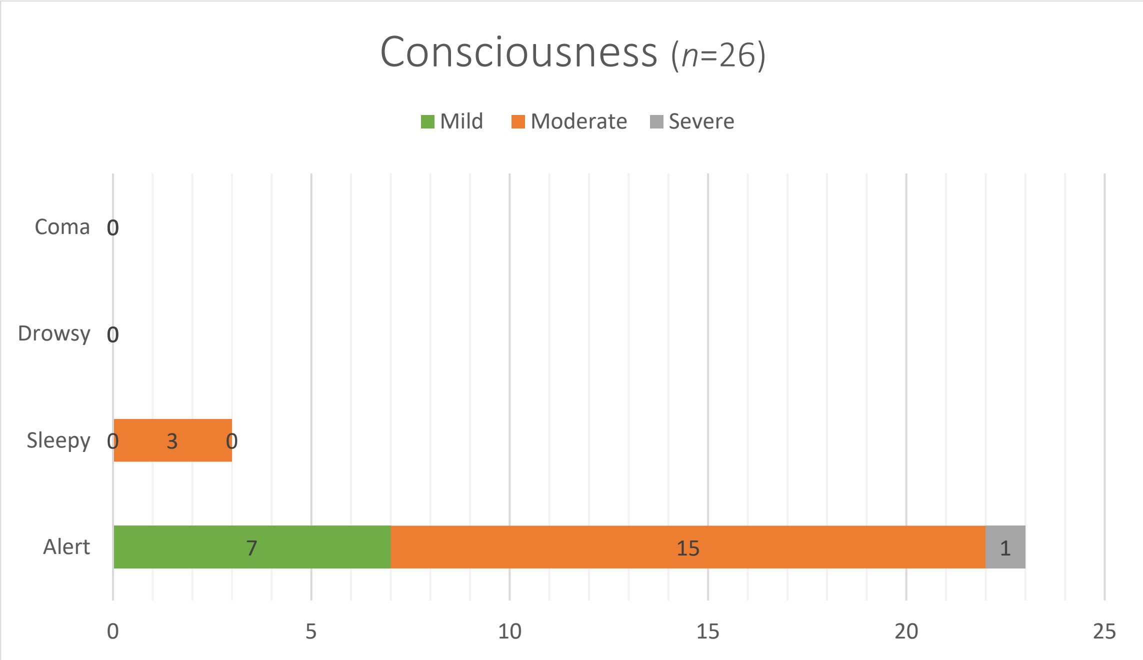


Figure 3-4 Consciousness level

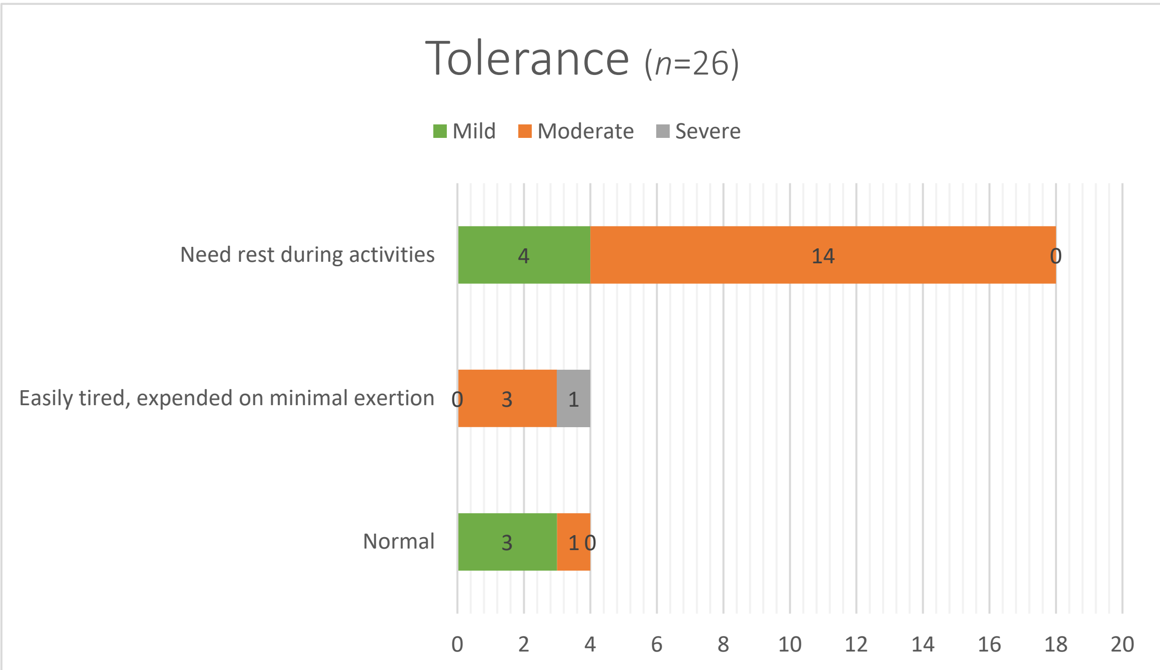


Figure 3-5 Tolerance level

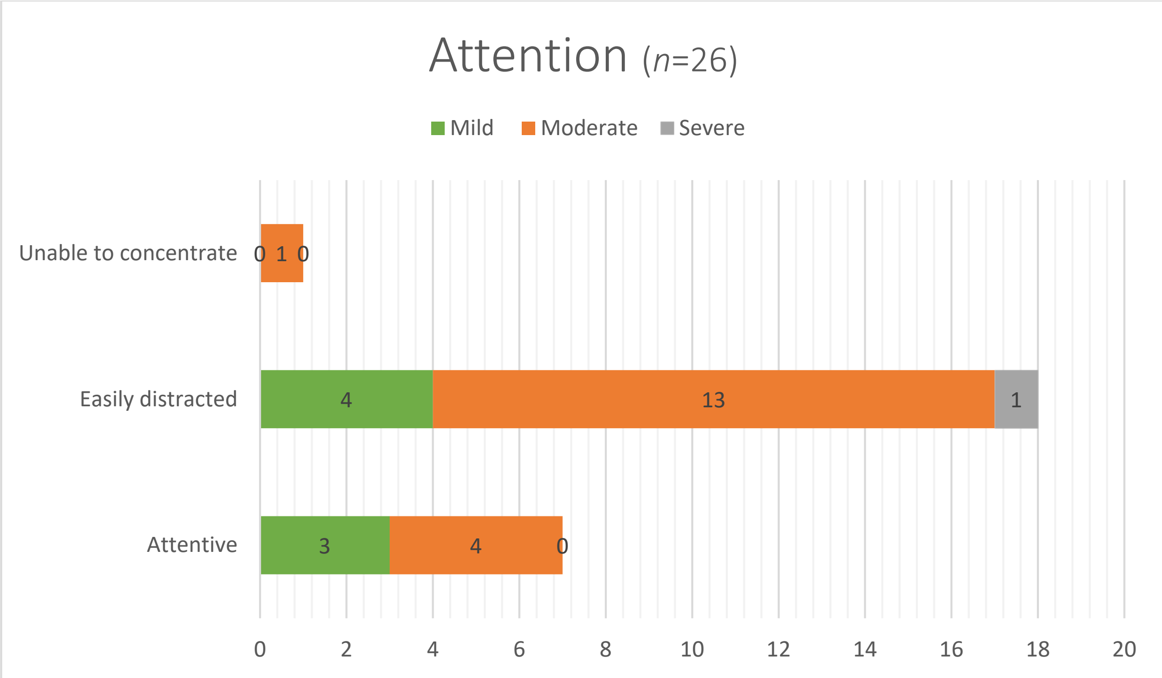


Figure 3-6 Attention level

Secondly, the five main cognitive capabilities including attention, working memory, use of language, visuospatial skills and executive functions are grouped together as the core cognitive capabilities in MCI player profile. In addition to this, a few cases (*n*=7) in the assessment form (*n*=26) had been diagnosed as cognitive impairment, and out of these 7 cases, 42.90% (*n*=3) were diagnosed with memory impairment. This research aims to design a cognitive serious game for MCI players with respect to memory ability, therefore, the therapeutic tasks will be introduced by using the player cognitive capabilities as the basis. Similarly, physical capabilities consist of upper limbs and lower limbs and are summed up in Figure 3-7 to Figure 3-10.

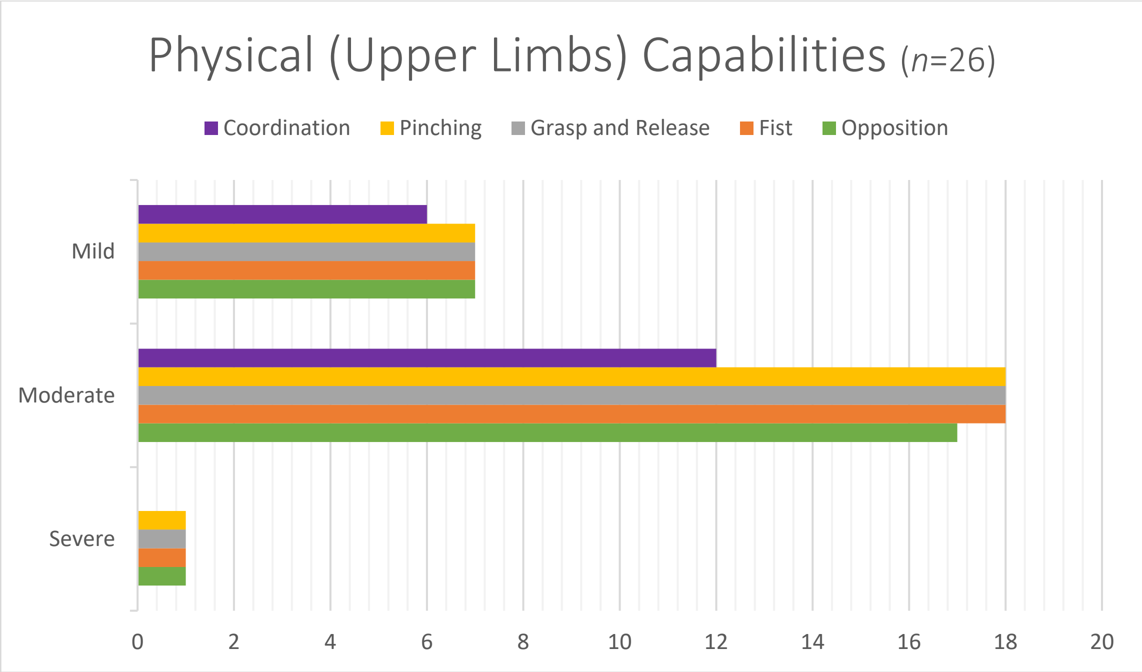


Figure 3-7 The residents' upper limb physical capability assessment

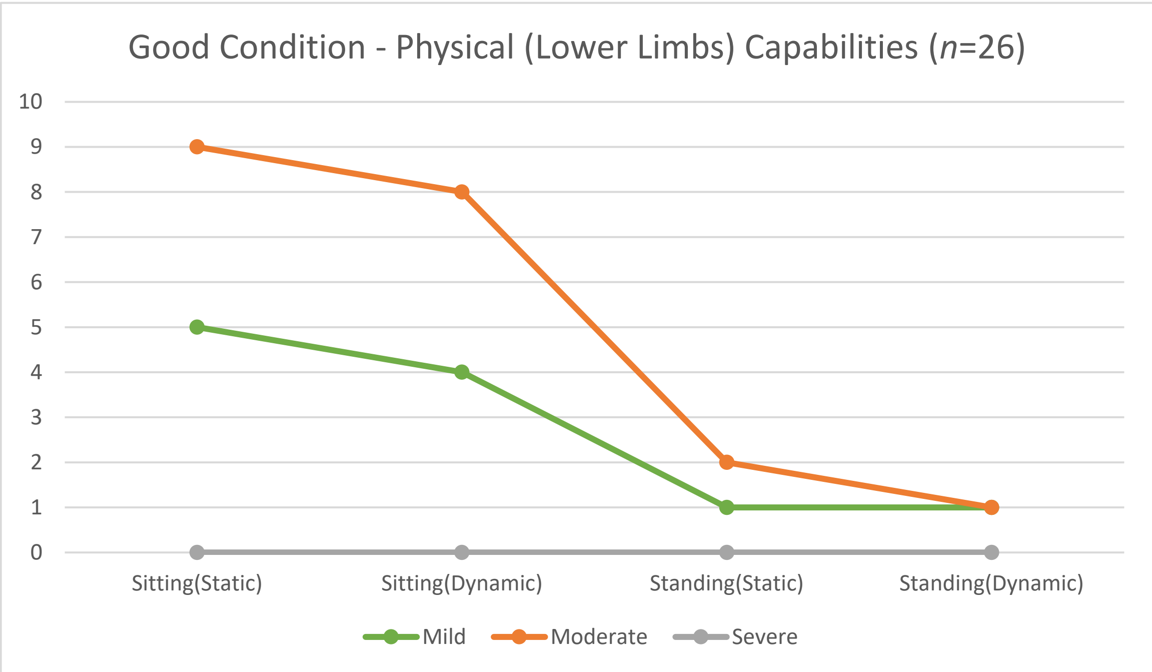


Figure 3-8 Physical capability assessment of residents with good lower limb condition

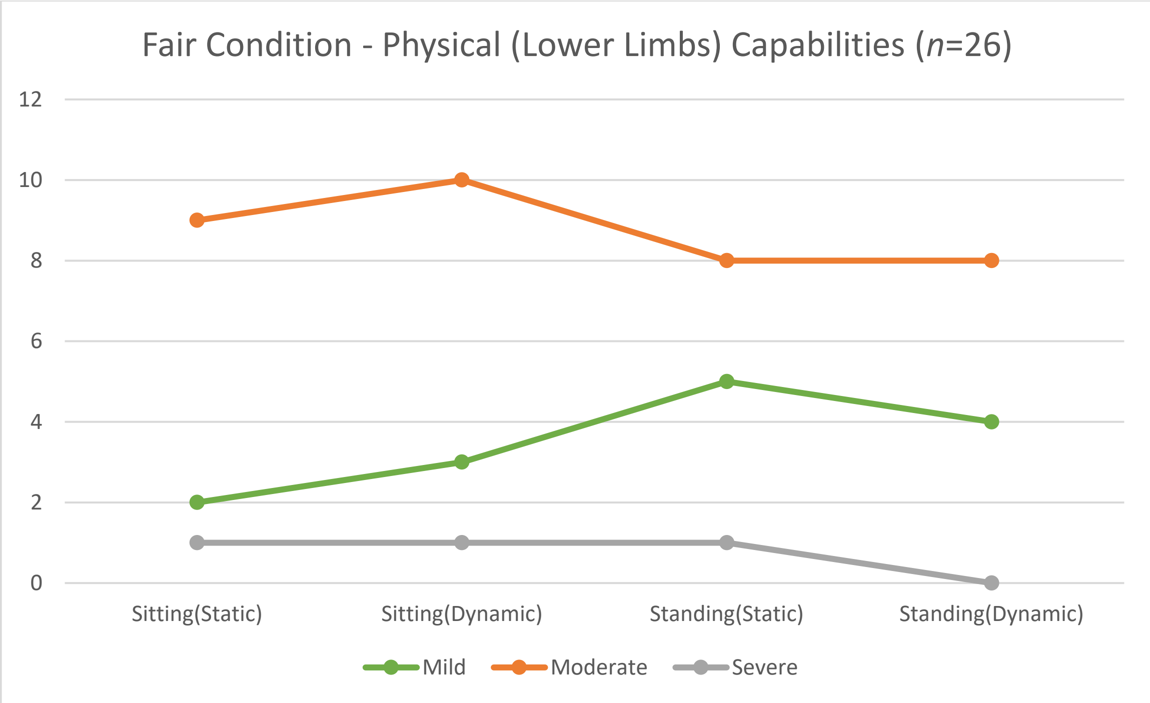


Figure 3-9 Physical capability assessment of residents with fair lower limb condition

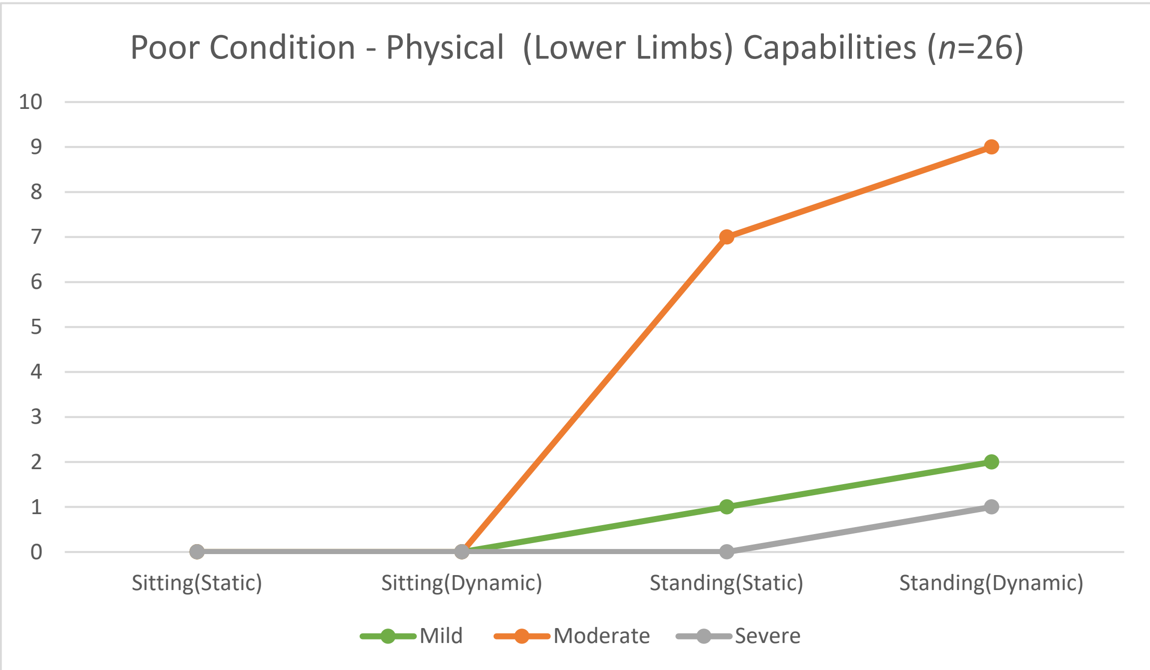


Figure 3-10 Physical capability assessment of residents with poor lower limb condition

The results of physical capability assessment (lower limbs) of residents as illustrated in Figure 3-8 to Figure 3-10 are ranked as good, fair and poor conditions. Their postures are measured and examined three to five times by the OTs. In the assessment form, full completion of posture is considered good condition, partially or potentially completed posture is considered fair condition, while an inability to maintain posture is considered poor condition. Six rehabilitation implementations were recorded within the individual care plan: rehabilitation exercises, cognitive training group, activities of daily living (ADLs), instrumental activities of daily living (ADLs), reminiscence activity, and reality orientation (RO). The latter four *therapeutic scenarios* present therapeutic tasks in various situations or settings, which would require the player to relate the assigned tasks to their daily lives, whereas the first two are general and non-targeted such as ad hoc hand functions or general training with other residents. These cognitive and physical capabilities will have to be taken into consideration when setting the therapeutic tasks.

In the following section, a detailed analysis of the themes that have been chosen for constructing the game framework will be provided.

3.7 The Initial Serious Game Framework with GNH Data

The GNH data presented in Sections 3.4 to 3.6 explain and analyse the nature of the data used for constructing the following initial *MCI-GaTE*. Two types of shaded boxes in Figure 3-11 represent the themes that are generated from the GNH data results, which are added on to complement the previous initial *MCI-GaTE*. The green boxes represent existing elements where the GNH data further validates the elements and the orange boxes represent a new set of themes for contributing additional data to the initial *MCI-GaTE*.

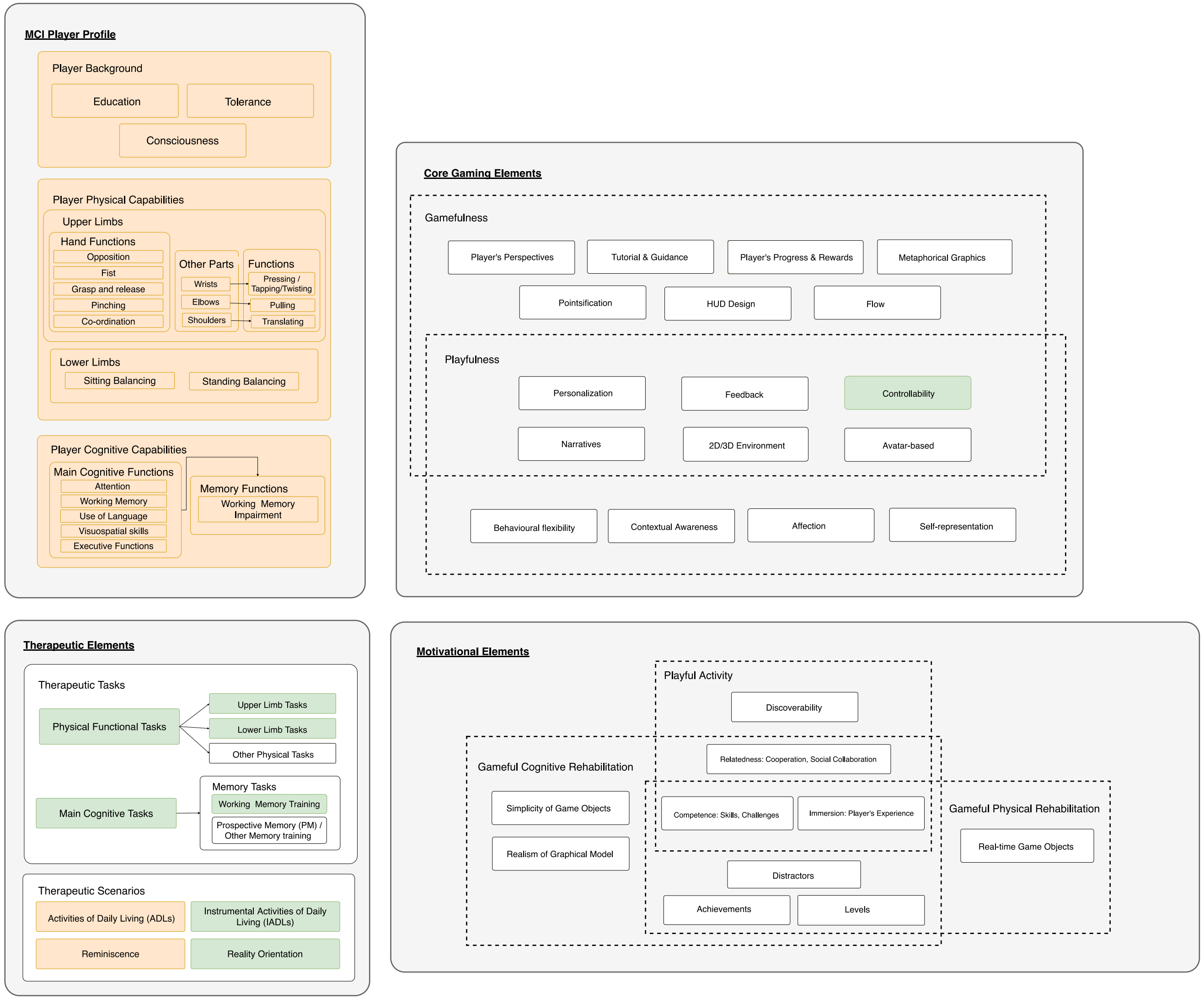


Figure 3-11 The initial serious game framework with GRACE nursing home data

3.7.1 MCI Player Profile

The MCI player profile defines the range of capabilities of a player with MCI and supports the design of an appropriate serious game for them. The elements were derived predominantly from the nursing home resident profiles as presented in Section 3.6.2. The profiles provide a particularly pertinent data set for identifying the potential aspects of the MCI Player Profile as follows:

3.7.1.1 Player Background

From the nursing home resident profiles, three main background characteristics emerged: *education*, *tolerance*, and *consciousness*. These are foremost in reflecting the background of an MCI patient relevant to rehabilitation. While attention was also prominent, it is generally considered a main cognitive function, and therefore indicative of player cognitive abilities rather than background.

The game framework design accommodates MCI players with differing educational qualifications to be able to complete the tasks. It is important to know that education level is not the only factor which might affect their cognitive ability to complete the therapeutic (gaming) tasks, but the emotional state is also a factor, e.g. depression. However, the education level of the player can affect their ability to understand the gaming context, especially the use of technology. The *education* level setting is perceived to be useful for designing an adaptive serious game environment for the players, in terms of core gaming elements, therapeutic elements and motivational elements, based on the MCI player profile. With reference to the collected data as shown in Section 3.6.2 (i.e. Figure 3-3), most of the nursing home residents were found to have no formal education, which is to be expected given that they are aged 72-100 and historically there were few opportunities to have a formal education during their youth, but they may have higher practical skills related to their daily lives. This may affect their understanding and learning ability and thus increase their likelihood of refusing or not continuing with a serious game. Therefore, it is important that a range of MCI participants are provided for within the framework. For example, in Section 3.6.1, imagery is prominent in the game interface designs to ensure the game can be used by those who cannot read. This will be further elaborated and discussed while identifying the player's crucial behaviours to formulate a persona profile and visual design in Chapter 5. Game design enables the rate of participation to be leveraged as it addresses player's requirements and needs in the context of rehabilitation. The player's performance depends on the communication between the player and the gaming elements displayed in the interface. Features should match cognitive conditions based on education background to enable players to discover and interact in the game scenes. Thus, the level of their education highly impacts on the MCI player during the game therapy. The interview data in Chapter 4 will further investigate what gaming elements can be suitable for the MCI player with respect to their education level for subsequent persona formulation to identify the crucial MCI player's features in Chapter 5.

Therapeutic gaming tasks exhibit different contexts which notably require the *tolerance* capacity of the player to be sufficiently high to accommodate the requirements of the serious game environment. The majority of residents in the nursing home had a tolerance level where they required rest during activities (i.e. Figure 3-5) and thus tolerance will influence what is considered a manageable period of time for the player to master a set of therapeutic tasks. Since the data range is not sufficient for determining a suitable time range for the player, the semi-structure interview with the specialists or occupational therapists will be conducted for further evaluating the duration in Chapter 4.

Consciousness is a long-term status of the player that is closely related to engagement during an activity and therefore important to take into account as well. Identifying the consciousness level of the player is a way to address the issue of lacking in engagement. The residents at the nursing home exhibiting mild dementia were all assessed as being alert and thus had sufficient awareness to respond to the surroundings. However, a small number of residents in the nursing home had a consciousness level of sleepy in Section 3.6.2 (i.e. Figure 3-4), which would imply that they would be unable to manage any tasks.

3.7.1.2 Player Physical Capabilities

Player physical capabilities are classified into two categories: upper limbs (i.e. hand functions and other functions) and lower limbs.

The OTs in the nursing home utilised several hand functions (opposition – using the thumb to touch the fingertips, pinching – exerting strength between the index finger and thumb, fist – wrapping the thumb across the other four fingers, grasp and release – involving hand grasp with a moderate power grip and wrist extension so that the fine motor muscles can be used to perform some functional tasks, and co-ordination) commonly-used in ADLs within the therapeutic training and testing of *upper limb* capabilities, particularly on both hands. For example, needling during sewing and picking up small items involves opposition and pinching actions that require control of the smaller or fine motor muscles of the hands; fist and grasp and release are operated for tasks such as wringing a towel or moving objects, which require muscle strength; and co-ordination is a popular action in rehabilitation where a series of movements switch the workload between left and right hands freely. Co-ordination may also involve hand-eye coordination to complete tasks. The workload in each hand for co-ordination requires a certain degree competence for manipulation and both are complementary. Co-ordination therefore reduces muscle fatigue and enlarges the reachable area through a small movement of exchanging hands. In a serious 2D or 3D game environment, these hand functions would be frequent actions operated along the XYZ axes in the game space. Regardless of the stage of dementia, residents in the nursing home could complete most of the hand functions (Figure 3-7), but relatively fewer residents could complete the co-ordination function as it requires sufficient tolerance for completion and the duration of the task is generally assigned based on the patient's tolerance. Therefore, co-ordination could be a hand function that cognitive-impaired persons have difficulty with. Other parts of the upper limb functions are also relevant to the framework since they enable expansion of the training area and physical movements of an MCI player within a serious game, notably: wrists for twisting, pressing and tapping; elbows for pulling, which involves flexion and extension movements that enable objects in front to be raised to a particular point; and shoulders for moving or shifting the whole upper limbs to perform activities. These enhance controllability (see Section 3.7.3) through intact upper limb movement and can further test the player's ability to manipulate objects. For example, wrist capability can help determine if the finger muscle mechanism is normal, while shoulders support different subtle motions of the player during tasks even where those tasks could be carried out without them.

Lower limb capabilities comprise balancing while sitting or standing and were assessed as poor, fair or good within the nursing home residents as shown in Section 3.6.2 (i.e. Figure 3-8 to Figure 3-10). Typically, patients are able to balance better when sitting rather than standing, therefore, it would be more conducive if an MCI player undertakes game-based rehabilitation in the sitting position than in the standing position. However, the profile serves to record both capabilities so that a serious game may be designed accordingly. In the following section, the main cognitive and memory functions will be discussed.

3.7.1.3 Player Cognitive Capabilities

In the nursing home, residents were assigned a range of functional tasks or personalised training, which included cognitive functional tasks targeted at the five *main cognitive functions*: attention, working memory, use of language, visuospatial skills, and executive functions. Therefore, the player profile reflects their capability in each of these functions.

The attention level of residents in the nursing home (Figure 3-6) varied from the range “unable to concentrate” to “easily distracted” to the range “easily distracted” to “attentive”, with most residents assessed as being “easily distracted”. Those diagnosed with MCI were in the range “easily distracted” to “attentive”, indicating that attention support will also be required as a motivational element to maintain a good cognitive condition for the MCI player to concentrate on the tasks, and maintain their interest to prevent them giving up. This will need to vary according to the player’s level of attention. *Working memory* is the most used cognitive function that allows for the temporary storage of information. Most of the MCI residents in the nursing home were assessed as being capable of processing working memory to complete tasks by recalling information, and were consequently assigned to individual memory training so as to train these capabilities. *Use of language* is normally assessed prior to other functions to ensure that the patient is able to verbally communicate normally and fully articulate themselves. Together with attention, these cognitive capabilities are considered the fundamental abilities to support MCI through the functional tasks. *Visuospatial skills* and *executive functions* for MCI were typically examined through ADLs or IADLs in the nursing home.

3.7.2 Therapeutic Elements

In the serious game framework for MCI, the therapeutic elements are chosen as follows:

Both *physical functional tasks* and *main cognitive tasks* were adopted within the nursing home where ADL is a part of the resident's assessments. Typical physical tasks include having meals, transferring, and grooming, which highly involve the *upper limbs* (both hands). Similarly, some *lower limb tasks* are also essential to daily life, such as sitting and standing balancing, and are used within the nursing home. Residents who often fail to maintain an appropriate sitting and standing position will face difficulty in the completion of therapeutic tasks. All upper and lower limb tasks used in the nursing home are suitable for MCI patients. Most of the cases with memory impairment in the nursing home were reported as undertaking *working memory training*.

In the nursing home, the therapeutic scenarios mostly utilised to treat residents with MCI were *ADLs*, *IADLs*, *reminiscence* and *reality-oriented* scenarios as these were deemed to have the highest positive effect on the target group. Generally, MCI residents in the nursing home achieved a standard level in *ADLs* and thus this scenario may be used as a basis for integrating more challenging functional tasks into a serious game. *IADLs* in the nursing home provided more complex tasks for those in mild dementia cases but may pose difficulties for those with later stage dementia. The individual care plans from the nursing home revealed that residents' cognitive abilities could deteriorate further due to old age and extended hospitalisation, and long-term confinement to the bed and lack of social stimulation can negatively affect their cognitive state. Therapeutic scenarios with an environment assessment context and reality-oriented activities can enhance the player's environmental awareness and acknowledgement of reality-oriented information, such as time, location, date and weather. Such a scenario would aid the player in deriving their player status from the gaming environment through visual gaming elements, such as warning signs, weather or clock icons. In order to improve environmental awareness, colours can act as indicators, e.g. red for danger. This supports the player in accomplishing and understanding the assigned tasks by providing memory aids and orientation information. In the *reminiscence* scenario commonly used in the nursing home, cultural elements were embedded into the tasks with the aim of encouraging residents to recall the past. The fact that the scenario setting is closely-related to the resident's personal experience and background can help to induce the patient to recall long-term memory. However, since reminiscence is associated with culture-related content, it may not be suitable for general administration to all MCI patients. This means that the cultural background and values of the target group are implicit in reminiscence.

3.7.3 Core Gaming Elements

The individual care plans from the nursing home indicated that residents were commonly assessed as having a reduction of physical *controllability*, such as mobility issues and stiffness of limbs. To support their contracture and stiffness, a *controllability* element is accommodated within the framework to reflect factors such as game object sensitivity, where less or more movement is required as necessary, working space flexibility, whereby the game environment can facilitate working space sufficient to accommodate the limb power of the MCI player, and freedom of movement, whereby the MCI player is able to navigate in-game scenes with as much freedom as their limbs are able to accommodate, e.g. via full upper body gestures, which helps bring a sense of control and positive satisfaction. In short, the functionality of the serious game should allow an adequate controllability including the above-mentioned upper limb functions in Section 3.7.1.2 for the MCI player to handle the physical movements. By doing this, it can improve the amplitude of each player's limb control ability.

3.8 Conclusion

The GNH data presented in this chapter aims to provide data-driven analysis for assembling the potential themes of the serious game framework for MCI. In the process of data collection in the nursing homes, the patients' profiles in the data set offered concrete materials for the MCI Player Profile with respect to player background, player physical capabilities and player cognitive capabilities. Thus, the serious game will cater specifically to MCI. Because the proposed framework is generally for the person with MCI, the aspects of the player background are given the most flexibility in range, i.e. education level range is for those with no formal education. Player Physical Capabilities consist of upper limb and lower limb tasks in which hand functions and balancing are included. Among all hand functions, co-ordination is relatively more challenging for those with cognitive impairment. In order to fully test the upper limbs of the target group, wrists, elbows and shoulders have to be taken into consideration for developing the serious game for MCI. Player Cognitive Capabilities includes all the main cognitive functions, but the WM function for MCI is impaired. GNH used a set of therapeutic scenarios to treat the cognitive impaired person, including ADLs, IADLs, Reminiscence and R.O. In the next chapter, *MCI-GaTE* will be finalized using interview data collected from the occupational therapists. Potential themes from the data will be identified by using the thematic approach and add further elements to the current framework.

4 Chapter Four – Data Analysis of Interview and Final *MCI-GaTE*

This chapter presents the interview method used for building upon the initial serious game framework constructed with literature and GNH data as shown in Figure 2-41 and Figure 3-11. This chapter consists of the following sections: Section 4.1 briefly introduces an overview of the aim; Section 4.2 presents the semi-structured interview method that will be used for conducting the interview with the occupational therapists; Section 4.3 outlines the background of the occupational therapists and provides an explanation of the sample size; Section 4.4 explains the procedure and techniques of selecting the themes using the thematic approach for constructing the *MCI-GaTE*; Section 4.5 presents a summary of the data results, which comprises the interview questions and a list of themes for the final version of the *MCI-GaTE*; Section 4.6 evaluates each of the themes with reference to the interview data and Section 4.7 presents two hypotheses based on the findings; and Section 4.8 summarizes this chapter with the findings.

4.1 Introduction

This chapter aims to finalize *MCI-GaTE* with the use of interview data. To further understand the rehabilitative settings for MCI, and to consolidate the hitherto identified themes within the framework, this chapter undertook interviews with four registered and experienced OTs from the following hospitals and nursing homes in Hong Kong: Kwai Chung Hospital HA, TWGHs Fung Yiu King Hospital HA, Hong Kong Caritas in Evergreen Home and Integrated Home Care Services, and TWGHs Jockey Club Rehabilitation Complex.

4.2 Interview Method

The Interview used a semi-structured method that allows for flexible and open-ended discussion between the researcher and interviewees [95], so as to directly address the problems with guiding questions. The aim of the interview is to further explore the background information and needs of the target group, i.e., MCI, through empirical evidence and the knowledge base of the interviewees (occupational therapists). They provided guidance and direction for the serious game framework and enhance the effectiveness of the investigation. During the interviews, they were encouraged to speak freely about their experience with and observations on the different levels of case studies. The interview gathered qualitative data from the participants for improving the serious game framework.

4.3 Participation

Four registered and experienced OTs from hospitals or nursing homes in Hong Kong as shown in Table 4-1 were interviewed and helped to further refine the MCI profile and the physical and cognitive therapeutic elements by harnessing their experience in designing and executing rehabilitations for their patients. Each OT was interviewed twice for 2-3 hours on two separate days and further followed-up via email where clarification or further discussion were required. Written consent was obtained from occupational therapists from different hospitals or nursing homes prior to the interviews. They voluntarily participated in this research.

Table 4-1 Participant background

Participant No.	Background
P1	Registered OT; 2.5 years in physical rehabilitation hospital (medicines & geriatrics) including community geriatric assessment team
P2	Registered OT; 8.5 months in hospital (acute mental health) and 5 months in rehabilitation centre
P3	Registered OT; 1.5 years in mental health hospital
P4	Registered senior OT; worked in hospitals for 17 years; 2 years in nursing home and home-based clients within the relevant field

Their experience in MCI and relevant fields will help to define the scope of the research, the MCI profile and especially the therapeutic elements. Even though the small sample size is not ideal for replicating or generalizing the results, and each of the interviews is time consuming, these interviews can produce an in-depth study and generate a sufficient amount of information from the four institutions. Most importantly, the interview aims to provide essential subject material, i.e., the physical and cognitive therapeutic assessments, for constructing the game framework for MCI by harnessing the therapists' experience in designing or manipulating tasks for their patients.

The serious game framework thus far comprises four aspects (i.e., MCI Player Profile, Therapeutic Elements, Core Gaming Elements and Motivational Elements) that could support those with MCI. Through conducting the interviews with the occupational therapists, supplementary comments and suggestions on the serious game framework will be obtained.

4.4 Data Analysis Method

The interviews were conducted in Cantonese and audio recorded and transcribed into English prior to analysis. Analysis was undertaken using the thematic approach of Braun and Clarke [54]. Data were selected and transcribed through the data deduction process, with irrelevant responses and repeated responses removed. For example, one of the interviewees responded that "some of the research papers in Hong Kong are requested by the login". The latter comprises repeated responses to the same question from the same interviewee during the discussion. These responses therefore become redundant and have to be eliminated. Given that potential themes were already identified from the literature and nursing home data, exploratory research was not the focus at this stage and thus interview responses not pertaining to the four core sectors of the serious game framework were not transcribed. To try and minimise such out-of-scope responses and to help the OTs understand the interview context, they were asked to review the initial construction of the framework as presented in Figure 3-11 in advance. Table 4-2 in Section 4.5 summarises the constructed themes from the responses to the questions. Participants are referred to as *P1* to *P4* for anonymity purposes.

During the theme identification process, two cycle coding processes were followed. The first cycle was used to pinpoint the common themes that were generated in the initial *MCI-GaTE*. The transcribed phrases from the interview were scanned through the symbolic attributes, which were not the exact wordings as the identified themes in the initial *MCI-GaTE*. The descriptive and simultaneous coding methods [55] were used to analyse the symbolic attributes. The former summarizes the insights of the phrases and the latter searches the repetitive patterns that were derived from the existing interview data to acknowledge the previous findings in the same context. The second cycle was to seek the supplementary materials based on the commonality of the identified themes. For instance, *visual* and *hearing impairments* under the category *potential impairment* were the extended part of the initial *MCI-GaTE*.

4.5 Interview Questions and Data Results

The initial *MCI-GaTE* framework was introduced to the interviewees before conducting the interview. They were requested to respond to the following interview questions and openly discuss the research scope using their experience.

Q1. To what extent do you agree that patients with MCI are interested in using computer-based rehabilitation/therapy? What makes them interested or uninterested (both initially and during the rehabilitation/therapy)?

Q2. What can increase a patient's attention and motivation during cognitive rehabilitation/therapy? What tools are used during the rehabilitation?

Q3. In general, how long does an intervention usually take? How do you know it is working based on the patient's capability? What is the minimum duration for it to be effective? Is there a maximum duration?

Q4. What basic level of physical movements (especially arms/hands/fingers) are patients with MCI able to manage? Please give some examples.

Q5. From the beginning to the end of the cognitive rehabilitation/therapy, which sessions or aspects are cognitively challenging for the patients? Please give some examples, e.g. attention, interactions, external/internal factors affecting them, etc. What factors might help make these sessions or aspects less challenging?

Q6. From your experience and observations, do you think computer-based rehabilitation/therapy can potentially contribute to patients with MCI more effectively than the traditional training platform? How? In what areas?

Q7. Can you show me some examples of cognitive rehabilitation with/without technological support? In your experience, what is the main difference between them? What are the positive and negative effects on the patients?

Q8. What type of memory training have you used with patients (including currently) and why? What are the differences/benefits between them?

Q9. Do you think patients with MCI are sufficiently competent to manage the basic functionality of a digital game? What are the common restrictions to be aware of? What range of interactions and range of physical movements do you think patients could manage? Using which parts of their body?

To further consolidate the identified concepts presented in the literature and nursing home data, the OTs were recruited to answer the above nine overarching interview questions. Figure 4-1 refers to the derivation of questions from four identified aspects in *MCI-GaTE*, presenting the leading questions related to *MCI player* profile, *therapeutic* elements, *core gaming elements* and *motivational elements*. The questions in the interview comprise the core questions associated with the stage of the player's initiative in participating in the intervention (Q1), the stage during the rehabilitation (Q2 and Q3), the capabilities of the MCI players (Q4 and Q5), and the advantages in using digitised training platform alongside the appropriate therapeutic tasks (Q6 to Q9). These questions related to the central research question, which in turn, further facilitate a robust technique through the medical point of view provided by the OTs, who have experience in designing interventions for those with MCI. The interview results were then analysed and refined the initial *MCI-GaTE* (discussed in later sections).

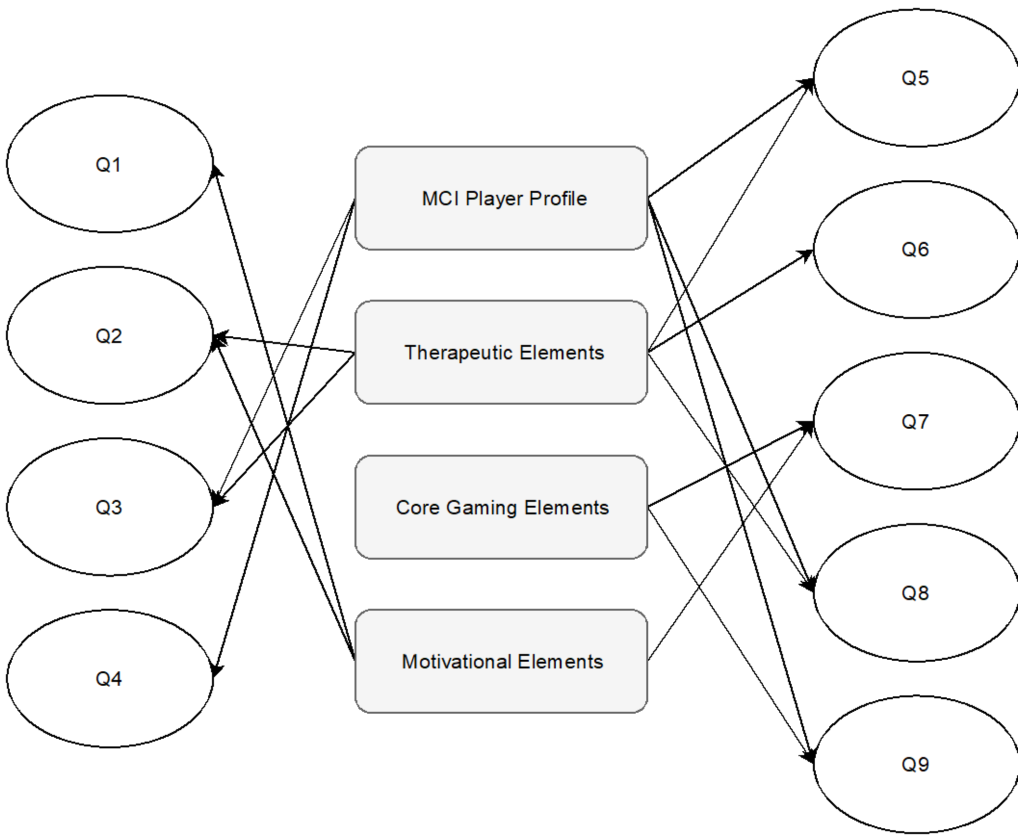


Figure 4-1 Interview questions arising from the initial *MCI-GaTE*

The interview responses and the themes that are constructed from the participants' responses are detailed in Appendix A (Table A-1). Table 4-2 presents the additional themes which will be built upon the initial *MCI-GaTE* that has already defined in Chapter 3. Table 4-3 summarises the constructed themes from the responses to the questions.

Table 4-2 Definitions of additional themes for initial *MCI-GaTE*

Themes for MCI-GaTE	Definition
Attention support	Provides support to players to help them to focus on making the right decision without straying from the task at hand
Duration	Length of time for rehabilitative activity
Learning approach	Process(es) of learning adopted by the game, e.g. errorless, cognitive, behaviourist

Potential impairment: visual and hearing	Deterioration in visual or auditory perception
Supervision & verbal encouragement	Support and motivation of the player by a trainer, e.g. OT

Table 4-3 Interview questions and emergent themes

	Interview Questions								
Themes for MCI-GaTE	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Q9*
ADLs								P1-P3	
Attention					P1, P2, P4				
Attention support	P1, P4	P4			P2, P3				
Autonomy: freedom of choice						P2-P4			
Controllability	P1								P1, P4
Co-ordination				P2					
Duration			P1, P2, P4		P3				
Education	P1-P4								
Flow		P1-P2							
IADLs								P1-P3	
Learning approach		P4							
Levels		P1-P4	P4						

Personalisation		P1							
Physical functional tasks: upper and lower limbs				P1-P4					P1, P4
Potential impairment: visual and hearing	P2	P4							
Reality orientation								P1-P4	
Reminiscence								P1-P4	
Supervision & verbal encouragement	P4	P1					P1-P3		
Tangible tools	P1, P3	P2							

Eight of the themes (over 40%) were mentioned by all OTs, in response to a single question or over multiple questions, suggesting their strongest relevance to the framework. These prominent themes were: *attention support*, *controllability*, *duration*, *education*, *levels*, *physical functional tasks*, *reality orientation*, *reminiscence*, and *supervision & verbal encouragement*. For example, for the *supervision & verbal encouragement theme*, responses included: "the relationship between the carer and patient is important for motivating them and building trust, because we understand their living style and they would be willing to listen and follow our instructions" ***Q1-(P4)***, "assistants or carers can provide verbal encouragement…[and] sometimes, the participants would need us to play with them or just watch them do the tasks for a few minutes" ***Q2-(P1)***, "there is no verbal reinforcement provided by technological support…[so] the support of the OT can… motivate the patients to do the tasks" ***Q7-(P2)***, and "I'm sure that technology can provide accurate measurement, and it is good for data recording, but I don't think that technology can replace the jobs of OT because we can provide concise analysis of our patients" ***Q7-(P3)***. Five further themes (*ADLs, attention, autonomy: freedom of choice, IADLs, and tangible tools*) were mentioned by all but one of the OTs. These themes reinforced those previously derived from the literature, such as *tangible tools*, or from the nursing home resident profiles, such as *attention*, e.g. "To initiate them into the rehab at the beginning would be the most challenging because it requires their attention and the correct mental state to perform the tasks. Sometimes, they will blame themselves and feel stigmatised…" ***Q5-(P4)***. An additional five themes were derived from more distinct responses. These suggested that what is potentially possible is not fully known to the OTs, such as *personalisation*: "It is hard to provide training that is tailored to each of them" ***Q2-(P1)***. In some cases, the theme seemed tacit due to its nature, such as *co-ordination*: "Co-ordination will always be involved, like using both hands to do the tasks, which mainly requires co-ordination and not just a simple physical movement. For example, picking up certain coloured objects with the co-ordination of the eyes and fingers." ***Q4-(P2)***. In the next chapter, it integrates all the themes from the research results in Chapter 2 to 4 into a serious game framework that may be used to develop serious games targeted at players diagnosed with MCI.

4.6 The Final *MCI-GaTE* with Interview Data

Drawing together the themes uncovered from related research literature, nursing home resident profiles, and OT interviews, a serious game framework for MCI player, *MCI-GaTE* (MCI-Game Therapy Experience), is derived. This section describes and explains the results of the interviews with reference to the quotations of the interviewees (i.e. *P1, P2, P3* and *P4*), supplementing the serious game framework in two ways: the green boxes are for existing elements where the interview data further validates the elements; the orange boxes are a new set of themes which contributes additional data to *MCI*-GaTE, as in Figure 4-2.

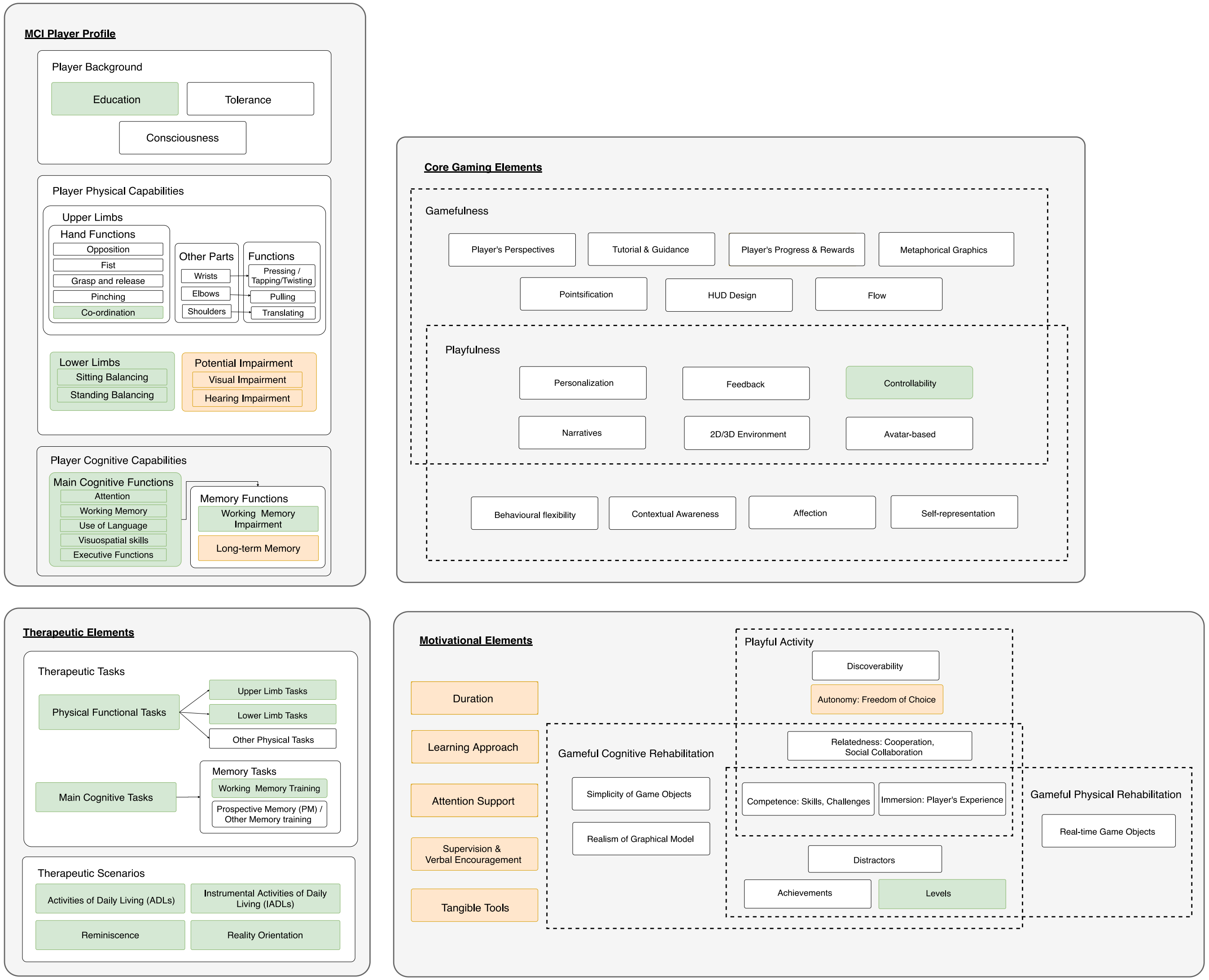


Figure 4-2 The final *MCI-GaTE* with interview data

4.6.1 MCI Player Profile

Education level and attention span are significant conditions for initiating the MCI player into the game-based rehabilitation or therapy. The player's physical and cognitive capabilities also need to be taken into account when personalizing the game framework for the player.

4.6.1.1 Player Background

The interviews reinforced that the MCI player's degree of interest in using digital rehabilitation or therapy strongly depends on their *education* level ***Q1-(P1-P4)***. Despite this, 30-40 percent of MCI patients are generally interested in performing therapeutic tasks using a digital platform ***Q1-(P1)*** and given that their cognitive impairment is at the onset, on-going explanation and assistance may help overcome any education issues.

4.6.1.2 Player Physical Capabilities

Co-ordination may involve hand-eye co-ordination to complete tasks, such as classifying coloured objects ***Q4-(P2)***.

Based on the OTs' experiences, it is evident that some of MCI patients may have *visual* or *hearing impairments* ***Q1-(P2)***, which may directly affect their sensory capability to process experiences. Recording this within the profile enables a serious game to adapt the therapeutic content accordingly, e.g. by enlarging images and amplifying sounds so that patients are better able to process the information. These are common methods to capture and sustain their attention ***Q2-(P4)***, interest and active participation.

Current nursing homes and hospitals prefer to also include a wide range of functional tasks (*all basic functional tasks*) when examining a patient's physical ability. The tasks should reflect day-to-day activities since patients have already acquired great proficiency in basic physical movements such as dressing and cooking gestures. As reported by the OTs, patients who have no medical condition such as brain injuries ***Q4-(P1, P4)*** generally have sufficient mobility competencies to perform all basic physical movements ***Q4-(P1-***

P4) including upper and lower limbs movement, i.e. sitting and standing balancing. Including the MCI player's level of capability for such tasks within the profile of the framework will ensure that the game is able to appropriately challenge the player.

4.6.1.3 Player Cognitive Capabilities

The interviews revealed that *attention* is required at the beginning of cognitive rehabilitation, and it is one of the more challenging cognitive domains ***Q5-(P1, P4)*** because sustaining patients' attention during the entire rehabilitation or therapy is difficult but crucial. In addition, prior to attention, the cognitive process requires sensory registration as a basis for processing the quality and quantity of visualisation, as seen in the example of using colours to stimulate the patients ***Q5-(P2)***. The importance of attention to the MCI player will be further discussed in Section 4.6.4 (i.e. *Attention Support*).

During the free discussion within the interviews, the OTs believed that those with MCI could typically manage all of the main cognitive functions and that cognitive training was shown to improve memory functions. Consequently, they argued that *long-term memory* support could improve an MCI player's *working memory impairment*.

4.6.2 Core Gaming Elements

The OTs indicated that most patients have sufficient competence to manage and understand new information including digital platforms for rehabilitation or therapy ***Q9-(P1)***, but it is recommended that the content is relevant to the therapeutic routines. Furthermore, the complex functionality of digital games should not be an additional burden or obstacle that prevents patients from understanding the therapeutic context ***Q9-(P1)***. For example, a mouse and keyboard are unlikely to benefit those with no computer experience ***Q9-(P1, P4)***. Thus, it is important that the range of interactions and physical movements within the therapeutic game environment are accessible and compatible with the MCI player's abilities. Consequently, through the typical factors discussed in the previous chapter (e.g. game object sensitivity, working space flexibility, and freedom of movement), *controllability* also serves to reflect the interaction modalities.

4.6.3 Therapeutic Elements

The OTs reported that they mostly assign a variety of tasks that comprise cognitive and physical rehabilitation to patients in accordance with their medical history, pre- and post-assessment results and intact profiles ***Q3-(P4)***. Based on the therapeutic tasks, the patients will be assigned various scenarios in accordance with their medical conditions.

4.6.3.1 Therapeutic Tasks

The OTs suggested that requesting the patients to perform the table tasks (working with upper limbs) with a good sitting position can reduce their physical limitation ***Q9-(P1, P4)***, i.e. lower limb ability – standing, as well as enhance their attention and tolerance levels. In addition, it is worth noting that the cognitive and physical rehabilitation should be examined separately ***Q9-(P1)***.

Besides, the OTs reported that they would assign all cognitive training to their patients, with working memory training given to those with memory impairment in accordance with their pre- and post- assessment history records. Working memory is the specific cognitive function used to identify the MCI group. However, *prospective memory* and other memory training may also be targeted, e.g. where the player is required to keep multiple thoughts in mind and switch between them while undertaking multiple therapeutic tasks within a given IADL scenario.

4.6.3.2 Therapeutic Scenarios

Numerous types of memory training are frequently integrated into a comprehensive rehabilitation design, the majority of which are targeted at improving working memory (short-term memory), which primarily declines with the increase in age. Instead of merely focusing on memory during training, integrating memory training elements with other training elements like reality orientation, ADLs/IADLs or simulated setting (e.g. reminiscence) can enhance the cognitive training because the other training elements already involve working memory ***Q8-(P1-P3)***. Additionally, long-term memory can further support working memory functioning by enabling patients to relate to the context of the setting. For example, in a shopping simulation, patients use long-term memory to recall their role as a consumer in a supermarket, whilst they use short-term memory to remember a list of items to buy ***Q8-(P4)***.

To sum up, employing reality orientation and rehabilitative simulation can improve cognitive capacity in patients, especially in the memory aspect. Patients require both short-term and long-term memory for solving problems in daily-life scenarios.

4.6.4 Motivational Elements

The OTs experience is that the duration of a therapeutic session is typically 30-45 minutes ***Q3-(P4)***. There are an optional 15 minutes of warm-up and 10-15 minutes for each rehabilitation task, with no break in between ***Q3-(P1)***. While some patients are willing to participate in a session of up to 60 minutes, those who feel unmotivated might only last for 15 minutes ***Q3-(P2)***. The variation in duration therefore should be tailored accordingly within the serious game. In addition, if patients have a sudden medical change during the cognitive rehabilitation or therapy, it will be uncertain whether they would be able to continue with the session ***Q5-(P3)***, which the serious game will need to accommodate.

The *learning approach* may help to counter problems of being easily distracted and losing focus, which may result in tasks being unfinished. Providing an errorless learning environment, which enables the player to focus on continuing to perform in the task in the absence of displaying errors [49], is perceived as being both an attention support and motivational tool, which hides feedback on errors during the session to enable patients to focus on continuing ***Q2-(P4)***.

Similarly, the OTs reported that *attention support* is essential for patients to be initiated into a rehabilitation and effective attention support can help patients to be focused on making the right decision without straying from the rehabilitation or therapy. Clear instructions which help patients visualise the training context can facilitate the explanation of the training goals and increase attention level ***Q5-(P2, P3)***. Furthermore, attention support can help to arouse and scaffold the patient's interest and attention during the rehabilitation or therapy if the content is closely-related to their daily lives and personal preferences ***Q1-(P4)***. However, patients may feel uninterested and unmotivated if too much effort into learning new knowledge or techniques is required ***Q1-(P1)***. Attention skills can support the visual and spatial perception of patients to aid in anticipating the next action. Consequently, working memory ability is required to temporarily store information for executing the actions once the patients can recognise the objects and receive the information through their senses. Therefore, sustaining patients' attention is a precursor to using their working memory ability.

Supervision and *verbal encouragement*, typically from one trainer, can benefit the patients in social and mental ways ***Q2-(P1)***. The biggest impact of technological support in rehabilitation is the increased precision of patients' quantitative analysis results ***Q7-(P1,P3)***. However, technology cannot provide better observation and analysis than an OT in more subtle areas, such as the behaviours and emotional quality of patients ***Q7-(P1-P3)***. Therefore, the serious game should assist the OT during rehabilitation but not fully replace them ***Q7-(P3)***. The technology can also reduce potential risks and enable diversity ***Q7-(P1)*** but may greatly reduce the social interactions between the trainer and patient ***Q7-(P2)***. In some cases, home-based patients might not have a chance to participate in certain technologically-based rehabilitation since they would need to travel to the nursing home or hospital ***Q7-(P4)***. In general, to achieve the best training effect, the serious game should incorporate a role for trainer supervision and verbal encouragement.

Even when patients have much interest and know-how regarding computer-based therapy, a well-maintained relationship between trainer and patient can further promote cooperation leading to a desirable training effect ***Q1-(P4)***. In respect of rehabilitation equipment, providing patients with *tangible tools* to touch or control objects with sensory feedback can improve their motivation towards the tasks ***Q1-(P3), Q2-(P2)*** and therefore should be accommodated within the framework.

Within the playful activity motivators, *discoverability* and *autonomy*: *freedom of choice* can potentially support patients in performing tasks more effectively compared to traditional training platforms due to the diversity of the digital platform ***Q6-(P2-P4)*** and the geographical constraints of traditional training ***Q6-(P3)***. With the former, various types of rehabilitation or therapy are highly compatible with patients' preferences and capabilities, and patients are less likely to find tasks tiresome compared to traditional training platforms. The serious game may produce notifications, hints or trials to patients responsively that are not available via traditional approaches. Moreover, the traditional platform cannot fully present simulated scenarios to the patients, and this might possibly lead to great confusion. With the latter, geographical constraints may be overcome by avoiding the need to utilise real space settings, for instance, in reminiscence therapy. When *relatedness* elements are also employed, the serious game may support collaborative or co-operative play with other local or remote patients. In short, computer-based rehabilitation or therapy has great potential to be implemented and it might replace some of the traditional platforms in future.

For both gameful cognitive and physical rehabilitation motivators, sorting and grading the patients according to their cognitive *levels* is a way to motivate them to achieve a clear goal, as well as improve a sense of competence ***Q2-(P1-P4)***. These patients' capabilities will be fully recorded in the MCI profile according to their medical history and thus the level of tasks may be adjusted accordingly ***Q3-(P4)*** and, in the long-term, therapeutic content may also be updated.

4.7 The Formulation of Hypotheses

In the preceding research findings through literature, nursing home resident profile data and interview data, *MCI-GaTE* is structured by the selected themes as MCI player profile, therapeutic elements, core gaming elements and motivational elements by using an inductive approach. The formulation of hypotheses began with the holistic literature on gamefulness and playfulness within physical and cognitive rehabilitative contexts, gathering the underlying factors and theories that potentially advance the MCI context, with the aim of formulating core gaming and motivational elements in *MCI-GaTE*. The investigation from nursing home resident profiles and interview data further enriched the framework by adding pertinent themes upon the MCI player profile and therapeutic elements. Based on these findings and primary and secondary research processes, the following hypotheses consider how selected themes, presented as MCI player profile, core gaming, therapeutic and motivational elements, via primary and secondary research processes might produce a comprehensive and tailored framework for optimal physical and cognitive gain in MCI players. The core gaming and motivational elements might also motivate the MCI players substantially through a gameful approach commonly-used in surveyed literature in Chapter 2. Now that the final serious game framework is constructed, it is pertinent to formulate two hypotheses to predict the insights derived from *MCI-GaTE* as follows:

H1. A comprehensive serious game approach specifically tailored to players diagnosed with MCI, that includes a profile incorporating their physical and cognitive conditions, therapeutic elements which enable the player to undergo suitable rehabilitative training, core gaming elements and motivational elements that enhance the player's motivation through gamefulness, will be better optimised for their MCI condition than a generic physio-cognitive serious game; and

H2. MCI players using a serious game with a supportive gameful approach derived from core gaming and motivational elements as a rehabilitative tool will exhibit enhanced motivation and engagement over traditional rehabilitative tools.

Based on these hypotheses, a serious game will be realised in accordance with the research findings. They will then be confirmed and evaluated accordingly by a deductive approach from the interviews with OTs and frameworks comparison in Chapter 7.

4.8 Conclusion

MCI-GaTE organises the themes as elements within four sectors: an *MCI player profile*, *core gaming elements*, *therapeutic elements*, and *motivational elements*. Related research led to a broad initial building of the framework, incorporating various therapeutic, core gaming and motivational elements. Most of these elements were further validated by the nursing home resident profiles and OT interviews. Similarly, analysis of the nursing home resident profiles led to the establishment of the MCI player profile elements, as well as additional therapeutic scenarios and core gaming elements, while the OT interview data established potential impairment elements within the player profile, and various motivational elements. The framework serves to conceptually represent the range of elements that may be incorporated when designing and developing a serious game for cognitive and physical rehabilitative support of patients with MCI. As such, it does not encompass particular implementation-level elements. Although the framework was influenced by the surveyed research which included solutions targeted at other diseases requiring rehabilitation, such as Parkinson's Disease, and involving related serious games for health, such as exergames, the resultant framework is specifically focused on MCI rehabilitation only. Each of the four sectors of the framework is discussed in turn and considered in relation to the results presented in the previous sections. *MCI-GaTE* as illustrated in Figure 4-2 will be adopted as a framework to design a serious game in the next chapter.

5 Chapter Five – Design of *A-go!*: a Serious Game based on *MCI-GaTE*

Prior to the design stage, data from the literature review, GNH and interview had been collected and analysed in order to form *MCI-GaTE* as presented in Figure 4-2 in Chapter 4. In this chapter, the proposed *MCI-GaTE* is the basis for determining the desired user models, i.e. persona, scenarios and journey map, which will be the essentials for generating the functional requirements and visual designs. The chapter is structured as follows: Section 5.1 explains how this chapter harnesses the MCI-GaTE to create the design modelling; Section 5.2 presents the creation process of the MCI player (i.e. *Foon Lee*) and OT (i.e. *Ching Lau*) personas which involves the crucial behaviours and intentions that may arise during the intervention; Section 5.3 entails the brief performance of *Foon* and *Ching* from the beginning until the end of the programme to construct a context scenario. Then, the data and functional elements are obtained and used together to form a key path scenario design; Section 5.4 details the journey maps of the MCI player and OT along with the user touchpoints and emotions; Section 5.5 presents the functionality of the proposed system; Section 5.6 explains the visual considerations which support the personas in interacting and communicating with the serious game. During the process, it also displays some examples of UI sketches; and Section 5.7 summarizes this chapter's findings.

5.1 Introduction

The proposed MCI-GaTE is derived from the literature, GNH and interview data which have been presented in previous chapters as research heuristics. These heuristics were analysed and categorized as themes to aid in the design of *MCI-GaTE*. The framework depicted how the heuristics are related to various areas, such as (i)*MCI Player Profile,* (ii)*Core Gaming Elements*, (iii)*Therapeutic Elements* and (iv)*Motivational Elements,* and aided the design modelling and game design.

This chapter was inspired by the methods which were proposed by *Alan Cooper* in the book *About Face* [96] to model the persona, scenarios and user journey map which satisfy the MCI player's goals. After the persona profiles have been designed, the MCI player and OT personas are then presented. The next step is then to set out a scenario design process together with the key features of each persona to illustrate the actions of the MCI player and OT during the journey. The effort spent on creating the persona and scenario designs will help in obtaining the overall MCI player and OT specifications and essentials, which are required to produce the journey maps and list of functional requirements later on.

5.2 Persona Designs

This section identifies the crucial factors for determining the underlying features of the personas, *Foon Lee* (MCI player) and *Ching Lau* (their OT). Figure 5-1 presents Cooper's persona creation process, entailing 8 steps to formulate a persona. However, this research does not fully follow all the steps in constructing *Foon Lee* and *Ching Lau* personas, as the findings derived from the nursing home and interview data are already sufficient to identify the behaviour patterns to construct the personas needed. Cooper's method begins with grouping the interviewees by their job description, followed by choosing behavioural variables, which will be mapped according to the interviewees. The behaviour patterns are then identified, and the persona formulated as a specific type through the synthesis of crucial characteristics and goals of the interviewees alongside the iterative process in finalising all the selected characteristics. Lastly, the characteristics of the persona can be elaborated in detail. The difference between the method used in this research and Cooper's method is the decision-making process of mapping behavioural variables, as shown in step 3 in Figure 5-1. Cooper gathers all the potential behaviour variables and prioritises them to derive the behavioural patterns which are used to create the persona. However, in the case of this research, the behavioural variables are not mapped before deriving the behavioural patterns, which are instead extracted and replicated from the GNH and interviews' pertinent data straight away. The prominent behaviour patterns are justified and summarised in Table 5-1 and Table 5-2. An iterative design approach is adopted to develop the persona designs as shown in Figure 5-2.

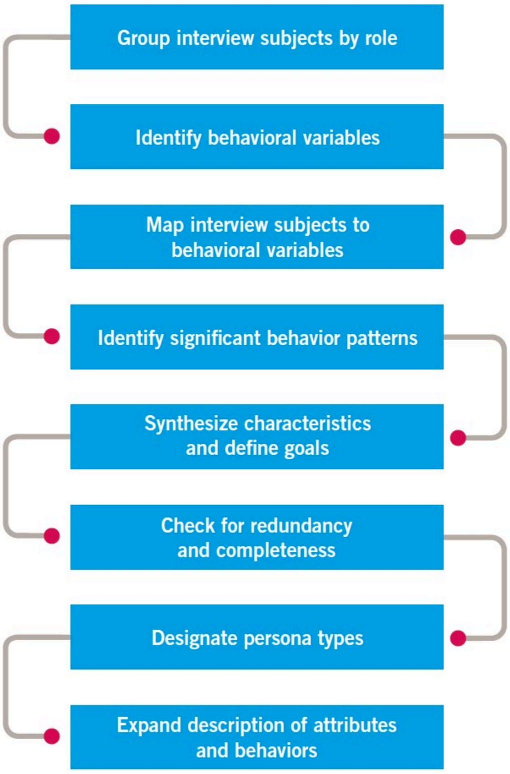


Figure 5-1 Cooper's persona creation process [96]

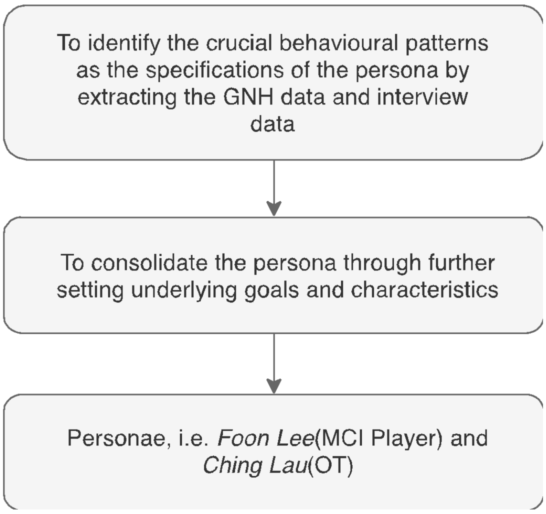


Figure 5-2 Persona design process used in this research

Data from the previous chapters replaces the traditional mapping process, i.e. the resident profiles in the GNH data, as well as the methods and attitudes of the OTs during interactions with their MCI patients as captured in the interview data. In the following Section 5.2.1 and 5.2.2, the procedure for creating the MCI player and OT personas will be further justified.

5.2.1 Crucial Behavioural Factors for MCI Player (*Foon Lee*) Persona

Identifying a set of crucial behavioural factors is a key process for formulating the MCI player persona. As previously explained, the essential materials summarized from the GNH data, and the MCI patients' behaviours described in the interviews are used to generate the player's background information and competencies. The following list of behavioural factors is grouped into the following categories: (i)player background information, (ii)action and orientations, (iii)interests and concerns, (iv)aptitudes and (v)motivations and (vi)competences. As shown in Table 5-1, the list compiles the behaviours, goals and motivations of MCI player (*Foon Lee*) which are used in creating the persona.

Table 5-1 Features for MCI player persona

Categories	Features of MCI Player	Justifications
i. Player background information	Education: no formal education	GNH data showed that the participants had no formal education.
	Tolerance: Need rest during activities	The majority of participants in the GNH data required rest periods.
	Attention span: Easily distracted	Maintaining attention is challenging and the state of being easily distracted was prevalent in the GNH data results.
	Consciousness: Alert	All the individuals at the mild stage from the GNH data results are alert.

ii. Actions and orientation	Seldom uses technology	The interview data revealed that participants' degree of interest in using technology mostly conforms to their education level, and they mostly had no formal education as shown in GNH data.
	Duration of training is in the range of 15 to 45 minutes	According to the interview data, the training duration for those who were unmotivated and motivated were 15 minutes and 45 minutes respectively.
	Preferred training contexts are meal preparation, strong cultural background activities, chores and grocery shopping	From the OTs' experience which is documented in the interview data, the scenario setting is closely related to the participant's experience and background, which can support their long-term memory and stimulate their short-term memory.
	Therapeutic training styles: ADLs, IADLs, reminiscence, reality orientation and tangible equipment for physical training	The interview data showed that the OTs assigned a range of rehabilitation （ADLs, IADLs, reminiscence, reality orientation）to support the participant's memory. Moreover, in order to motivate the participant to undertake the training, they suggested using tangible equipment during the rehabilitation.

iii. Interests and concerns	Many concerns about the training context	The interview data revealed that the OTs frequently explained the training context to the participants, implying that they would need to acquire more information before completing the assigned challenge.
	Interested in similarities between their life experience and the training	During the interview, the OTs pointed out that the participants' preferences would affect their interest. In order to gain participants' interest, their life experience elements are integrated into the training.
iv. Aptitudes	Able to understand and learn the functionality of the computer	During the interview, the OTs said that the participants were capable of understanding the new platform, but it depended on their motivation. However, only 30% to 40% of them would be interested in adopting a new environment, i.e. computer-based training. The clarity of the OT's explanation was crucial in enabling participants to understand.
	High learning ability in understanding the context through visuals	The OTs explained during the interview that the quality and quantity of visualization is based on the sensory registration, which is required to support the participant's attention span.

	Fair adaptability in new environment	The interview data revealed that visual and hearing impairments can be crucial obstacles in the participant's ability to adapt to a new environment.
v. Motivations	Reason for quitting the game: feeling inferior because game is too difficult	The OTs from the interview suggested that the game difficulty should correspond to the player's ability in order to motivate the player to achieve the goal.
	External factors: duration of the training, good relationship between the therapist along with patient and verbal encouragement	The interview data showed that tolerance is required for the patient to undergo a sufficient duration of training. A good relationship with the OT can improve the player's tolerance.
vi. Competences	Good physical abilities, in terms of upper and lower limbs	The GNH data showed that all basic functional tasks involving upper and lower limbs were manageable for all the mild cases.
	Good cognitive abilities but weak working memory and attention skills	Both the GNH data and interview data showed that patients normally had good cognitive abilities, but their working memory and attention qualities were relatively weak.
	Communication skills are good, but sometimes they are unwilling to ask for help	During the interview, the OT responded that the participants could express themselves very well but sometimes their relationship with the OT

		would affect their engagement.
	Sensory disabilities: visual and hearing impairment	Visual and hearing impairment are common in elderly as shown in the interview responses.

This research identifies key features which have causative connections and will result in implications for the serious game design from the table above, thus are used to generate the MCI player persona. For instance, an MCI patient “seldom uses technology” (in (ii) actions and orientations) which causes only “approximately 30% to 40% of MCI to be interested in taking the initiative in new experience” (in (iv) aptitudes). This implies that one of the features in the MCI player’s persona is “not being familiar with technology”, thus an easy-to-learn game application should be designed for MCI players. This causative connection inference is used to select the key MCI player features which are included in the MCI Player (*Foon Lee*) Persona as illustrated in Figure 5-3 below.

Figure 5-3 MCI player (Foon Lee) persona

5.2.2 Crucial Behavioural Features for Occupational Therapist (*Ching Lau*) Persona

In order to adhere to a consistent standard in designing the persona for the proposed game, the crucial behavioural factors for the OT persona are selected using the same method as the MCI Player Persona in 5.2.1. The features of the OT persona are mainly obtained from the interview data results and are presented in Table 5-2:

Table 5-2 Features for the OT persona

Categories	Features of an OT	Justifications
i. Actions and orientations	High frequency of one-to-one training, such as individual-based cognitive rehabilitation and cognitive training	From the interview data, the OTs would assign all cognitive training to their patients in accordance with their medical history and capabilities. Due to the variation of the cases, one-to-one training is usually given to each participant.
	Preferred training contexts are physical training and cognitive training	The interview data revealed that physical and cognitive assessments were the main types of training contexts which the OTs would provide to their patients.
	Therapeutic training styles: group-based cognitive stimulation, personalized individual-based cognitive training and individual-based cognitive rehabilitation	The interview with the OTs indicated that they would provide all training styles according to their patients' needs and goals.

ii. Interests and concerns	Keen interest in using technology due to its diversity, safety and precision in measurement	During the interview, the OTs mentioned that technology could help to reduce their workload and achieve better training results. However, it cannot fully replace the role of OTs because existing technology is not developed enough to instantly spot out the player's problems and provide an in-depth analysis.
	More focused on the usability and effectiveness of the game, and less on how fun and engaging it is	The role of OTs as shown in the interview data is mainly to support the player in achieving the training goal.
	Serious concerns about the adaptability of gaming content	As revealed in interview data, the OTs need to ensure that the player can undertake the training smoothly. They need to provide support, such as the adjustment in image size if necessary.
iii. Aptitudes	Able to teach the patient to adapt to the new environment or context and provide an errorless learning context	As discussed during the interview, when the player encounters difficulties, the OTs need to provide the explanation and support to assist the player in completing the training.
iv. Motivations	The capabilities of the patient are sufficient to participate in the training: for instance, the patient can fully manage tasks with intact physical abilities, and cognitive	The OTs explained during the interview that only players with mild cognitive impairment and upper/lower limb functions can effectively participate in the training

	impairment remains at a mild stage	
	The relationship and cooperation between the therapist and patient	As mentioned in the interview data, a good relationship with the participant can motivate the OT to further help the patient.
v. Competences	Comprehensive understanding of the patient's condition	As discussed during the interview, the OTs needed to fully understand the player's profile to foresee any problems which they may encounter during the training

Cooper's method incorporates the designation of persona types to determine the target of the design, so as to achieve design solutions in a more focused way through prioritizing the persona needs. Since the role of the OT is to assist the MCI player - a primary player in completing the game, the method used in constructing the OT Persona as shown in Figure 5-4 is almost the same as the MCI Player Persona except for the physical and cognitive capabilities sections, which are not required. The OT is a served persona as they do not directly use the game interface but will respond to the game system and demonstrate the game functions to the MCI player when it is necessary. Despite the fact that the OT is not the primary player, they will also support the MCI player verbally throughout the game. Thus, the OT persona with crucial behaviours and key requirements are presented to further understand the quality of the OT in order to best support the MCI player. Although the OT is not directly using the game, they will be using the same interface designs as the MCI player.

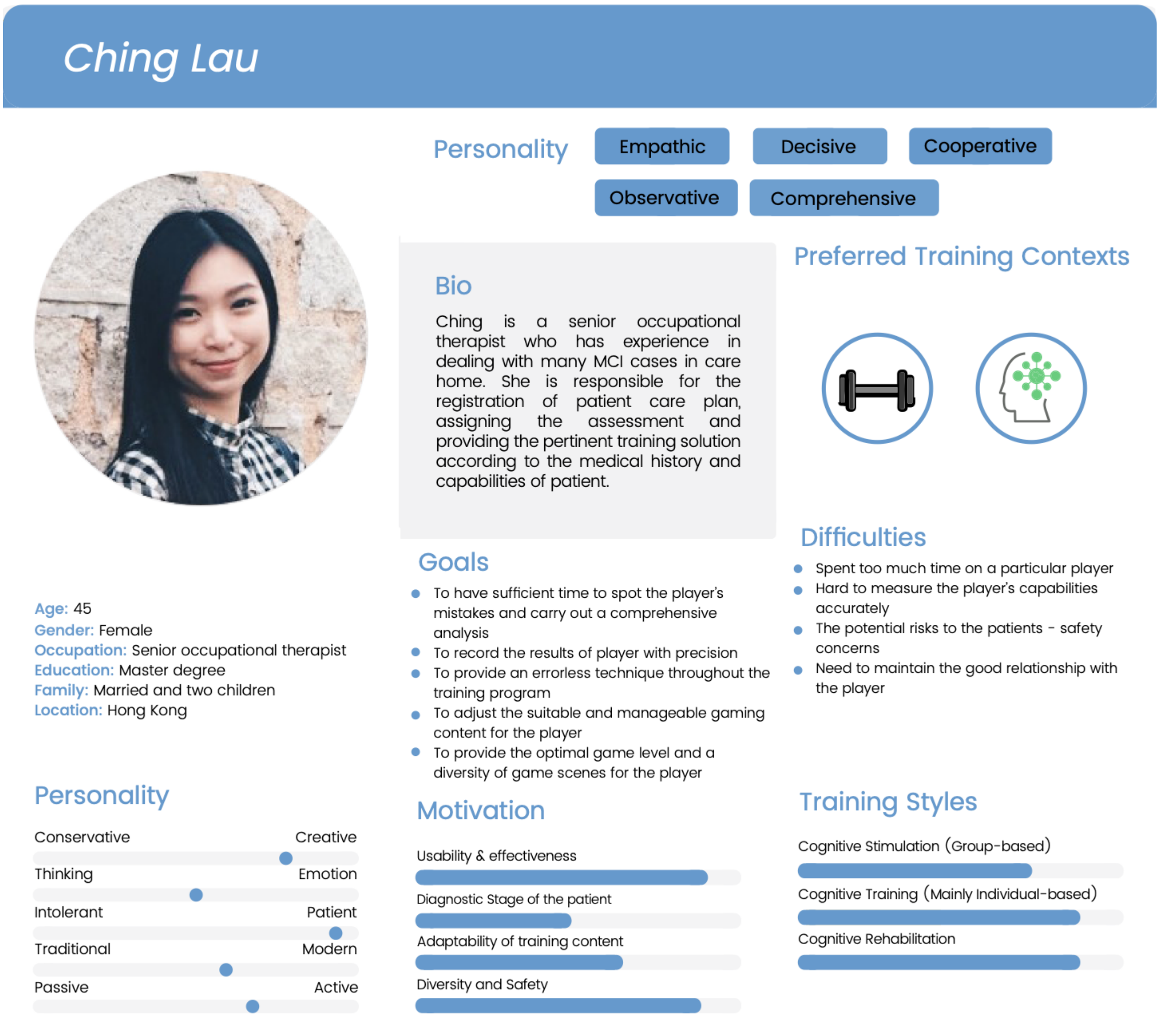


Figure 5-4 OT (Ching Lau) persona

As can be seen in this section, the personas (i.e. *Foon Lee* and *Ching Lau*) are formulated with reference to the GNH and interview data. These data sets have reflected the behaviours, goals and motivations of the MCI player and the OT which are now used to construct the context scenarios and key path scenario designs in the following sections.

5.3 Scenario Designs

Once the persona profiles are designed, the defined features, goals and difficulties form components of the scenario designs. The context scenario is the narrative-based description for depicting the "story" of the persona with their goals, desires and motivations [96]. The context scenario is then used to develop the key path scenario, which includes the data and functional elements which will interact with the persona. Selected features from the persona designs in Section 5.2 were first used to construct the context scenarios which are documented in Appendix B (Table B-1 and Table B-2). The MCI player and OT key path scenarios are then derived from their context scenarios to illustrate the entire serious game training procedure with interactions as follows.

5.3.1 MCI Player Key Path Scenario

The MCI player (*Foon Lee*) persona as portrayed in Figure 5-3 comprehends all the crucial behaviours, motivations, goals and other pertinent factors that may arise while undertaking the serious game training. These factors are presented in the context scenario which anticipates the performance and intentions of *Foon* from the beginning to end of the training. It begins with a brief background of how *Foon* is introduced to the training programme routine. *Foon* has been diagnosed with MCI. She participates in the training programme every Wednesday in a care home to strengthen her memory capacity. Her goals are to participate in a training programme that suits her preferences or past experiences, and to complete the programme actively without feeling belittled and confused. The context scenario from *a.* to *i.* in Appendix B (Table B-1) broadly exhibits *Foon*'s behaviours and responses to the training programme (i.e. serious game) in order to better focus the serious game design. The key path scenario is derived from the context scenario and describes how *Foon* responds to or interacts with the serious game interface. It is essential for the data and functional elements to appear on the user interface (UI) from the diagnosis submission to the training review stage so as to collate *Foon's* responses and interactions for constructing the key path scenario. The UI sketches are drawn accordingly and shown in Appendix B ((Table B-5). The following is *Foon*'s Key Path Scenario:

a. Early Wednesday morning, *Foon* is getting ready and preparing a full version of a diagnostic document that comprises all the background information in detail to join the training programme in the care home. This is the very first time she is going to the care home, so her grandchild, *Yuet*, is to accompany her to the centre, to help *Foon* get used to the new surroundings during the programme.

b. *Foon* and *Yuet* arrive at the care home and check in at reception. The centre checks *Foon*'s booking and assigns an available OT to follow up on her case. *Foon* submits the diagnostic document for *Ching* to set up a personal care plan in accordance with her diagnosis and abilities. *Ching* has to ensure that *Foon* is part of the MCI group and has intact physical abilities with no fracture or stroke.

c. *Ching* introduces the game-based training programme visually to *Foon* and asks *Yuet* to be with her throughout the entire programme. The training is set for around 30 to 45 minutes. *Foon* looks at the monitor and places both hands upon the motion capture device to calibrate the hand movements. The virtual hands are displayed in the game scene. *Foon* cannot see the contents clearly and asks *Ching* for help. *Ching* adjusts the content size from the menu bar at the top right corner to suit *Foon*'s vision quality, so as to improve the adaptability, and then continues.

d. *Foon* observes and follows *Ching*'s instructions pertaining to a set of hand movements which will be used during the training. It includes: (i)opposition, (ii)fist, (iii)grasp and release, (iv)pinching and (v)co-ordination; and other upper limb functions: (i)pressing/tapping, (ii)pulling and (iii)translating. *Foon* practices the hand movements for around 5 to 10 minutes, trying to perform the gestures with the given game objects and constantly checks with *Ching* if she is doing them correctly.

e. *Foon* has completed all the given tasks and the monitor displays the completion of the demonstration. By showing the "thumbs up" hand gesture to the monitor for 3 seconds, *Foon* is able to go to the "game levels" page. *Ching* sets the level for *Foon* to begin the game-based cognitive training by showing "thumbs up" for 3 seconds to enter the desired level. *Foon* looks at the game menu and picks one of the preferred training contexts provided (i.e. cooking scene) by showing "thumbs up" for 3 seconds. The chosen training context is familiar to her.

f. *Foon* explores the cooking scene with hand movements and tries to understand the game context. She uses the upper limb gestures which she practiced during the previous stage to respond to the tasks. When she lacks sufficient attention and working memory, the training system automatically provides support and gameful components to guide her in accomplishing the level.

g. Sometimes, she needs to ask *Ching* for further explanation of the game context, and *Ching* will walk *Foon* through some of the steps with hand movements.

h. *Foon* is able to finish the level without being distracted by errors because the training system will not display errors which demotivate her.

i. After the training, *Foon* tells *Ching* about her experience in using the game-based training. The game-based training has recorded and scored every single interaction that she has made. The system displays *Foon*'s results on the monitor.

5.3.2 Occupational Therapist Key Path Scenario

The occupational therapist (*Ching Lau*) persona in Figure 5-4 shows how *Ching* interacts with the primary persona, i.e. *Foon*, and the training system. The context scenario lists *Ching's* various job functions. *Ching* is a senior occupational therapist who has experience in dealing with many MCI cases in the care home. She is responsible for registering patients' care plans, assigning the assessment, and providing the key training solution according to the medical history and capabilities of the patients. The game-based training aims to assist her in recording the player's inputs with precision, allowing her to spend more time on monitoring the player's weaknesses. *Ching*'s context scenario as presented in Appendix B (Table B-2) articulates her role as an OT in assisting *Foon* to initiate the training programme and supporting user engagement throughout the game. The interaction between *Ching* and the proposed game is comparatively lesser than *Foon* as the role of the OT is focused on assisting the MCI player to adapt and attempt each stage of the game. Thus, the UI components include not only data and functional elements, but also MCI player documentation procedures, such as player registration in the beginning and data recording after the game. The following is *Ching*'s Key Path Scenario which reveals the demonstration stage and adjustment of screen size:

a. On an early Wednesday morning, *Ching* receives a new case (*Foon*). She evaluates *Foon*'s medical report and ensures that she is accurately diagnosed with MCI. She sets up the player's profile by inserting the data into the system.

b. *Ching* understands that *Foon* is illiterate and has visual impairment which has been fully recorded in her medical report. In this case, *Ching* needs to display several training elements on the monitor to gauge her visual ability. She activates a set of physical and cognitive functions in the game settings and enlarges the size of the training elements by sliding the menu bar button with a pinching gesture for *Foon* to clearly see the images. Then, they proceed to calibrate the hand movements.

c. *Ching* demonstrates and practices a set of designated hand gestures (see *F-d.*) with *Foon* before the game-based cognitive training. She observes how *Foon* interacts with the game objects and ensures that she can apply all the hand gestures. Then, *Ching* motivates *Foon* by reviewing the completion of the demonstration stage complimenting her for passing all the given tasks. She then moves on to the game-based training.

d. *Ching* displays the game menu on the monitor and patiently introduces and walks through some of the functionalities of the game with *Foon.*

e. Sometimes, *Foon* seems confused with the action and context while trying to respond to the task. Meanwhile, *Ching* needs to record and discern the difficulties that *Foon* is encountering.

f. *Ching* motivates *Foon* to carry on with hints and verbal encouragement when *Foon* is inattentive or unmotivated during the training.

g. Finally, *Foon* relates her attitudes and feelings during the game-based training experience to *Ching*. *Ching* documents *Foon*'s comments and records the touchpoints, emotions, thoughts and level of personal engagement during the training.

h. *Ching* analyses all the collected data and findings using the scoring system to determine the suitable game level for *Foon* in the next training.

The following section is going to depict the user experience of the proposed game.

5.4 Journey Map Designs

After creating the persona and scenario designs in 5.2 and 5.3 respectively, it is important to generate a full picture of the user experience in a journey map which depicts an average day for the MCI player and occupational therapist personas. The journey map is based on the context scenarios which have been described in 5.3, illustrating the MCI player and OT interactions with the proposed game. The journey map visualizes the user experience through five journey phases which both personas undergo: (i)player profile sign up, (ii)demonstration and practice, (iii)game-based cognitive training, (iv)results and review and (v) post-training as stated in Figure 5-5 and Figure 5-6.

MCI player *Foon's* journey map comprises her touchpoints and interactions at each of the phases. These are inferred from her persona profile containing her personal background and motivations. *Foon* actively responds in phases (ii) and (iii) as she is the primary player in the programme. During the programme, the OT can get involved and assist *Foon* to solve the problems which she may encounter. In Figure 5-5, phases (iii) to (v) in the secondary path of "Level of Personal Engagement" show *Foon's* various choices and emotions.

In *Ching*'s journey map, *Ching* has to assist *Foon* throughout the process, from evaluating *Foon's* medical report during phase (i) to providing evaluations in phase (v), even though she is not the primary player in the training programme. In Figure 5-6, the level of *Ching*'s engagement is comparatively higher than *Foon* since *Ching* is responsible for assisting *Foon* and recording her responses during the game. *Ching's* engagement level refers to the engagement with the game and the MCI player, so it is more like "an experience engagement" rather than "a game engagement". Regarding the interactions between *Ching* and the game, she only needs to interact with the system during the demonstration phase and during the times when *Foon* needs help to continue with the game, therefore her primary job is to record the data and keep an eye on *Foon's* interactions with the game.

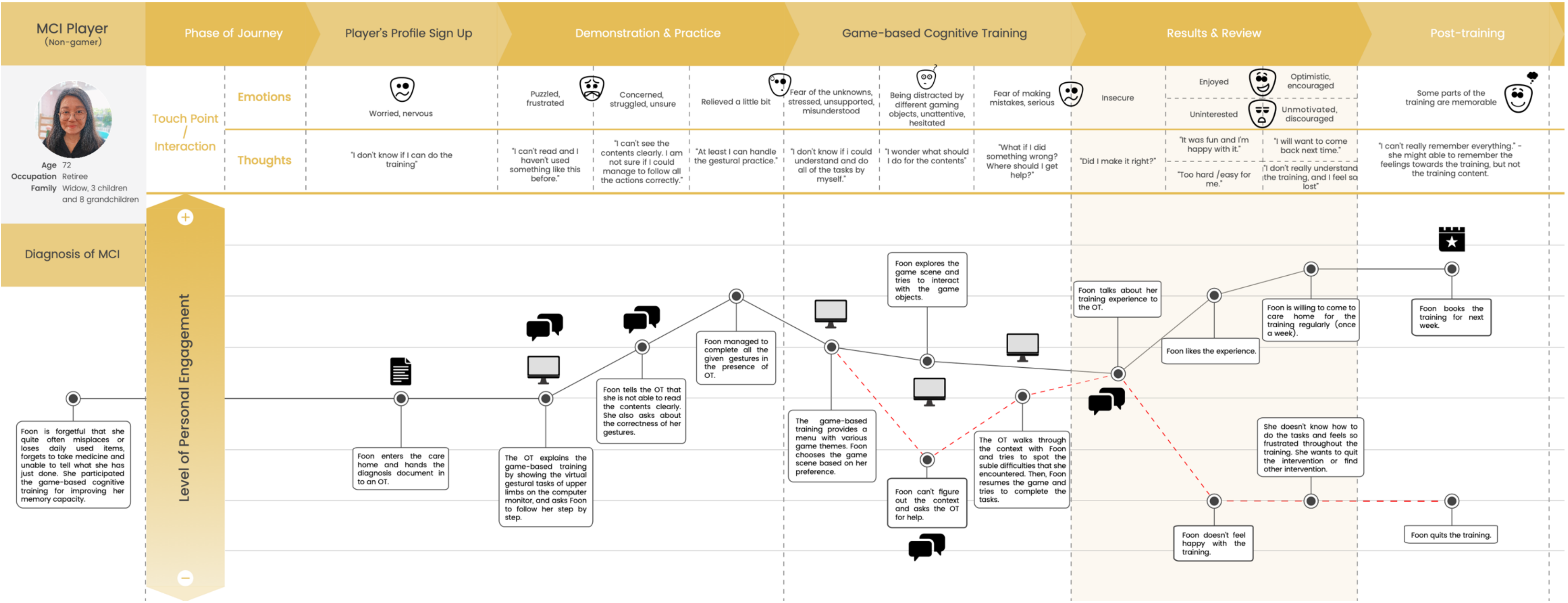


Figure 5-5 Foon Lee journey map design

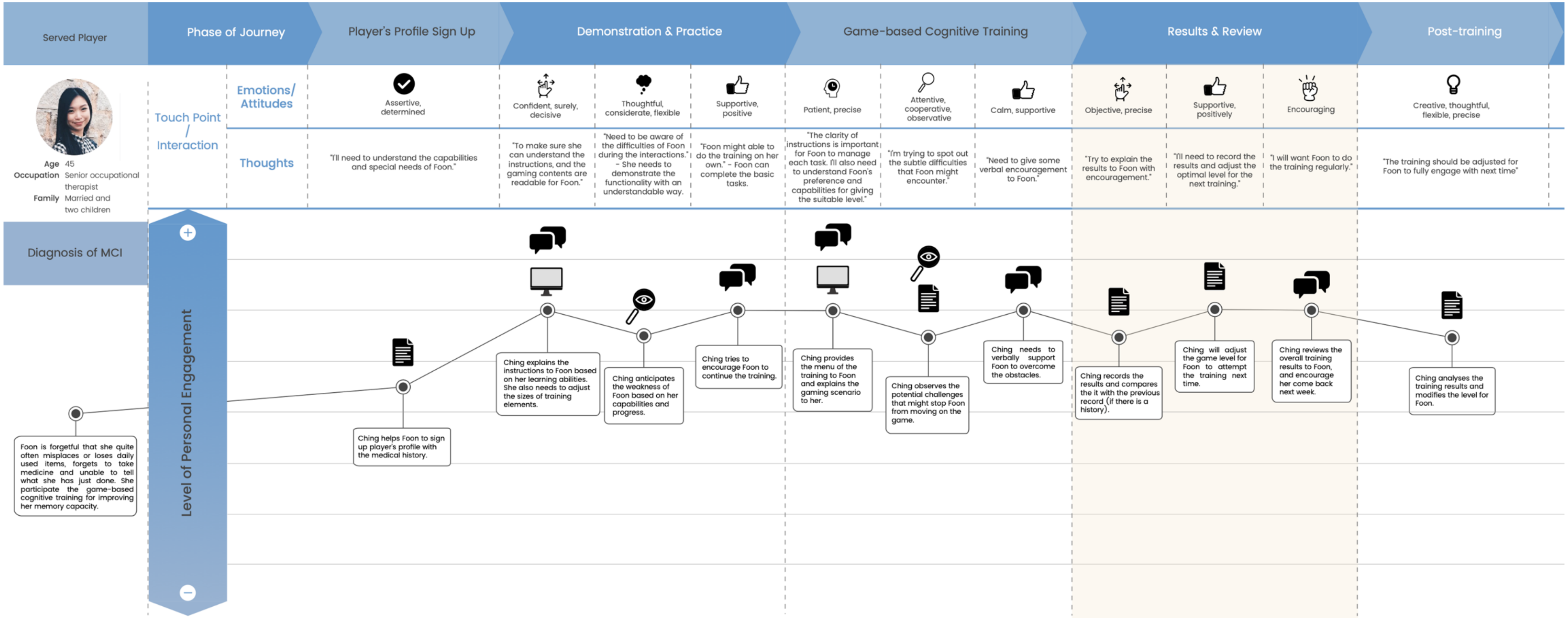


Figure 5-6 Ching Lau journey map design

The above journey maps comprehensively illustrate the user experience of the proposed game. They serve to further improve the experience of the proposed serious game.

5.5 List of Functional Requirements

Based on the above findings, *Foon* and *Ching* have different functional requirements which the proposed serious game needs to address. The functional requirements are set according to the touchpoints and interactions in the journey map which incorporate the crucial behaviours derived from the user persona and predictions formed from the scenarios. The visual designs will be created based on the requirements to suit the persona. For instance, *Foon* is puzzled and frustrated to use a new platform to undergo intervention as she cannot read due to her low educational background (no formal education). In this case, *Ching* needs to assist *Foon* to calibrate the device according to her hand position, and ensure that her virtual hands are display in the play area. Similarly, a demonstration phase provides all designated gestures for *Foon* to complete it, which aims at resolving her struggles prior to the game phase. Meanwhile, *Ching* needs to respond to the game interface according to *Foon*'s needs, such as adjusting the screen size. The various functional requirements are compiled as follows.

These are the functional requirements for the MCI player:

- Display virtual hands in play area after automatic recognition of player's hands
- Calibrate the device from the device panel (supported by the OT)
- Adjust size of work area by using the slider
- Confirm input using 3-second thumbs up gesture.
- Display all designated gestures on side bar at key input stages: eight designated gestures: (i)opposition, (ii)fist, (iii)grasp and release, (iv)pinching, (v)co-ordination, (vi)pressing/tapping, (vii)pulling and (viii)translating.
- Complete the demonstration when all the designated gestures are completed.
- Display completed tasks at the end of the demonstration.

- Provide hints and attention support
- Provide OT verbal guidance with hand movements
- Reveal the results in the form of a list with scores and errors at the end of the game.

Ching's (the OT) functional requirements are not as many as *Foon's* (MCI player) since *Ching* only supports *Foon* in interacting with the game objects, and the process of calibration is specifically for the MCI player, not the OT.

The following are the functional requirements for *Ching* (the OT):

- Insert the MCI player information on profile page.
- Adjust the size of the UI elements on the screen.

There are other requirements which do not relate directly to the game. For example, *Ching* will verbally support *Foon* during the demonstration (as in *F-d.*), but this does not involve any interactions and thus is not a functional requirement. Likewise, scenarios *C-e.* to *C-h.* do not involve any interaction with the game:

- List out the player's difficulties
- Record and anticipate the player's problem
- Provide verbal encouragement
- Give some hints to motivate the player to continue the game
- Record the player's review of the game
- Jot down the player's attitudes and feelings toward the game
- Analyse the player's data by reviewing the scores and errors from the game

This section has presented the list of *Foon* and *Ching*'s functional requirements of the game before progressing to the UI design stage. However, the visual design elements need to be analysed in advance because they are highly important to the branding of the proposed serious game. The following section presents the visual design which makes the system more purposeful and functional for the MCI player.

5.6 Visual Design

The presentation of the above personas and scenarios of the MCI player and OT is to build a goal-directed serious game which incorporates a selection of purposeful visual design elements. By integrating the basic elements of visual interface design, the core visual ideas along with various properties are meant to support the players in interacting or communicating with the system. The following visual considerations as inspired in [96] describe an array of properties, i.e. shape, size, colour, texture, orientation, position and text and typography, which are intended to create design consistency and harmony in the gaming objects throughout the system in order to communicate better with the target players. The visual design of the proposed system is presented in Figure 5-7 and analysed in this section. The comprehensive interface design is documented in Appendix B.

Figure 5-7 The design of key visual design elements for *A-go!*

The serious game design is primarily divided into two phases. The first phase provides a demonstration for the player to practice the key interactions which are necessary to manipulate target objects and navigate the game – the interaction logic. This phase focuses on MCI player's physical capabilities where the player practises all designated hand gestures prior to the cognitive tasks by using their upper limbs, i.e. both hands. It requires the player to understand the interaction through eight-gesture tasks in controlling the virtual hands within the game scenes. The second phase begins the actual game with the training content. It is important to note that the physical hand gestures are the player's interactions in response to the game tasks. This ensures that hand gestures are not an impediment to the cognitive training. Four game themes (i.e. *Sandwich Making* (IADL), *Toileting* (ADL), *Reality Orientation Board* (reality orientation) and *Mahjong* (reminiscence)) are the cognitive tasks designed for the player to work with the hand gestures. The visual design of game objects in the first phase is significantly simpler than the visual design of game objects in the second phase. This is because the first phase demonstration is intended to allow the player to pick up practical gestures and movements which will be applied in the game, without paying much attention to the scenario context. Therefore, the simplification of the geometrical design utilized in the first phase to distinguish between interaction logic and actual training contents, e.g. virtual hands, as shown in Appendix B (Table B-5) scenario-demonstration (low-fidelity UI Sketches for *Foon Lee*), so that the player can focus on learning designated interaction. As mentioned previously, the use of 2D and 3D may affect the cognitive load of the player thus a flat design is widely used in *A-go!*. Furthermore, virtual hands with a simple design are used throughout *A-go!* to enable the player to differentiate between their hand movements and game objects easily, which further assists the player in being more focused on their tasks. Additionally, *A-go!* offers a wide bandwidth of input to enable the player to manipulate the game objects with eight gestures as freely as in reality. Other devices, such as joysticks, may highly hinder the player to apply the actual hand movements towards the game objects. On top of that, scenario context is of paramount importance in the second phase when the player starts the game proper, therefore the visual design of the second phase gaming objects is more detailed and realistic.

To create an effective visual system which accommodates the various needs of the players, the size of the work area can be adjusted from the toolbar as demonstrated in Figure 5-8.

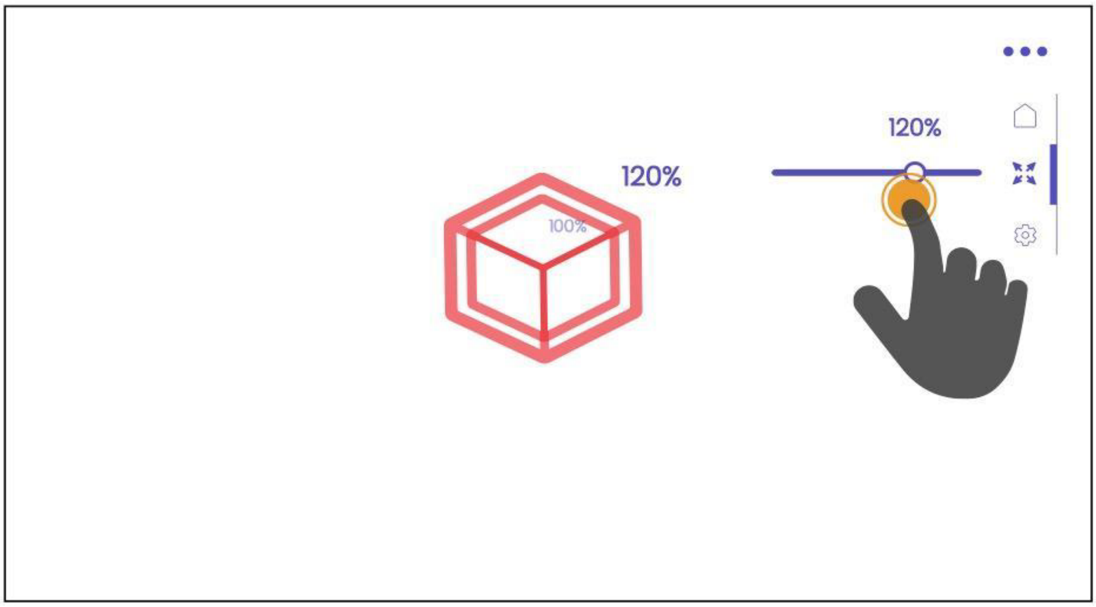


Figure 5-8 The screen settings can be adjusted through the toolbar by the OT

Additionally, the form of interface design varied between the target gaming objects within the work area and non-target gaming objects elements so as to emphasise the important gaming objects and information hierarchy. For example, the visual icons represent the set of toolbar functions with simplicity.

In Figure 5-7, the different colours of the colour palette play an important role to convey various types of information throughout the game. The use of colour classification enables the player to more easily understand the information presented on the game heads-up display (HUD). For example, purple represents information about the player's current status or progress. This shortens the time of the player to understand the responses from the game system by a quick glance at the colour. Likewise, the virtual hands on the game screen which display the proper physical gestures are highlighted in yellowish orange, which helps the player to mimic and perform the correct gestures. Colour wheel [97] is a common design guideline for colour considerations, arranging specific colour usage in interface design. For example, the use of complementary colours, e.g. purple and yellowish orange, are applied to demonstrate the information hierarchy with high colour contrast to enable the player to intuitively understand the visual message. To develop a visual perception in the player to interact with a certain target object, high intensity of hue and saturation in red acts as the hint to imply the importance of the event. Moreover, the opacity has been used on all icons to distinguish the selection, deselection and hovering (from high to low values of the opacity) of the game objects. These colours make the training system more accessible to players.

HUD superimposes the real-time information onto the player's screen, which enables the player to focus on the 3D work area while allowing the player to be aware of themselves in the game via the player status. To establish an obvious distinction between the work area and heads-up display (HUD), a flat design is employed for the HUD area to clearly show information without complicating the content visually. Thus, the flat design texture in the HUD area contrasts with the work area and allows the player to pay more attention to the given tasks in the work area.

The game also uses arrows to convey the movement of game objects and act as a support for orienting the player's direction. For example, the arrows in Figure 5-9 *i. Opposition* point inwards above the thumb and index fingers' position to guide the player in performing thumb-index opposition.

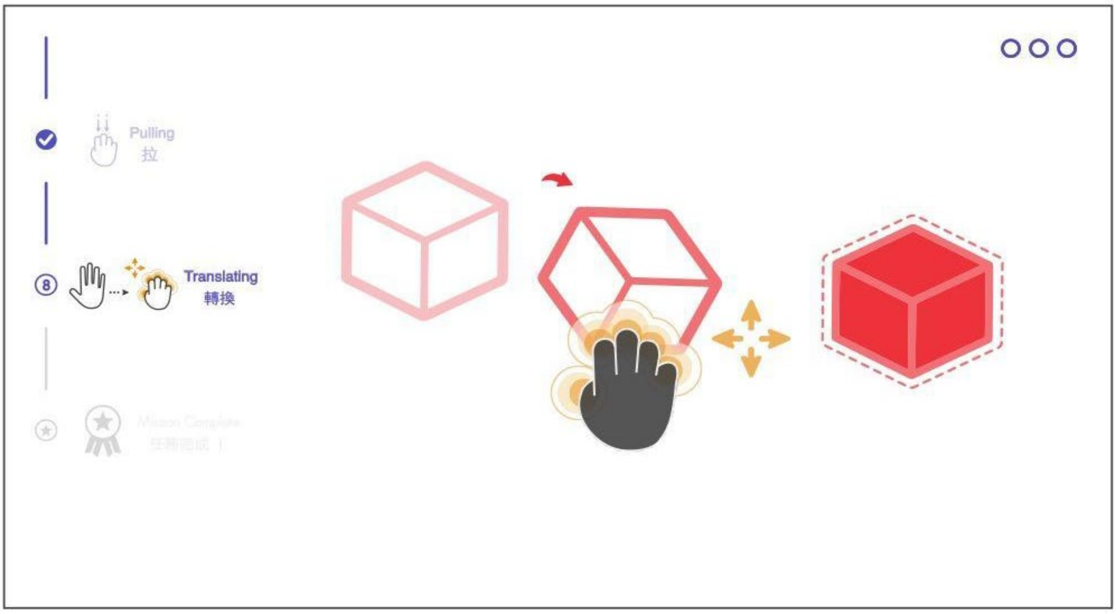


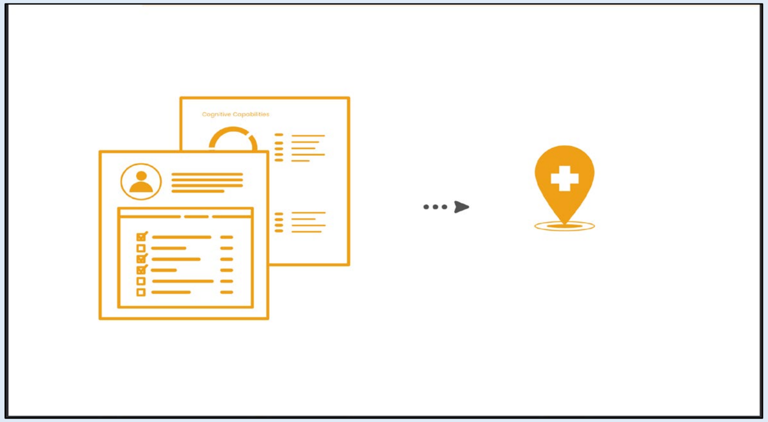
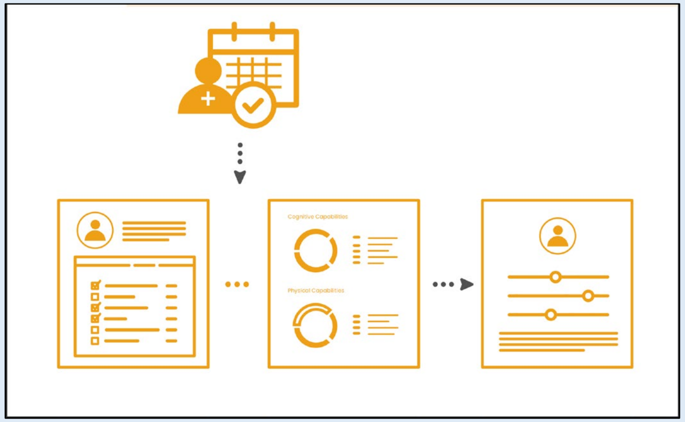
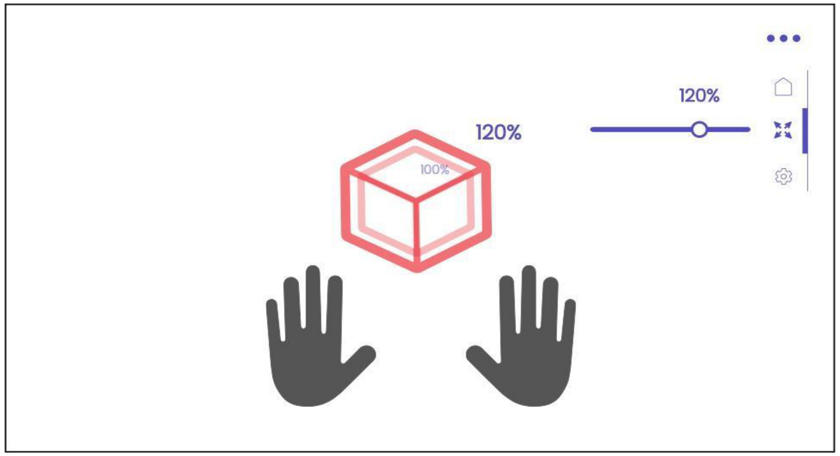
Figure 5-9 Yellow arrows as the orientation guidance to assist the player in completing the task

The player's progress and status are positioned on the left-hand side of the screen while the work area is positioned on the right as shown in *F-d*. This organizes the structure of the serious game interface and helps the player to locate information and take the appropriate actions quickly.

Regarding the text and typography used in the game, it is best to keep messages to the OT within a few words, while communicating with the player mainly through visual non-text gaming content. Helvetica, a sans-serif typeface, is the font applied for English words as it provides a plain form of letters without decorative flourishes on the ends of the strokes, and 黑體 is the font for traditional Chinese words in the game. In order to enhance communication, all texts are displayed next to icons, which has been illustrated in Figure 5-7, when demonstrating given tasks to the player. This ensures the gaming context is clear and comprehensible, enhancing player—attention and recognition. In the aforementioned physical capability stated in *Foon*'s persona profile in Section 5.2, hearing and visual impairments are the constraints for the MCI player to play the game as these impairments are associated with their age. However, *A-go!* is designed for those with intact physical upper limbs or the visually-impaired, but not for those who are almost or fully blind, thus screen size adjustment and images are well-supported to enable the player to receive the messages given from the game. These can resolve the player's struggles in first attempting the game. *A-go!* provides comprehensive visual and auditory support to the MCI player. However, visual and auditory aids can be further taken into account in future development through using accessibility consideration guidelines [98] to assist players according to their impairments. For example, a symbol-based chat [99], namely *Phantasy Star Online*, can display a set of emoticons to enable the MCI player (i.e. *Foon*), who is illiterate, to choose a desired action in the game, and pre-recorded voiceovers [100] can replace the text to explain the scenarios to the player via a narrative. This can enrich the gaming experience and learnability, and importantly ascertain that *Foon*, who has received no formal education, can adapt to the game.

The high-fidelity UI sketches based on the general visual design elements are presented in Table 5-3 and Table 5-4, while the low-fidelity UI sketches are documented in Appendix B (Table B-5 and Table B-6). The sketches start from the beginning of the training programme and document the serious game training until the evaluation section.

Table 5-3 High-fidelity UI sketches for Foon Lee

High-fidelity UI Sketches
 


Demonstration

i. **Opposition**

ii. **Fist**

iii. **Grasp and Release**

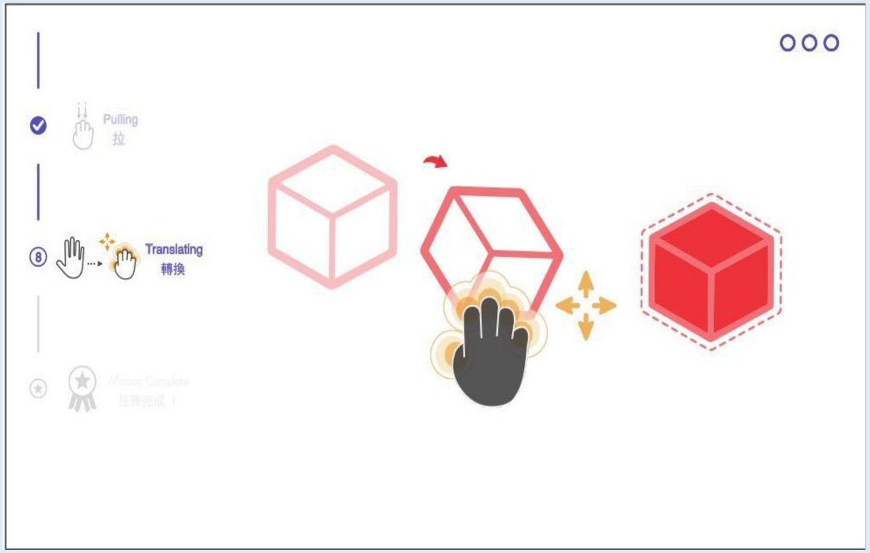
iv. **Pinching**

v. **Co-ordination**

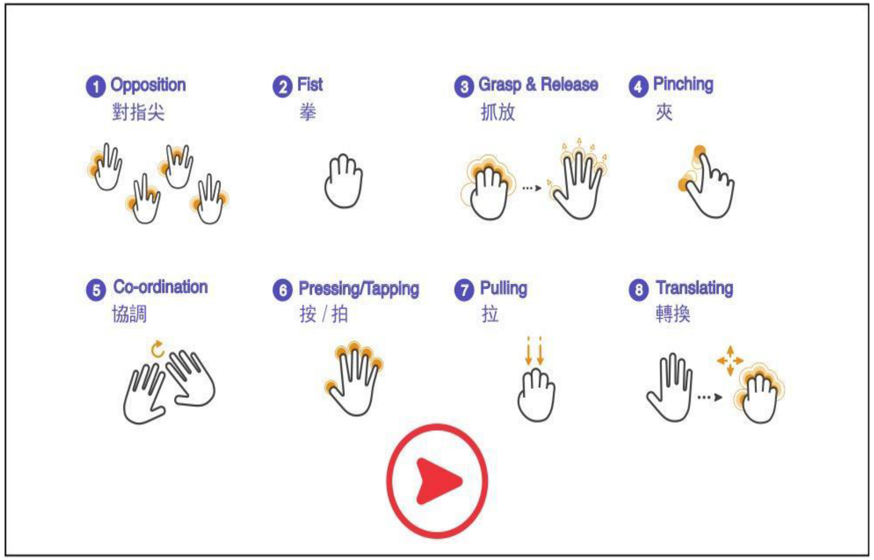
vi. **Pressing / Tapping**

vii. **Pulling**

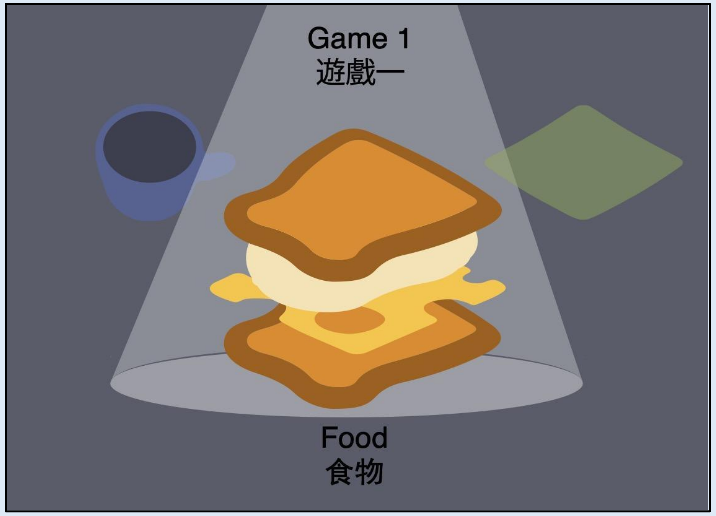
viii. **Translating**

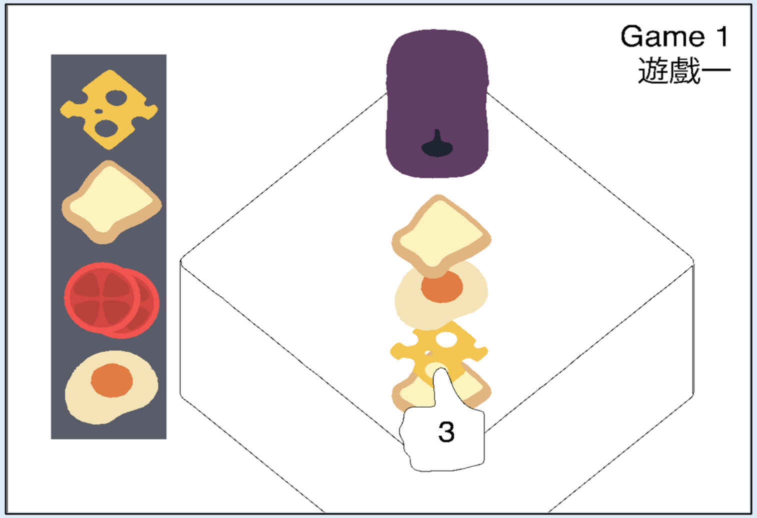


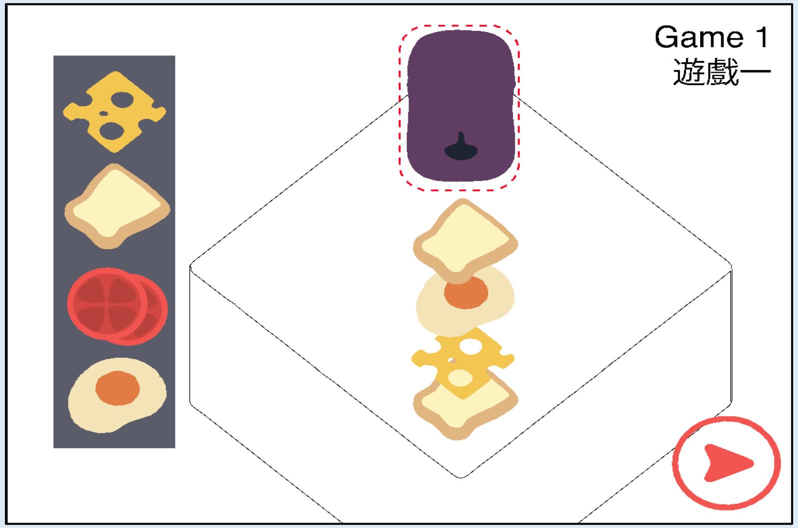
Completion of demonstration

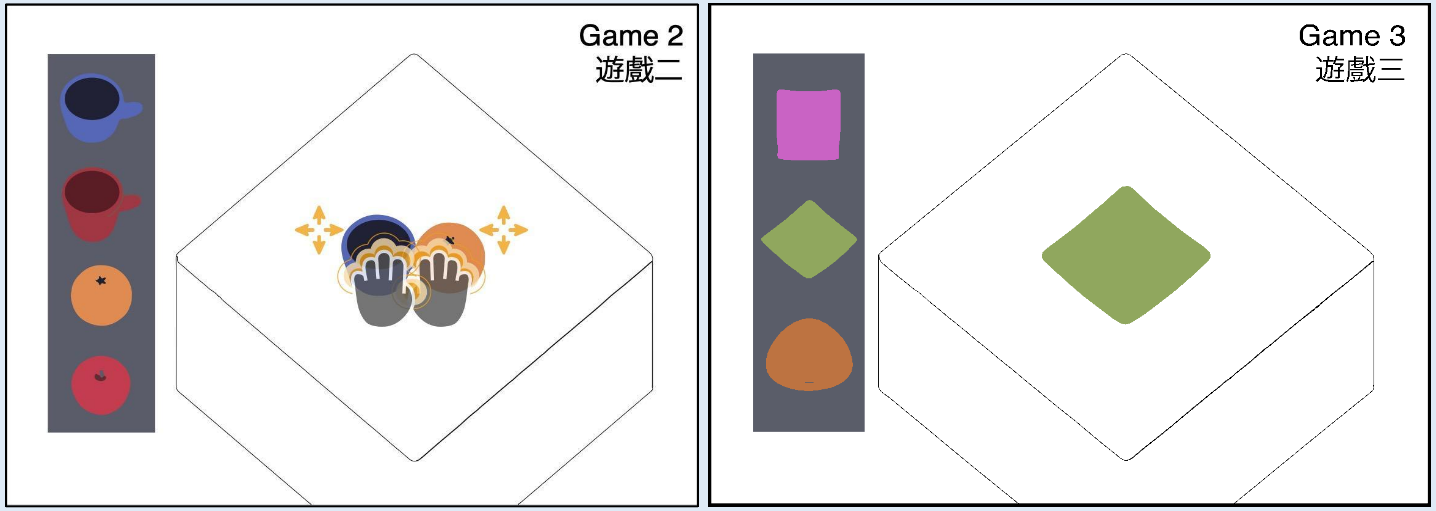


Game scenes



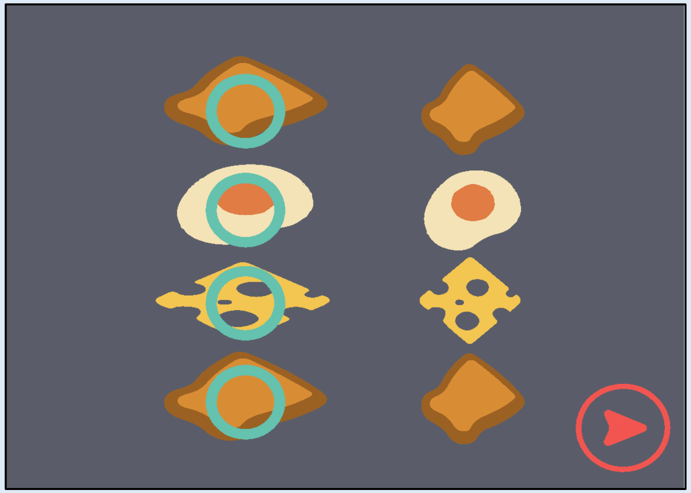


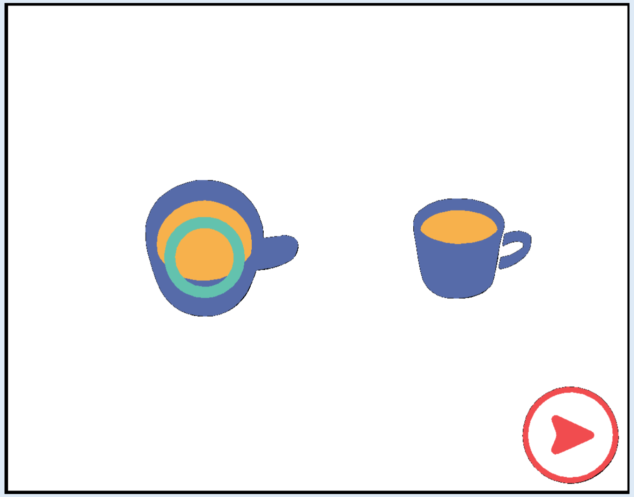




Verbal guidance with hand movements (This interaction will be using the same screen as in scenario *F-d.* or *F-f.*, e.g. *Foon* might be confused or forget to use the designated hand gestures, so that *Ching* would need to guide her with the hand movements.)

Results





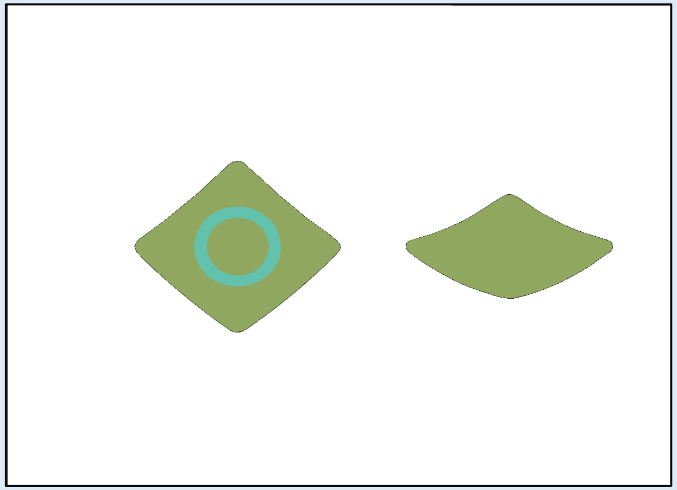
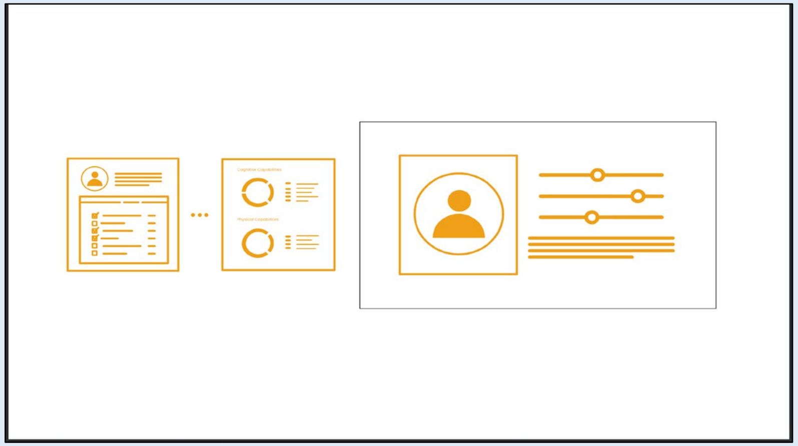
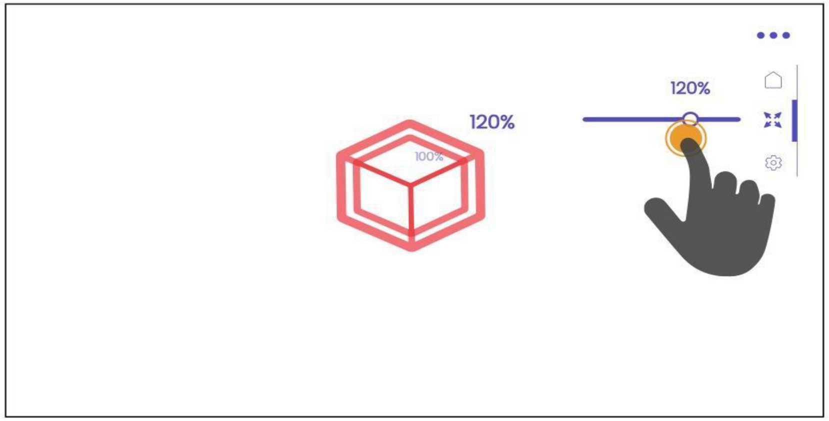
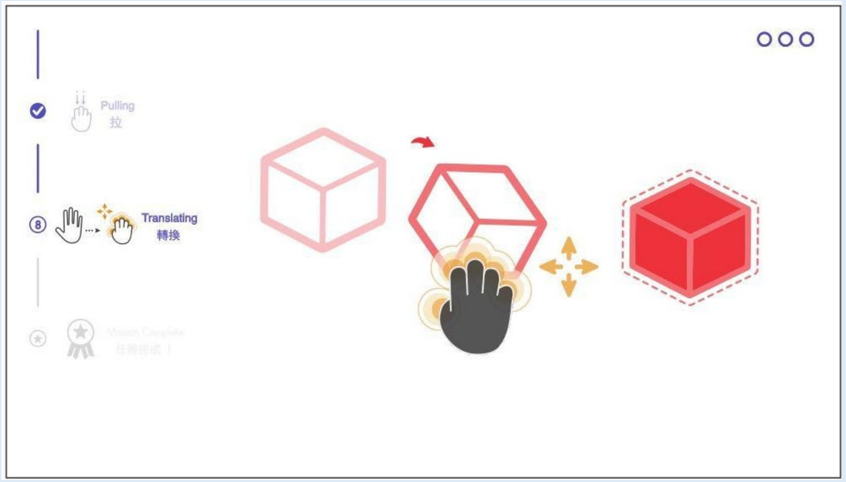


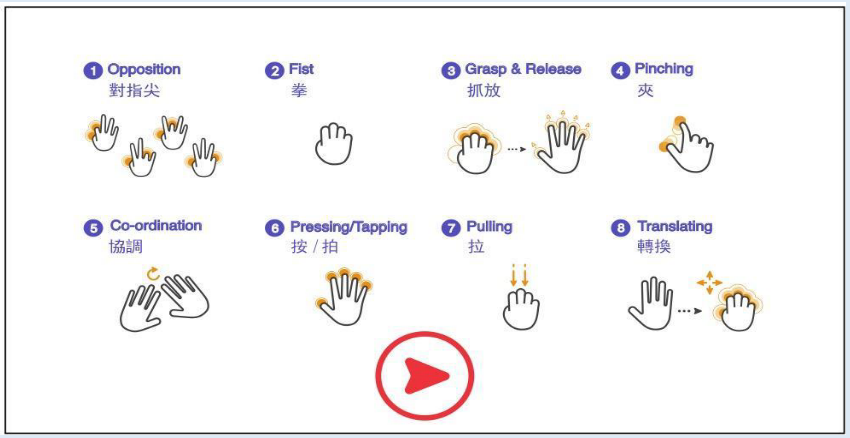
Table 5-4 High-fidelity UI sketches for Ching Lau

High-fidelity UI Sketches



Demonstration



Completion of demonstration



These scenarios i.e. *C-e.* to *C-h.* do not involve any interaction with the game. **Listing out *Foon*'s difficulties**
Verbal encouragement
Experience comments
Data analysis

5.7 Conclusion

This chapter used the *MCI-GaTE* from the previous chapter as a reference for designing the models, i.e. personas, scenarios and journey map designs, which illustrate MCI player (*Foon Lee*) and OT's (*Ching Lee*) initiation into the training. Referencing Alan Cooper's goal-directed design methods in creating personas and scenarios, an iterative design process using the GNH interview data resulted in the creation of MCI player and OT personas and their respective key path scenarios with UX&UI designs. The personas were designed by recording the crucial behaviours and key features of *Foon* and *Ching*, which were then used for developing "a story" which depicted their training programme performance along with key interactions. Then, the journey map designs presented the user touchpoints and emotions where *Foon* (the primary persona) has a more fluctuated engagement level than *Ching*, who only has to assist *Foon* during the training programme. The persona, scenario and journey map model designs were followed by a list of functional requirements and an explanation of the game's visual designs with UX&UI sketches, in order to illustrate user interactions with the game. After completing the aforementioned processes, the realisation of the game is ready to be presented in the next chapter.

6 Chapter Six – Realisation of *A-go!* as an Interactive High-fidelity Prototype

In order to demonstrate the use of *MCI-GaTE* as presented in Chapter 4, this chapter introduces *A-go!*, an immersive serious game targeted at MCI players and the OT, where the OT may use it as an assistive cognitive training tool. The chapter is structured as follows: Section 6.1 explains the scope of the serious game realisation; Section 6.2 presents how the selective elements which derived from *MCI-GaTE* creates *A-go!,* a design artefact; and introduces the applications used for testing the gameplay of *A-go!*; Section 6.3 demonstrates the relevant therapeutic, core gaming and motivational elements from the framework which are integrated into the game environment; and Section 6.4 concludes the chapter.

6.1 Introduction

MCI-GaTE was constructed inductively through the holistic literature survey and GNH data of thematic analysis which enabled successive refinements. The in-depth interviews with the OTs were then conducted, where they were asked to review a close-to-final iteration of the framework, which fed into final refinements including consolidating the predefined elements. To demonstrate the use of *MCI-GaTE*, which may serve as an effective means for physical and cognitive rehabilitation for the players with MCI, a serious game was designed in the previous chapter. This chapter presents the realisation of that design as *A-go!*, an immersive serious game targeted at an MCI player and their OT, designed through the exploitation of *MCI-GaTE.* Immersion is considered as "the subjective feeling of being enveloped by the games' stimuli and experiences" [101]. Therefore, *A-go!* exploits gesture recognition and 3D game objects from a first-person perspective to facilitate immersion without requiring any physical HMD (head mounted device), which would prove impractical for the targeted elderly players. Since this research focuses on the serious game design, and not implementation, the formative evaluation will be obtained (detailed in Chapter 7) through an interactive, responsive high-fidelity prototype running on an iPad alongside an *InVision Studio* application, where the OTs have to use the direct manipulation on the touchscreen. The interface designs, given tasks and game objects, however, remain in 3D to provide the same design methodology. The 2D and 3D assets for the game were created in *Autodesk Maya 2019* and *Adobe Illustrator CC*. The virtual hands within the 3D space are responsively operated through point-and-click input gestures, and they provide real-time feedback which instantly show the actual interaction between the player and the VR scene as would be captured by an infrared image controller such as *Leap*.

6.2 Use of *MCI-GaTE* for *A-go!*

The establishment of *MCI-GaTE* begins with assembling the analysed data in accordance with published literature articles, GNH data and in-depth interviews with the OTs, thus facilitating *A-go!* as a proof-of-concept serious game. *A* suite of themes derived from *MCI-GaTE* are embedded in *A-go!* highlighting significant level of acquisitions for producing a set of games with various themes for MCI player. The main concept of *A-go!* is to deliver a goal-direct serious game for MCI player by implementing a comprehensive personalised approach with four aspects (the sectors of the framework): (i) *MCI Player Profile* encompasses MCI player background and physical and cognitive capabilities to ensure the player complies with the criteria of MCI player profile; (ii) *Therapeutic Elements* offers a wide range of common therapeutic tasks and scenarios that the MCI patients usually use during therapy; (iii) *Core Gaming Elements* have been integrated into various rehabilitation by using gamefulness and playfulness to enhance player's motivation and engagement; and (iv) *Motivational Elements* not only aims at motivating MCI player but optimising adherence to therapy to maximize its effect through appropriate gameful and playful elements. Given the functions of these four sectors, *A-go!* embraces different degrees of theme selection for optimization.

MCI Player Profile is a crucial part for personalisation where the pre-assessment takes part to evaluate the player's background, physical and cognitive capabilities. *Player Background* (*education, tolerance* and *consciousness* levels) is the basic threshold to determine the suitability of the game level for the MCI player to perform the tasks. *Player Physical Capabilities* are involved in *A-go!* including all *upper limbs* (presented as eight designated hand gestures) and *lower limbs* (*sitting balancing*), *potential impairment* (size adjustment for visually impaired player and visual support for hearing impaired player).

Even though the full MCI player profile is incorporated into *A-go!*, it is noted that the nursing home residents had a poor condition in *standing balancing* (Figure 3-10). Moreover, the OTs revealed that upper and lower limb tasks tend to be assigned separately to the patients due to cognitive load concerns. Consequently, the lower limb tasks embodied in *A-go!* are *sitting balancing* only so as to optimise the patients' cognitive capabilities under light physical interaction conditions. In addition, *other physical tasks* are not deployed as only MCI patients who are in late-stage dementia may manifest signs of other physical impairments affecting mobility and gait. *Therapeutic scenarios* are presented as ADL (*Toileting game*), IADL (*Sandwich Making game*), reminiscence (*Mahjong game*) and reality orientation (*Reality Orientation Board game*) activities, to reflect those used in conventional rehabilitative therapy.

Choosing the appropriate *core gaming elements* for *A-go!* depends on the MCI context, therefore, the themes carry different degrees of usage to offer an effective training tool. A first-person *player's perspective* has been adopted throughout to enable the MCI player to focus on their tasks with the designated hand gestures, thus *A-go!* is not *avatar-based*. *Tutorial and guidance* and *HUD design* are primarily manifest in the form of a demonstration phase, with a minimal HUD design subsequently to provide some *contextual awareness* and report *player's progress* and *feedback* in a manner that reduces cognitive load and supports the adopted errorless *learning approach*. Thus, *pointsification, player's rewards* and *achievements* (from motivational elements) are not employed. *Metaphorical graphics* serve to assist the MCI player in understanding their status. Overall, *flow* helps to sustain the MCI player's motivation and enjoyment, supported by implicit use of *narratives* within the context of individual therapeutic scenarios. In terms of *2D/3D environment*, *A-go!* is predominantly a 3D game space with 2D virtual hands in order to help the MCI player more readily distinguish their movements. Together with *personalisation* and *controllability*, these elements are complementary to each other, providing *behavioural flexibility* to enable the MCI player to manipulate the game objects via their own hand gestures with responsive *feedback* according to their personal capabilities. *Affection* and *self-representation* are not specifically apparent, but the use of reminiscence-based therapeutic scenarios is likely to engender them somewhat.

From the *motivational elements*, since *supervision and verbal encouragement* are provided by the OT, *A-go!* adopts *duration* guidance rather than time limits (15-20 mins for demonstration and 15-60 mins for therapy) and uses essential on-screen prompting and feedback. *Discoverability* and *autonomy: freedom of choice* echo *behavioural flexibility* to allow the MCI player to intuitively explore the game scene. *Distractors* are reflected in the game's levels and player's *competence: skills, challenge*. However, the distractors are simple since MCI players may be more sensitive to them due to their generally lower attention level (Figure 3-6). Similarly, *simplicity of game objects* is highly utilised throughout the game to enable players to focus, albeit in conjunction with *realism of graphical model* so that objects may be recognisable by the MCI player as those from daily life, depending on their cognitive load and attention level. Due to the standing balancing physical tasks not being adopted at this stage, *tangible tools* are not utilised. The OT suggested that multi-sensory elements can further promote MCI player's cognition and enhance their motivation during the game, however, this is beyond the scope of this research. However, *real-time game objects* ensure that the player's hands are synchronised with those on-screen and help to facilitate the sense of *immersion: player's experience*. While the involvement of the OT in providing support at all times may provide some notion of *relatedness: cooperation, social collaboration, A-go!* is not a co-operative or collaborative serious game per se as this would require assessment comparisons to ensure players of similar capabilities.

The above listed themes are ubiquitous in serious games but the themes that were selected and embedded in *A-go!* are presented with a sufficient degree to achieve the research objectives and to be validated and discussed at length in the subsequent chapter.

6.3 Game Architecture

The game architecture of *A-go!* is illustrated in Figure 6-1 and composed of several components that are now discussed. The architecture serves to represent an intended implemented environment involving *Leap* and *Unity*, and various data sources, such as the player profile. The intervention is led by an OT with prior introduction to the MCI player in using *A-go!* in a clinical setting. *A-go!* is run using eight designated hand gestures as user inputs through a natural user interface (NUI) provided by a *Leap* controller in front of the display. The components of *MCI-GaTE*, i.e. MCI player profile, therapeutic, core gaming and motivational elements, are used within the game environment during the demonstration phase, themes, game levels, tasks and game scenes. Pre- and post-assessment are updated in accordance with the scores and errors recorded by the OT from the game. As stated previously, the implementation per se is beyond the scope of this research which is focused on design. Thus, the high-fidelity prototype developed for this research conforms with the architecture but represents the interface rather than the underlying logic and processing which remains as further research. The following subsections elaborate the details of the game architecture of *A-go!*.

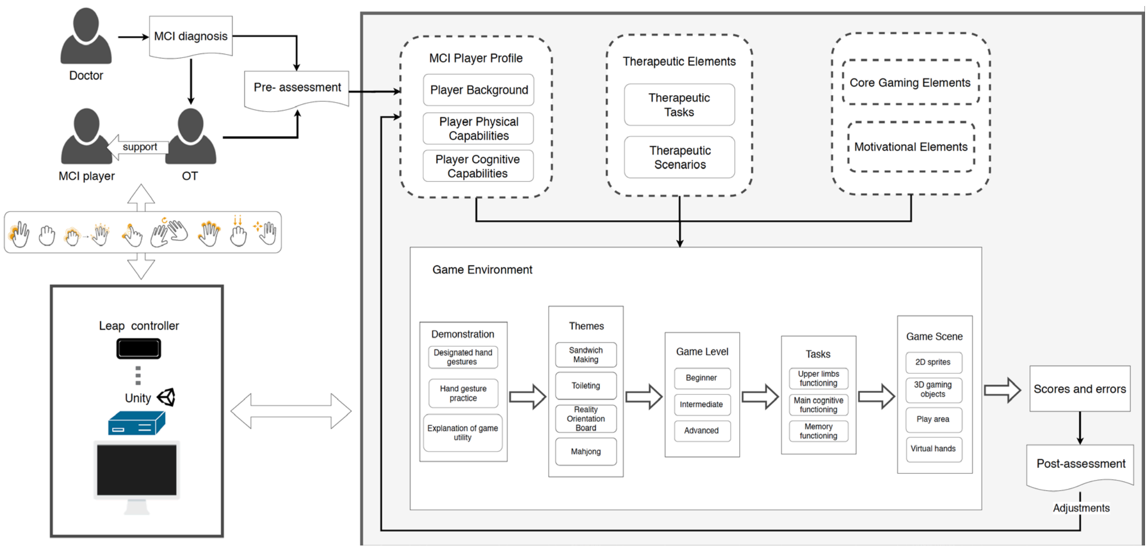


Figure 6-1 A game architecture illustrates the deployment of *A-go!*

6.3.1 Human-Computer Interaction (HCI)

i. Users

A-go! is targeted at an MCI player and their OT, where the OT is responsible for supervising the player, including demonstrating the tasks, and verbally supporting them throughout the game. This is further supported by a registered medical doctor, who serves as an external participant. The doctor makes the MCI diagnosis and passes to the OT for reviewing of background information and player capabilities. The game works in conjunction with a standardised pre-assessment screening (that works complementarily with a post-assessment), to assess the player's cognitive and physical qualities which are used to populate the player profile.

ii. Interaction

a. *Leap* controller and Unity game engine

A-go! assumes an implementation in *Unity* to provide appropriate controllability given the common profile of MCI patients, with interaction being via gesture recognition through a *Leap Motion* controller which can provide the natural user interface (NUI) for the players to facilitate the non-verbal behaviours and communicate to the system, thereby expanding the input bandwidth between the user and the computer. The directness of communication reduces the performance time and allows the users to intuitively manipulate the UI. In this way, it facilitates first-person perspective immersive interaction where the player can be more attentive and experience interaction without requiring a wearable physical device. To perform the player's gestures, the virtual hands would be navigated on the desktop display through the infrared image recognition of *Leap*. The MCI player and OT are required to place their hands upon the device and apply the designated hand gestures freely to interact with the 3D game objects in real-time. The increase in a sense of controllability encourages the player's hands to freely interact with the 3D game objects within the 3D space. Provided with 3DVE and realistic adherence with 2D UI motivational elements, it creates an intuitive series of therapeutic tasks that allow the player to choose an action among eight designated hand gestures with the responsive core gaming elements.

b. Hand gestures

The hand gestures imitate recognisable daily-life hand functioning as used in the nursing home. This allows the interaction behaviours to be compatible with conventional operations, since users who are not well-grounded in a technological platform tend to base their response on their previous experience. Two-handed interaction is a conventional approach and thus may serve as a starting point for developing user interaction, since this is how humans work subconsciously in the physical world. The parallelism of manipulation with two hands reduces the duration of task-switching and speeds up the learning process, as well as providing high satisfaction of control thanks to its intuitiveness. Memory supports provide additional guidance when necessary, e.g. in the *Sandwich Making* task presented in Figure 6-2, the dotted red circle appears around the toaster if the player forgets to toast the slices of bread before entering the next stage.

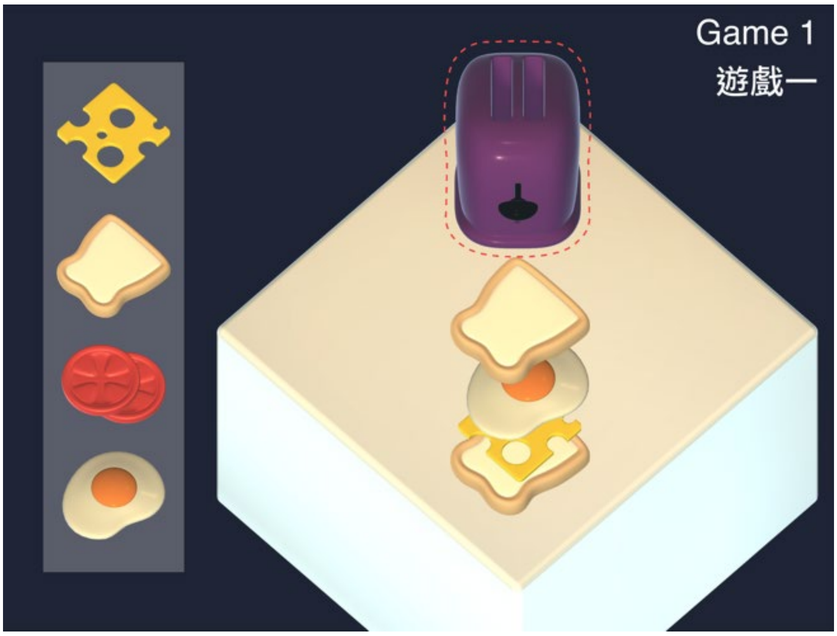


Figure 6-2 Memory support provides a dotted red circle as guidance in Sandwich Making

6.3.2 *MCI-GaTE*'s Components and the Game Environment

In this section, the application of the pertinent elements from *MCI-GaTE* to the game environment are discussed.

i. Demonstration

The game environment commences with a *demonstration* phase to help the MCI player, supported by the OT, gain familiarity with the environment before undertaking the tasks. This phase typically lasts 15-20 minutes, according to patient capabilities and needs so as to maximise their participation in the subsequent therapeutic scenarios. Thus, the *MCI player profile* enables the demonstration and the game-based training to be pitched at the correct level for the player's diagnosis (to achieve the optimal training effect), to ensure that the physical and cognitive capabilities are tested by completing the substantial hand gestures during the demonstration as presented in Figure 6-3. The purpose and benefits of the game are explained, with the OT verbally supporting and encouraging the player. The demonstration tasks involve the player placing 3D game objects on a target by performing the necessary gesture. The OT will demonstrate the common daily hand gestures to the player (opposition, fist, grasp and release, pinching, coordination, pressing/tapping, pulling, translating), where the opposition gesture comprises the confluence of fine motor skills incorporating the other gestures. Thus, once the player successfully completes the opposition demonstration, they will manage to complete the remaining gestures. Therefore, it serves as a quick form of screening to ensure that the player has sufficiently intact upper limb (hands) capability. The player is assigned to do the tasks with upper limbs when sitting still, thus the lower limbs are not involved during the training. As previously discussed, both upper and lower limb training usually operate separately to allow the player to focus on cognitive functioning with light physical interaction. The hand gestures are distributed in four games with a close-to-reality approach.

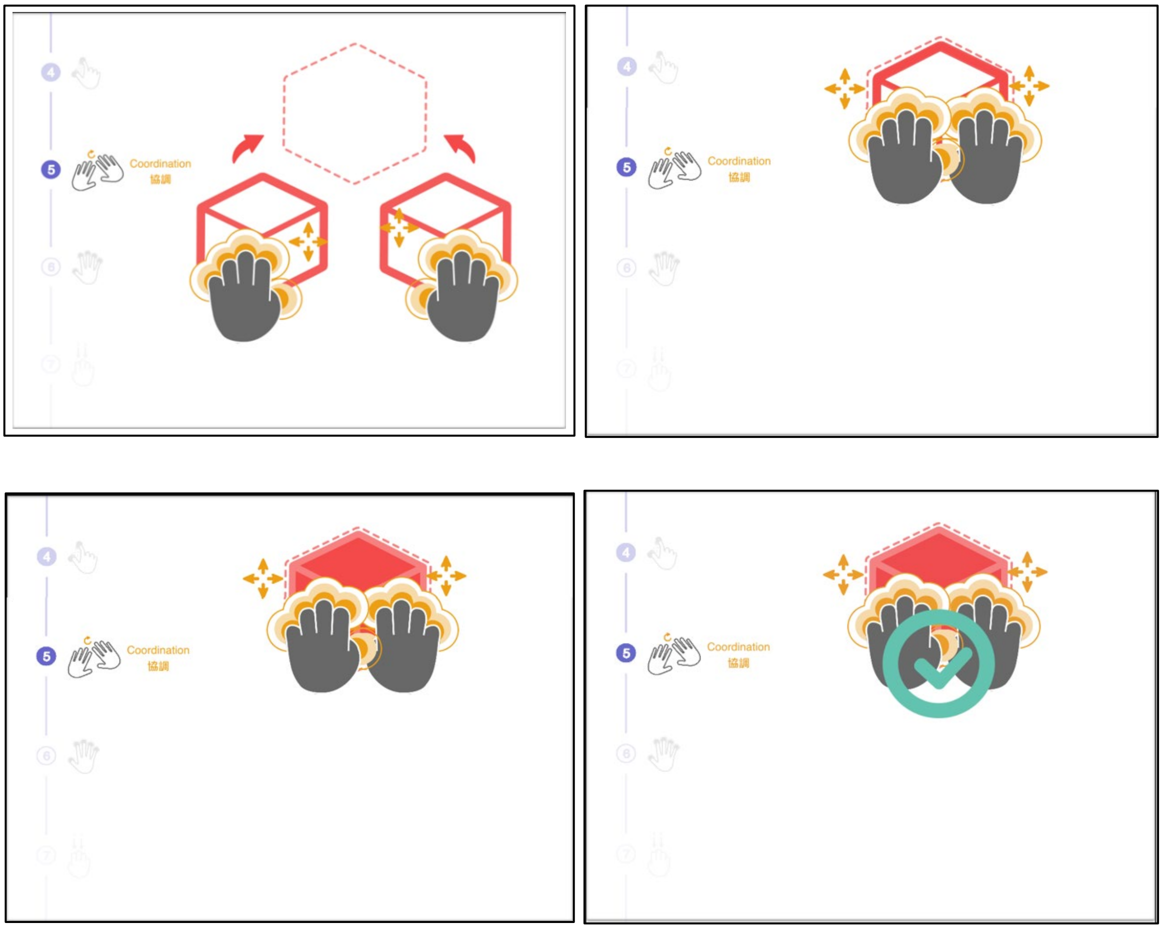


Figure 6-3 Eight designated hand gestures are provided in demonstration phase

ii. Themes

Four *themes* based on therapeutic scenarios are then employed in the game to mimic real-life activities using various gaming elements and incorporating suitable gestures: (i) *Sandwich Making* as in Figure 6-4, which is an IADL. Sandwich and drink ingredients, and dishware are the game objects to train a player to prepare a meal while remembering all the steps and the order of the ingredients. (ii) *Toileting* as in Figure 6-5, which is an ADL. ADL tasks take place in the washroom that enable the player to remember the steps in using a toilet including flushing the water, washing and drying hands. (iii) *Reality Orientation Board* as in Figure 6-6, a reality orientation scenario. The board incorporates weather and time to allow the player to realise themselves to the surroundings by selecting the correct answers through gestures. (iv) *Mahjong* as in Figure 6-7, a reminiscence scenario. *Mahjong* tiles as cultural materials to stimulate the player's long-term memory and reminisce the past in memorising the tiles. These serve as relatable and familiar scenarios where the MCI player can train. This rehabilitative training typically lasts for 15-60 minutes according to the player's capabilities and as overseen by the OT, and reflects the typical durations specified in the interview ***Q3-(P4)*.**

Figure 6-4 Sandwich Making game scene enables the player to undergo IADL training

Figure 6-5 Toileting game scene enables the player to undergo ADL training

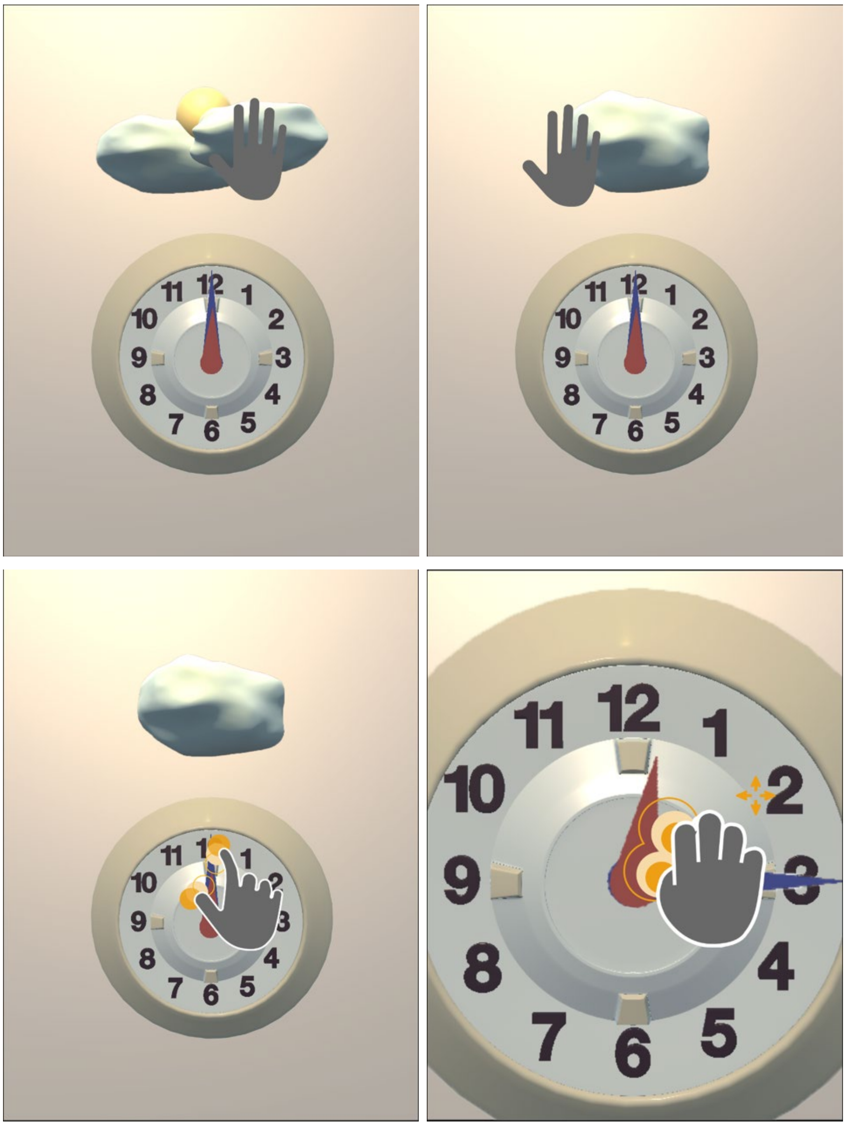


Figure 6-6 Reality Orientation Board game scene enables the player to undergo reality orientation training

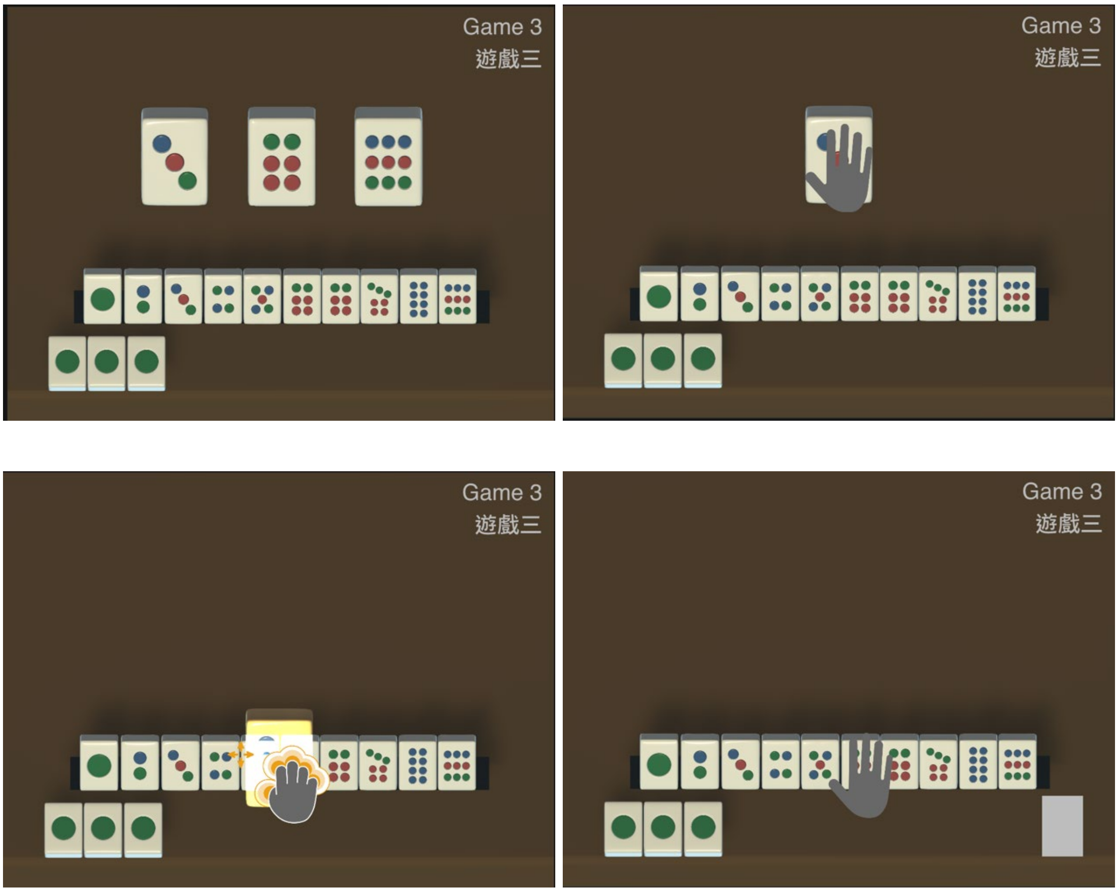


Figure 6-7 Mahjong game scene enables the player to undergo reminiscence training

iii. Game level

The game *level* maps to the MCI player's physical and cognitive capabilities from the profile, which are adjusted during *post-assessment* with the OT which occurs after each game session, so as to determine the level for the MCI player by altering the complexity of the tasks. As shown in Figure 6-8, these range from: (i) *beginner*, a novice who is inexperienced in the serious game and requires clear and detailed explanations from the OT due to their lack of background, and thus step-by-step guidance ensures that they are able to apply the hand gestures and concentrate on a single game, e.g. *Game 1-Food*, without excessively being concerned about the game utility (which would increase the cognitive demand); (ii) *intermediate*, an experienced player who understands the gaming context and managed to complete the game tasks correctly at the beginner level, and thus is qualified to consecutively accept the challenge of taking two games, e.g. *Game 1-Food* and *Game 2-Drink*; and (iii) *advanced*, an experienced player who can complete the intermediate level and has been making progress from the previous game results, suggesting that the player is able to achieve positive progress in serious tasks and undertake three games in a row. Figure 6-8 reflects the three games that would be utilised in these levels for the *Sandwich Making* theme. For the *Toileting* theme, the games are *Game 1- Toilet flush, Game 2-Hand wash* and *Game 3-Paper towel;* for *Reality Orientation Board,* the games are *Game 1-Change weather, Game 2-Tune the clock and change weather* and *Game 3-Tune the clock, change weather (with more options),* and for *Mahjong,* the games are *Game 1-Missing one tile, Game 2-Missing two tiles* and *Game 3-Missing three tiles.*

Figure 6-8 Game level from beginner to advanced where its complexity is based on the number of games

iv. Tasks

To enable the physical (hand gestures) and cognitive tasks during the training, each game theme requires the player to recognise the need to perform and carry out two to three hand gestures as they would need to do if controlling the objects within the task in real life. This notion is to be perceived by the player in achieving the goal and committing to the intervention, as a result of the ease of use and intuitiveness. This enhances the efficiency of the training. For example, *Sandwich Making* (Figure 6-9), adopts pinching and coordination gestures for meal preparation training. This commences with operating the press handle of a toaster in *Game 1-Food* where the player is required to pinch down the press handle to toast the slices of bread and pinch up when the bread is sufficiently toasted. Pinches up is then extended in *Game 2-Drink* to involve both hands to simulate an orange being squeezed and poured into a blue mug. *Game 3-Dishware* requires the player to select the correct plate through grasp and release gestures. As another example, the *Toileting* theme (Figure 6-10) requires the player to press and hold the flush plate momentarily in *Game 1-Toilet flush,* and to memorise the amount of hand wash and paper towels in *Game 2-Hand wash* and *Game 3- Paper towel* respectively, with pressing/tapping and pulling gestures to perform the actions. Two hand wash boxes are placed at different positions as distractors to train the user's attention. The *Reality Orientation Board* theme's tasks (Figure 6-11) challenge whether the player is able to understand real-time surroundings. In *Game 1-Change weather,* translating and pinching gestures are required by the player to "change the weather". This is combined with tuning the clock in *Game 2-Tune the clock and change weather*. *Game 3-Tune the clock, change weather (with more options)* provides all elements from *Games 1 and 2* with a greater number of weathers to increase the difficulty. *Mahjong* (Figure 6-12) requires the player to use the grasp and release gesture. A series of *Mahjong* tiles is displayed with 1-3 tiles missing according to the level of the game, and the player is required to grasp the correct tile from the centre of the table to complete the task. Reminiscence is introduced to support the cognitive functioning by drawing the MCI player's attention. These tasks focus predominantly on memory to support the impairment of memory in an MCI player, especially their working memory (short-term memory), while sustaining their other cognitive capabilities, in line with the research literature discussed previously.

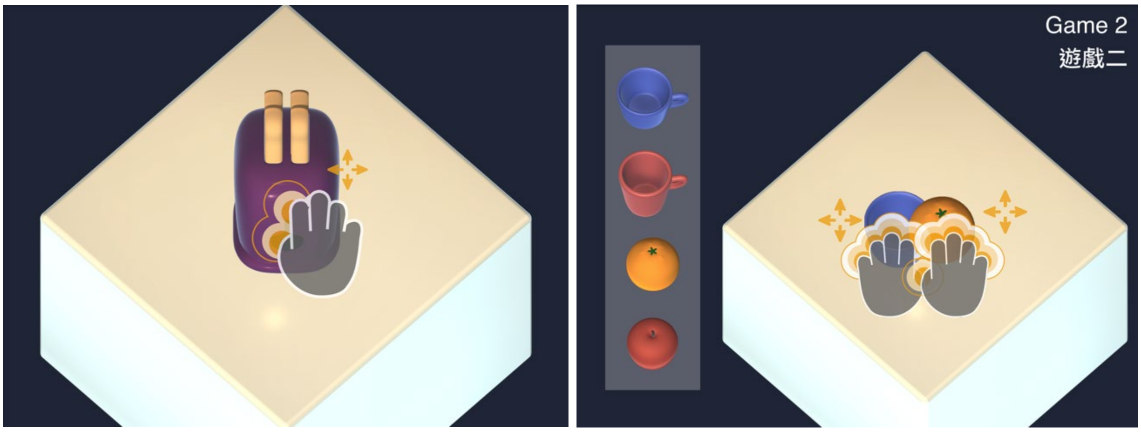


Figure 6-9 Sandwich Making game requires the player to use pinching and coordination gestures

Figure 6-10 Toileting game requires the player to use pressing / tapping and pulling gestures

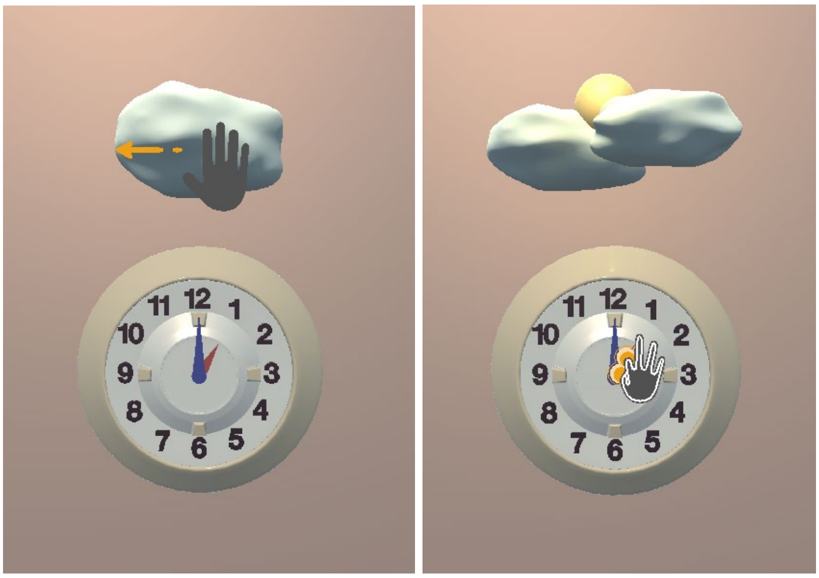


Figure 6-11 Reality Orientation Board game requires the player to use translating and pinching gestures

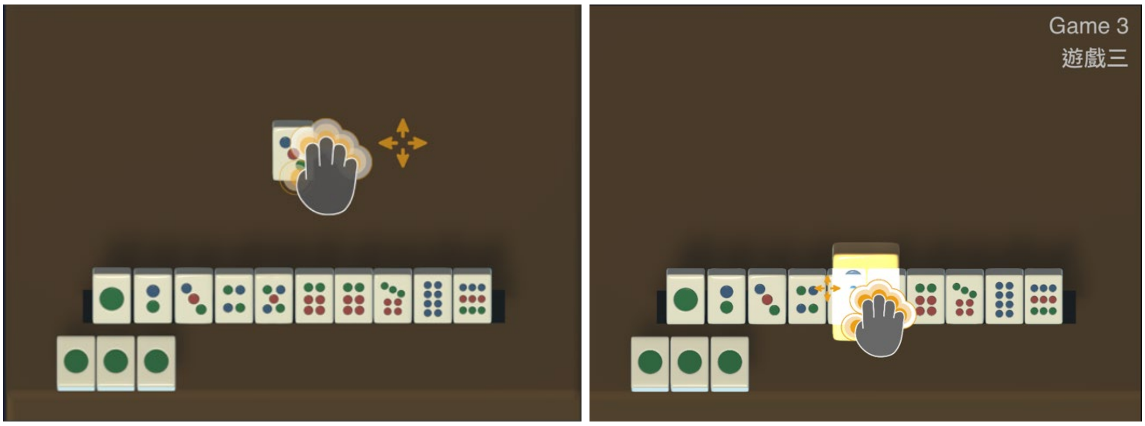


Figure 6-12 Mahjong game requires the player to use grasp and release gestures

v. Game scene

The *game scenes* visualise the gaming context and current status to the player, with additional text for the OT who will additionally support by providing comprehensive instructions throughout to leverage the training quality and player's motivation. The information hierarchy is organized by 2D and 3D graphics. The screen size determines the play area's boundaries where the player's virtual hands can freely move within the 3D space. To distinguish the player's movements from the 3D game objects, the virtual hands with orange gestures are in 2D.

6.3.3 Results

As with conventional training, the game environment is errorless to enable the player to focus on the tasks without interruption until the end of the game. Thus, while some prompting may be used as attention support to guide the player to take action, error feedback is not shown at that time. Instead, errors and scores are displayed at the end of the game session as shown in Figure 6-13. These results, together with those gathered in game, are evaluated by the OT as part of a *post-assessment,* shown in Figure 6-14, which used to inform adjustments to the player profile for subsequent gaming sessions which will consequently adapt the game. For example, this will involve determining the player's flexibility in using hand gestures, their understanding of the given therapeutic scenarios, their working memory functioning in remembering a list of items (e.g. sandwich ingredients), and so on. The adaptations involve difficulty adjustment via upgrading or downgrading of game levels, or repetition of training tasks. To enable the player to go up to a higher level, their scores must reach 80% or higher of the total score, while the player is assigned to repeat the same level when achieving 50-79% and downgraded if below 50%. It is worth noting that the serious game would be played once or twice a week to maintain the training progress, with more extensive post-assessment taking place every one to two months to validate the player's training progress. Therefore, downgrading is likely to be rare, as MCI player's cognitive levels would be expected to be maintained within the manageable range. Improvements in post-assessment score would indicate the positive impact of the serious game on the MCI player.

Figure 6-13 Errorless learning approach is used, and scores and errors are displayed at the end of the game

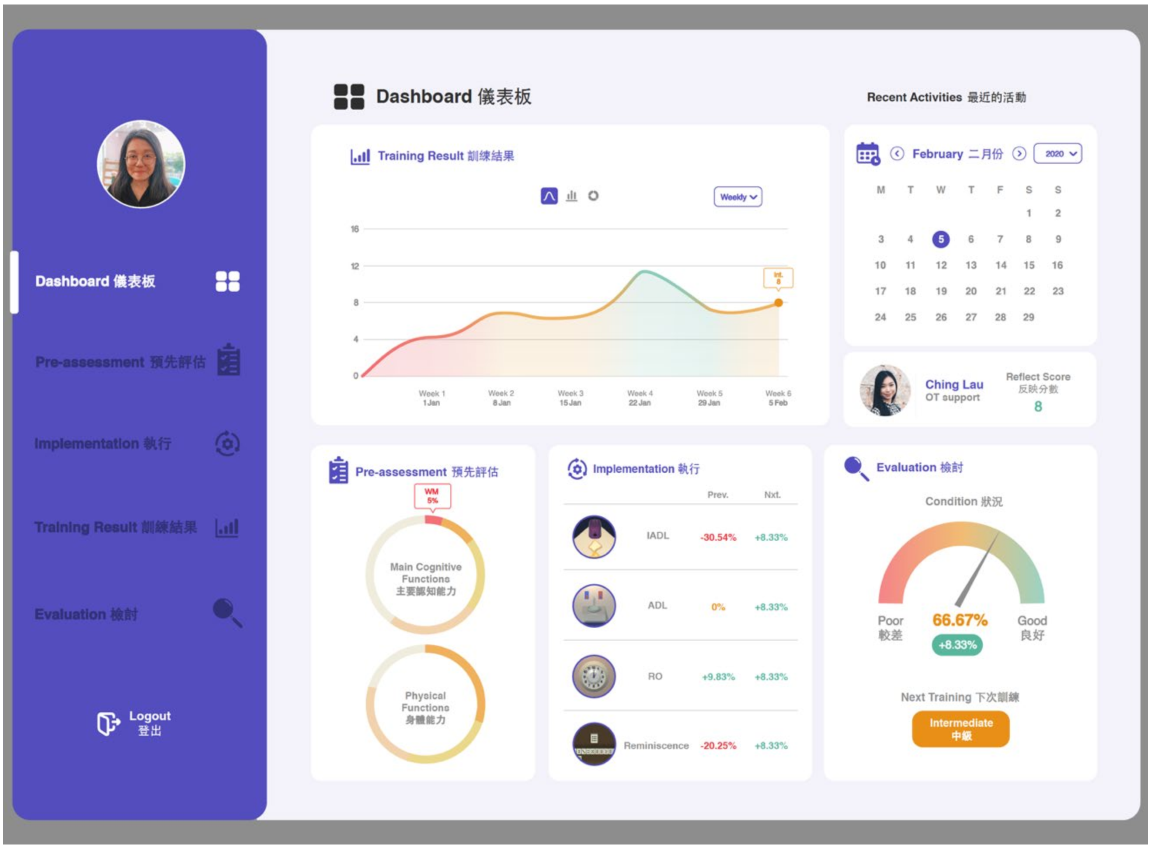


Figure 6-14 OT dashboard for updating the player 's progress

6.4 Conclusion

This chapter demonstrated the use of *MCI-GaTE* through presenting *A-go!*, an immersive serious game targeted at an MCI player and their OT. The OT is responsible for supervising the MCI player and demonstrating the tasks with verbal support throughout the game. Relevant MCI player profile criteria, therapeutic, core gaming and motivational elements from the framework are principally selected and integrated into the game environment and discussed. The next chapter will conduct the usability testing and evaluations of *A-go!*.

7 Chapter Seven – Serious Game Usability Testing and Evaluation

This chapter explains the procedure of usability testing and evaluation of the proposed serious game designed for MCI players, *A-go!*, that was presented in the previous chapter and the proposed *MCI-GaTE* serious game framework that was utilised for its design. The sections are organized as follows: Section 7.1 outlines how the techniques are being used during usability testing and analysis; Section 7.2 presents the procedure of game testing with four OTs; Section 7.3 explains the deductive data analysis for summarizing the data results and findings; Section 7.4 demonstrates the significance and efficacy of *MCI-GaTE* and *A-go!* by comparing the existing serious game frameworks; and Section 7.5 summarizes this chapter with findings.

7.1 Introduction

This chapter details the processes shown in Figure 7-1 which comprise of the usability testing and evaluation of the collected feedback, together with evaluation against the existing state-of-the-art of serious game frameworks. These processes serve to identify possible improvements and insights regarding the interfaces and user interactions as well as the efficacy of the game and framework in terms of motivation and engagement. A brief introduction of the game architecture as presented in Chapter 6 and an array of eligible *MCI-GaTE* materials which were deployed in the proposed serious game were first explained to the OTs. Next, the OTs completed the usability testing individually by using the concurrent think-aloud (CTA) technique, before undergoing a semi-structured interview. After the OTs had responded to all the interview questions, a deductive thematic analysis of the findings and design insights was performed. Subsequently, existing rehabilitative serious game frameworks were compared and contrasted with *MCI-GaTE* according to their therapeutic context and support for player profile, core gaming, therapeutic and motivational elements. This comparison further reveals the novelty, effectiveness and comprehensiveness of the proposed framework.

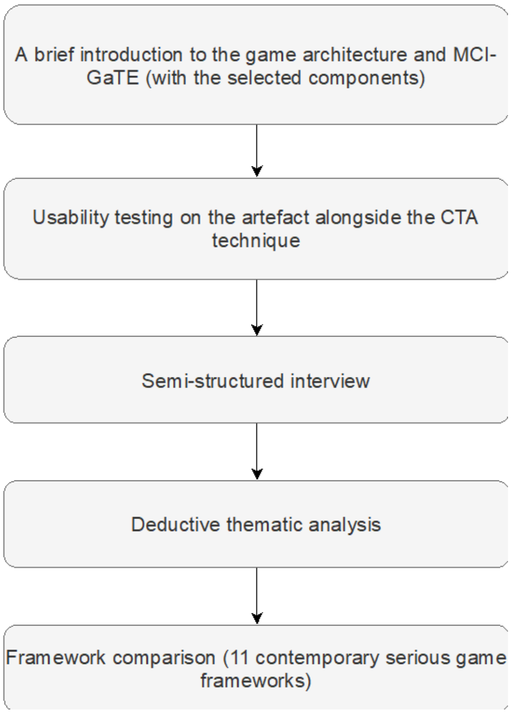


Figure 7-1 The techniques used in usability testing and evaluation

7.2 The Proposed Serious Game Usability Testing and Data Collection Process

Due to the target users being a vulnerable group and the ethical implications of testing with such users, the interactive high-fidelity prototype described in the previous chapter was instead provided to four OTs to undergo the usability testing separately over several days, in order to obtain their professional and in-depth insights based on their extensive experience with the target user group. As described in Chapter 6, *A-go!*, an interactive high-fidelity prototype, enables the OTs to test and evaluate its game interface by walking through the artefact which comprises three testing stages: (i)demonstration – eight designated hand gestures, (ii)game scene – three stages of the game including *Food, Drink and Dishware* and (iii)results – scores from three stages of the game to indicate and prioritize the issues based on the MCI patient's goals and training basis in addition to UX&UI. The identified issues and comments have been recorded and raised during the interview session for probing discussion.

7.2.1 Participants

To evaluate *A-go!* safely and reliably, four occupational therapists were invited to participate in the interviews. They had previously taken part in the initial interviews for the construction of *MCI-GaTE* as documented in Chapter 4 (in 2017). MCI patients are perceived to be forgetful and/or manifest signs of lacking certain cognitive abilities which may result in inaccuracies and omissions in the user testing. In addition, it was important to avoid causing undue stress to the patients. Since the OTs have considerable experience observing MCI patients over prolonged periods, assessing their physical and cognitive states based on screening tools and protocols, and designing appropriate interventions for them, they are highly able to provide rigorous validation of the proposed serious game. Thus, the end-users (i.e. MCI player) were excluded from the usability testing for ethical, practical and accuracy reasons.

Although only four OTs were involved, small groups are typically deemed sufficient for usability testing for uncovering the vast majority of issues [102]. The OTs have a prolonged observation of the MCI patients and a considerable experience in designing the interventions, assess the MCI patients' physical and cognitive states based on the standardized screening tools and protocols; hence, they can provide a rigorous validation of the proposed serious game.

In order to effectively determine the boundaries of the testing aims, it was crucial to explain the multitude of analysed mixed-method data from *MCI-GaTE* with reference to the game architecture as well as the research assumptions to the OTs. They are the key users who will assess if the proposed serious game can effectively meet the MCI players' rehabilitation goals. The efficacy of *MCI-GaTE* and new insights which the OTs discover during the game are unveiled during the interviews.

7.2.2 Interview Method and Interview Questions

A qualitative method has been adopted in semi-structured individual interviews with the OTs (i.e. *P1, P2, P3* and *P4*) who participated in this study voluntarily previously in Chapter 4. The OTs were invited to test *A-go!* thoroughly for an hour, from demonstration through to the scores and errors stage, during which the concurrent think-aloud (CTA) technique [103] was used, which allows the player to talk about their thoughts while undergoing the tasks. Identified issues and comments were recorded and raised during subsequent semi-structured interview sessions, which were scheduled on two separate days totalling 2-3 hours per OT. Further discussion as required took place subsequently via video call.

Six open-ended interview questions were asked based on the given artefact, which focused on the design strategies used at each stage i.e. demonstration, game scene and results. This helped to steer clear of irrelevant tangential information as well as ascertain the preconceived research questions. To help the interviewees develop an in-depth and extensive understanding of the issues, supplemental information, i.e. the screenshots of the game interfaces, were provided, which enabled them to refer to the issues and their unspoken responses when they were concentrating on the game. The following open-ended questions were used to validate *A-go!*'s effectiveness for improving MCI patient rehabilitation:

Q1. Which stage (s) of the proposed serious game do you believe that MCI players would need further explanation from you, e.g. demonstration, utility of the game, new environment, etc.?

Q2. What signs immediately tell you that it may be necessary to support MCI players during the game? Do you think players can understand the UI designs easily?

Q3. Should any elements/features in the game be removed or added in order to improve the training (cognitively and physically)?

Q4. To what extent do you think the proposed serious game can improve MCI players' motivation and engagement through the gameful elements? Why?

Q5. What advantages and disadvantages does the proposed serious game have compared to the traditional training method?

Q6. In terms of a-MCI, do you think the game can potentially sustain MCI players' (episodic) memory capacity after a certain period of training? To what extent and why or why not?

The interviews were carried out in Cantonese and the interview questions and responses as documented in Appendix C have been translated into English and transcribed verbatim. The quotations from the interviews indicate the improvements of the current system that have been referenced and analysed in Section 7.3.

7.3 Summary of Data Results and Confirmation of the Hypotheses

Deductive thematic analysis which aims to generate new insights from the predefined hypotheses and analytic interests [104] was utilized in summarizing the data results in this section. Four interviews, each containing the six interview questions above, have been administered and all responses have been collated for deductive thematic analysis. The aim is to seek validation of the proposed approaches in the *MCI-GaTE* which purport to support MCI players' motivation and engagement while playing the game, and importantly, sustain their memory capacity. The detailed responses are given in Appendix C.

The hypotheses developed in Chapter 4 propose that *MCI-GaTE* and the immersive gesture-based serious game, *A-go!*, are potentially effective for rehabilitative training of MCI players. The expectations of the proposed approach are derived from the hypotheses established earlier. The research findings which were identified and established from literature, nursing home and interview data (Chapter 2 to Chapter 4), were presented as the *MCI-GaTE* framework. This led to the realisation of *A-go!* to serve as a proof-of-concept of *MCI-GaTE* in Chapter 6, incorporating the necessary elements, i.e. MCI player profile, core gaming, therapeutic and motivation elements. Subsequently, the hypotheses will be confirmed by in-depth interviews with the OTs and the six interview questions presented in Section 7.2.2 are associated with *H1: comprehensive and tailored* and *H2: motivated and engaged*, as illustrated in Figure 7-2.

For reference, the previously stated hypotheses were:

H1. A comprehensive serious game approach specifically tailored to players diagnosed with MCI, that includes a profile incorporating their physical and cognitive conditions, therapeutic elements which enable the player to undergo suitable rehabilitative training, core gaming elements and motivational elements that enhance the player's motivation through gamefulness, will be better optimised for their MCI condition than a generic physio-cognitive serious game; and

H2. MCI players using a serious game with a supportive gameful approach derived from core gaming and motivational elements as a rehabilitative tool will exhibit enhanced motivation and engagement over traditional rehabilitative tools.

Below, the hypotheses are presented in Figure 7-2 in relation to the interview questions constructed previously.

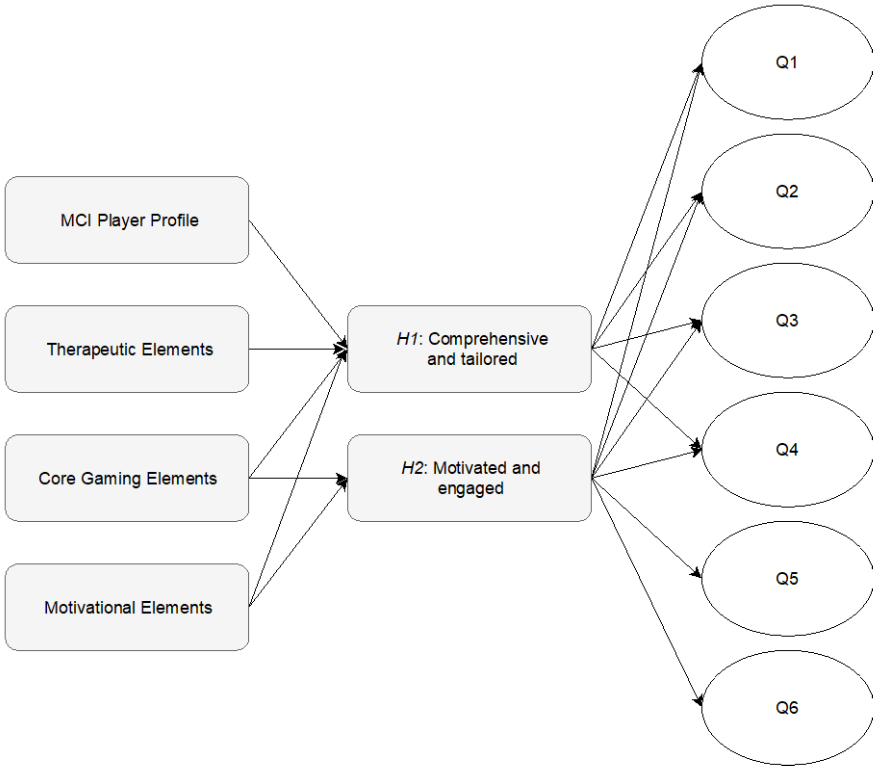


Figure 7-2 The findings in relation to the hypotheses, which are to be tested through interview questions

The interview data analysis in which the proposed serious game was individually tested by the OTs confirm the above-mentioned hypotheses in the following subsections accordingly.

7.3.1 *H1*: Comprehensive and Tailored

The purpose of *MCI-GaTE* is to present a comprehensive approach entailing the pertinence of data to specifically produce a serious game as one of the alternative rehabilitative tools to MCI players. A tailored and optimised serious game is achieved through satisfying the MCI player profile criteria, which comprises of the MCI player's background information and capabilities. This enables the player to accommodate themselves to *A-go!*, a serious game containing appropriate therapeutic, core gaming and motivational elements. The evaluation of serious game commences with MCI player's initiation into the game and subsequent MCI player's performance and adaptability in the therapeutic context of serious game.

MCI-GaTE offers an elaborate *MCI player profile* including all crucial features collected from interviews with OTs and the GNH resident profiles to enable the MCI player to receive suitably tailored game functionality. However, the interviews revealed that the first challenge of the entire intervention journey is the initiation of the MCI players into the game. The majority of OTs acknowledged that a very clear prelude to the game scene can help MCI players to understand their participation goals and diminish their hesitation to participate, especially new players ***Q1-(P1-3)***. Hence a clear prelude enables MCI players to acquire the training contents and adapt to a new environment. The OTs also agreed that the demonstration is a significant phase to introducing the game functionality ***Q1-(P1-3), Q2-(P2)*** and hand gestures to the player ***Q1-(P2)***, which allows the OT to demarcate mistakes arising due to the player not understanding the game functionality and those due to the player's declining cognitive and physical capabilities ***Q1-(P3)***. Thus, the game functionality has been clearly explained in order to obviate any misunderstanding. The hand gestures used in *A-go!* were noted as being suitable and manageable for MCI patients, but OTs would still need to assess the player throughout the game, particularly on their use of the gestures ***Q1-(P2)***. Additionally, the player's training history, physical constraints (visual and auditory problems) and education level, as represented by the MCI player profile in *MCI-GaTE*, were confirmed as being suitable for providing effective support and anticipation of the player's needs ***Q1-(P4)***. However, it was suggested that the prominence of hand interaction in the game could be further emphasised in a future version by appropriately stimulating the player's physical senses ***Q3-(P2)***, e.g. through haptic feedback, which may help overcome some physical constraints for the MCI player. This would relate to the *tangible tools* element of the proposed framework.

Taken together, the demonstration phase provided with manageable physical hand gestures indicates that MCI player profile offers the tailored user interactions, which are apt to player's physical capabilities, to enhance the accessibility so as to leverage player's acceptance into the game. It is noteworthy that the game cannot entirely substitute the presence of OT due to the necessity of further assessment on player's gestures while undertaking the game tasks, thus OT's supervision (with verbal encouragement) can further promote adaptation. The interview responses reflected that the inclusion of the *MCI player profile* within *MCI-GaTE*, commencing with the *player background*, supports the initial identification of suitable MCI players with pre-assessed conditions. The profile also incorporates the construct of *player physical capabilities* in devising eight hand gestures in demonstration stage and throughout a number of game themes to specifically establish a comprehensible player's interaction design, and *player cognitive capabilities* to glean gaming elements in creating the therapeutic content within the player's proximal performance level. It can be seen that a range of suitable game functionality, which is derived from GNH data results, pertaining to MCI player's features and their daily context is fully incorporated in *A-go!*. Furthermore, four game themes with a set of core gaming elements are designed and generalised through an in-depth literature survey and investigation of GNH training contents, enabling *MCI-GaTE* to produce appropriate and beneficial game contents to MCI players to undergo the training.

The OTs also pointed out several exceptional situations which may occur during the game: inappropriate operation of the given equipment ***Q2-(P1)***, pausing for a considerable amount of time in the middle of a task or even opting out of the game ***Q2-(P1-P3)***, and constantly asking questions ***Q2-(P2, P4)***, the latter of which would manifest with significant memory or attention issues ***Q2-(P4)***. It was not felt that these could be accounted for by the game and given their rare and anomalous nature would best be managed by the OT as part of their in-game supervision and support. In looking at the memory and attention problems, they vary significantly from patient to patient depending on the results of their medical report or pre-assessment which may subsequently influence the game progress. Thus, the raised situations may be rare on the premise that the player must conform to the MCI player profile. It can be seen that *MCI-GaTE* may enable the *MCI player profile* to serve as a screening tool to discern the MCI group as it broadly encompasses multidimensional and significant MCI player features, embodying common MCI patients' limitations and capabilities arising from conventional interventions, such as those in GNH.

A crucial purpose of the inbuilt core gaming elements is to convey the supportive therapeutic content to the player. Through thematic derivation and summarisation of current existing serious games in the literature, profiles of nursing home residents, and interviews with OTs who have experience in designing therapeutic content for MCI patients, *MCI-GaTE* has established a comprehensive range of appropriate gaming elements needed for an MCI-relevant serious game, extending across therapeutic, core gaming, and motivational elements. The OTs agreed that the gaming content within *A-go!* is understandable to an MCI player, but several refinements were proposed to further facilitate the player's learning speed and adaptability. It was suggested that allowing the player to engage for longer may enable them to better learn the interface elements and context by themselves ***Q1-(P3)***, ***Q2-(P2)***. This is already accommodated in *A-go!* since no timer is embedded. More explicit in-game instructions may also further support the player's understanding in line with their individual attention span ***Q1-(P4)***. For instance, the utility of the toaster which an elderly player may not be familiar with (as they were not prevalent in Hong Kong for domestic use) could be demonstrated ***Q4-(P1)***. The accessibility of the game can also be elevated through further realism ***Q2-(P1)***, such as realistic hands, game objects ***Q2-(P3)***, and a 3D simulated kitchen setting ***Q3-(P1)***. However, the minimalistic hands are presented as a function of first-person interactions which can be easily distinguished between the player's hands and game objects in presence of game hints (i.e. the orange arrows) and thus the minimalistic hands should be applied irrespective of realism. Indeed, 3D simulated background is worth providing for each game scene to enhance player's context understanding; however, as documented in the literature the MCI player's cognitive load which is associated with their limited attention span has to be considered to provide neither too simple nor too complicated rendered background and thus the future work will take theme background into account. These *core gaming elements* derived from *MCI-GaTE* extend from the minimalistic representation of the player's hands to the realism of appropriate gaming elements. Moreover, the game hint (dashed line) on the toaster could be in sharper contrast ***Q2-(P1)***, ***Q3-(P1)*** to better alert the player to the feedback, and a motivating indication of completion, such as "Good job!", could be displayed ***Q3-(P4)***. In terms of the level adjustment, it was also advised that the game offer a few gestures at a time since the player is less likely to recall all the gestures learned during the demonstration ***Q2-(P1)***.

Looking at the evaluations and recommendations gathered, several significant points are presented to respond to the hypothesis *H1*: (i) A comprehensible demonstration phase, together with the OT's supervision, specifically offers a tailored gaming experience to the MCI player through providing a set of user interactions (eight designated hand gestures) in accordance with MCI player profile. All hand gestures are manageable for the MCI player, provided that the player complies with the entailed crucial criteria documented in MCI player profile. Additionally, the MCI player profile may potentially serve as a screening tool to discern the MCI player by assessing their physical capabilities as MCI player is evident that remain physically intact. (ii)Therapeutic elements involve cultural related material (i.e. *Mahjong* game) to produce favourable association for the MCI player to perform. (iii)core gaming elements and motivational elements are generally accessible to MCI player but several refinements including a realism enhancement of 3D simulated background, sharp contrast on the game hint, instant feedback after each of the small tasks and considerable numbers of hand gestures at a time, are mentioned to facilitate player's adaptability. The above-mentioned factors can influence MCI player's actions towards the game, and determine the underlying complexity to justify the level of effectiveness of *MCI-GaTE*. In short, *MCI-GaTE* offers a comprehensive rehabilitative gaming experience to the MCI player as it is extensively supported by a thorough literature survey comprising all derived themes to enable the generation of a broad range of MCI-based serious games from the framework. The complete feature set of an MCI player's physical and cognitive capabilities, based on the analysis of the GNH data and interviews with OTs, enables *MCI-GaTE* to present an inclusive, tailored and robust method in aiding particular MCI players to undergo the serious game with appropriate contents where they can apply common hand gestures from demonstration phase to game scenes that they have used in conventional therapeutic settings. The framework also considers all significant methods and *motivational elements* that are used in accordance with OTs' common intervention designs.

7.3.2 *H2*: Motivated and Engaged

A-go! has been produced based upon MCI player profile and therapeutic elements that are comprised of MCI player's features, goals and needs to principally select the potential core gaming elements and motivational elements for improving MCI player's motivation and engagement. These elements are selected to motivate the MCI player to perform the therapeutic tasks on a digital platform, so as to promote an active participation in what is otherwise a repetitive rehabilitation process. The interview findings are evident that the selected gaming elements in *A-go!* can overcome significant clinical difficulties and the constraints of traditional rehabilitation tool, which can effectively support the MCI player as they undergo the training and improve their motivation and engagement.

To enhance motivation and engagement, it is necessary to create a "training atmosphere" by emphasising the training purposes to the player (e.g. supporting cognitive functions ***Q3-(P4)***) and the context of the game ***Q1(P1)***. It is also worth drawing attention to the advantages of the game, such as the beneficial outcomes on particular muscles and memory ability, so as to further raise the player's awareness of the therapeutic goals ***Q1-(P4)***. Such aspects may be carried out before or during the demonstration phase by the OT. Among the factors that may affect the player's behaviour during the game, contextual awareness and understanding of the therapeutic goals may alleviate the additional impediment to progress. It appears that the player's motivation and engagement may be initially stimulated by attributing to the training purposes. This may explain that the established fundamental relationship between the player and training purposes can be a technique to motivate the new players to attempt the new training environment.

Overall, the OTs concluded four factors that may be indicative of the player's motivation and engagement. Firstly, the interaction between the player and the interface during the game is crucial ***Q1-(P4)***. The freedom of hand movements within the virtual environment of *A-go!* motivates the player to acquire an exploratory attitude towards the game ***Q4-(P1)***, while the incremental adaptation of game content and level each time the game is played is likely to further sustain player interest ***Q4-(P2)***. Secondly, the cultural relevance within *A-go!* is an important motivator ***Q4-(P4)***, e.g. the *Mahjong* game scene is close to the player's daily routines whereas the *Sandwich Making* game scene is comparatively less familiar to them ***Q4-(P3-P4)***. However, *Sandwich Making* creates an opportunity for the player to cook safely (operate the toaster) ***Q4-(P3)*** and eliminating the risk of injury may also serve as motivation. Thirdly, players are more likely to accept the game if they have similar prior experience ***Q4-(P4)*** with digital games, suggesting that a demonstration phase or 'trial run' of the game should be carried out in the days before the training proper. Fourthly, although *A-go!* is tailored for an individual MCI player to undertake the training, some players may prefer not to play alone ***Q1-(P1)***, thus a multiplayer option would serve as further motivation ***Q4-(P4)***. This would necessitate involving those with a similar game level to generate a collaborative gaming environment via the *relatedness: cooperation, social collaboration* element of the framework. The presence of the OT also serves as an important external motivator to help the player relish the training ***Q2-(P1)***. However, further development of *A-go!* could extend beyond an individual-based serious game training by offering multiple MCI players who have similar game level to each other to generate a collaborative gaming environment.

All OTs confirmed that the selected gaming elements in *A-go!* can potentially overcome significant clinical difficulties and the constraints of traditional rehabilitation tools, effectively supporting the MCI player and improving their motivation and engagement as they undergo the training ***Q4-(P1-P4)***. In this way, *MCI-GaTE* and *A-go!* can potentially outperform the traditional methods. The game's novelty can unleash a player's curiosity and motivation towards the game which appears to be sustained through responsive gaming features and in-game support by the OT. The following were noted as being of particular relevance: the variety of game themes ***Q5-(P1)***, the tailored features ***Q5-(P1)***, the high flexibility in operating the training for home-based patients as well as those in clinical settings ***Q5-(P2)***, and the simple setup which reduces preparation time compared to traditional methods ***Q5-(P1, P3, P4)***. Notwithstanding there may be some players who have a specific preference for the traditional methods due to familiarity and a preference to avoid the stress of new technology ***Q5-(P1-P2)***. The OTs also saw distinct advantage in the automated feedback which can reduce the manual overhead ***Q5-(P2)*** and enable the OT to focus purely on player support during the therapeutic session. Potentially, the game may maintain the player's memory capacity ***Q6-(P2)*** and achieve positive results ***Q6-(P4)*** after a suggested period of training of twice a week ***Q3-(P3)*** over a period of 4-6 weeks ***Q6-(P4)***. Some also reported that the skills the player acquired from *A-go!* may be transferable to real life ***Q5-(P3)*** particularly with respect to the player's upper limb competence ***Q5-(P2, P4)***. Additional use of haptic feedback would further support this ***Q5-(P4)***, ***Q3-(P2)***. However, the MCI player typically possesses high competences which are almost on par with a normal person ***Q5-(P4)***. This may plausibly explain that the haptic function is regarded as dispensable. Collectively, these findings including the aforementioned discussion on the prominence of hand interaction (physical sensory ***Q3-(P2)***) lead to further investigation in the future development as the physical enhancement may effectively support MCI player's engagement and training quality. Ideally, it was suggested that *A-go!* be further assessed against standardised screening tools ***Q6-(P1-P3)*** and that the player's results of pre-and post-assessments should be compliant with the standardised scoresheet ***Q6-(P2)***.

The OTs generally agreed that the *MCI-GaTE* framework is more effective in supporting the MCI player than traditional training and advocated assessing the efficacy of the proposed techniques through standardized screening tools. A plausible explanation for testing the efficacy of *A-go!* is that *MCI-GaTE* provides multidimensional research-based elements evidenced by the current literature and used widely in healthcare settings. The data interpretation in the literature has demonstrated how digital games with gamefulness and playfulness remarkably impact the medical field. Results from all interview responses are summarised as follows to return to hypothesis *H2*: (i) *A-go!* offers responsive training platform which traditional training tool cannot do. For instance, *A-go!* can motivate the MCI player to engage in the game scene through eliciting their exploratory attitude and curiosity in the presence of the responsive gaming contents with real-time feedback. Additionally, *A-go!* is portable and flexible such that it can facilitate various clinical settings which can drastically reduce the therapeutic session time. (ii) The incremental changes on game content and level are offered to maintain player's motivation. A number of game themes with tailored gaming features may satisfy the MCI player and enhance their engagement. It can increase the effect of favourable association due to the culturally relevant gaming contents, i.e. *Mahjong*. 3D simulated scenes, such as cooking utility in *Sandwich Making* and reminiscence settings, are presented on computerized platform. These scenes allow the MCI player to engage in the training with low risk of injury and reminisce their past. (iii) A stimulative group-based training environment and sensory stimulation through tactile function can potentially motivate the MCI player further. However, these suggestions are beyond the research scope, which will be considered in the future development.

Overall, the evaluation revealed that *A-go!* could be more effective in supporting MCI patients than traditional training tools, but that further assessment through standardised screening tools should be undertaken. The addition of further features, such as haptics and multiplayer options, would facilitate additional effectiveness and engagement. In the next section, a comparative assessment of *MCI-GaTE* against relevant serious game frameworks is undertaken.

7.4 Comparison of *MCI-GaTE* Against Existing Rehabilitative Serious Game Frameworks

There are many challenges to developing a comprehensive serious game framework for rehabilitation due to currently inconclusive research regarding target player, gaming and motivational features pertaining to specific rehabilitative contexts. To further demonstrate the significance and efficacy of *MCI-GaTE* and *A-go!*, the framework is considered against the existing state-of-the-art in physical and cognitive rehabilitation frameworks for serious games. Table 7-1 compares *MCI-GaTE* with 11 contemporary serious game frameworks for physical and cognitive rehabilitation according to the degree with which they incorporate player profiles and therapeutic, core gaming, and motivational elements.

Table 7-1 Comparison of frameworks with *MCI-GaTE*

Serious Game Framework	Therapeutic Context	Criteria			
		Player Profile	Therapeutic Elements	Core Gaming Elements	Motivational Elements
AGAS (Avatar Grammar Animation System) [105]	Upper-body exercises	⊗	●	○	⊗
ARSG (Augmented Reality Serious Game) [106]	Hand muscle movements	●	○	⊗	⊗
E-health framework [107]	Hand rehabilitation	●	●	◗	◗
Full body rehabilitation framework [108]	Full body rehabilitation	●	●	○	○
Intelligent pattern framework for MCI screening and intervention [109]	MCI (screening only)	⊗	●	N/A	N/A
Machine learning- based serious game framework [110]	MCI	⊗	●	○	○
PROGame [111]	Motor rehabilitation	◗	●	○	○
RGM (Rehabilitation Game Model) [112]	Upper arm rehabilitation	●	⊗	○	●
SIERRA [113]	Post-stroke (for recovery of motor function)	●	●	○	○
Smart Thinker [50]	Cognitive rehabilitation	⊗	●	◗	◗
VR-based holistic framework [114]	Motor rehabilitation	⊗	●	◗	⊗
MCI-GaTE	**MCI**	●	●	●	●

●: significantly incorporated; ◗: partially incorporated; ○: virtually no incorporation; ⊗: not incorporated

As can be seen, the majority of proposed serious game frameworks target physical rehabilitation only [105]–[108], [112]–[114]. Several of these [106]–[108], [112], [113] construct a player profile by investigating player's characteristics pertaining to the rehabilitative context. The framework in [108] customises full body rehabilitation within a VE through therapist support and deep learning to profile the patient and evaluate their performance in order to generate a suitable serious game. Two of the frameworks allow specialists to collect and manipulate the patient's profile data in order to provide a suitable serious game: *SIERRA* [113] allows the therapist to take actions with a patient's profile and therapeutic-related data in order to design the game interface, while *ARSG* [106] retrieves the patients' personal health records through the Health Level Seven (HL7) healthcare data exchange standard, allowing the medical doctor to update the patient's data and monitor the rehabilitation progress. Other frameworks are intended to produce more personalised serious games. The e-health framework [107] proposes adaptive hand therapy by constructing a hand disability data model (joints and motions) from the player's health records and medical procedures with the therapists. The players' profiles, interests and limitations are constructed to generate a personalised design via deep learning through undertaking analysis of full body exercises. The rehabilitation game model (RGM) [112] introduces a personalised exercise game by combining a set of six player types with a set of player behaviours, but this does not reflect the full range of behaviours and motivation of players' with medical conditions as much as players in conventional games. *PROGame* [111] records player's previous game actions but it does not reflect any player capabilities initially. The remaining physical rehabilitation frameworks [105], [114] do not define any player characteristics or profile.

In terms of therapeutic elements, most of the physical rehabilitation frameworks [105], [107], [108], [111], [113], [114] embed these within a game scenario and mechanics to enable the player to undergo the therapeutic tasks within the range of their capabilities. For example, the frameworks in [105], [107], [113], [114] target upper limbs, the full body rehabilitation framework [108] targets full body exercises, upper limb to lower limb (plank walk, single stance, and hand and fingers interaction), and *PROGame* [111] incorporates an interaction mechanism for postural control. The remaining frameworks [106], [112] do not take therapeutic elements into account and thus have no specific means to provide a specific rehabilitative context which leads to insufficient support for the particular player: *RGM* [112] mainly focuses on player personality towards the game, while *ARSG* [106] only considers muscle movement training as one of the rehabilitative goals.

The physical rehabilitation frameworks tend not to demonstrate a systematic approach to providing the substantial core gaming and motivational elements to support the player. The full body rehabilitation game [108] features only a limited number of basic core gaming and motivational elements, such as obstacles and simple geometric forms as game objects, so that the player can carry out the designated postures, and points and time limits to motivate them to continue with the exercises. *PROGame* [111] demonstrates player's movements in an interaction module where the controllability occurs for the player to interact with the game object. The notable motivational element for the player is visual and auditory feedback which proved insufficient during validation, and therefore was augmented with an ability to change the appearance of the objects to use images displaying themes of particular interest to each patient. The e-health framework [107] uses a simple design interface to motivate those with mental distraction together with a visual avatar that the player may customise. Avatars are also used by other frameworks [105], [114]. *RGM* [112] enables certain game mechanics for the player according to the interactions or behaviours associated with their player type. Both *RGM* and *SIERRA* [113] rely on visual, auditory, or haptic feedback as motivators. The *ARSG* framework [106] does not incorporate any notable game features but focuses on the technology of providing an augmented reality platform.

Frameworks addressing cognitive impairment [50], [109], [110] are much more limited than those targeting physical rehabilitation, and none seek to construct a player profile to support the particular players or tailor the game experience, which limits the effectiveness of the intervention. However, all provide therapeutic elements: the intelligent pattern framework [109], which is for MCI screening, focuses on various cognitive spheres (attention, processing speed, memory, and reasoning capacity), the machine-learning based serious game framework [110] provides training for recognition, learning, memory, recall, and other executive functions, and *Smart Thinker* [50] supports attention and memory. In terms of core gaming and motivational elements, *Smart Thinker* [50] uses feedback, score and rewards, and attention support such as 'warning signs' to notify the player to overcome the assigned tasks. However, the framework in [110] only provides score and levels as core gaming elements throughout the entire training.

MCI-GaTE is intended to provide a comprehensive and multidimensional set of elements so that an optimised, tailored, motivational and engaging serious game may be provided for an MCI player, thereby improving upon existing frameworks. The comparison reveals that *MCI-GaTE* is currently the only serious game framework that accommodates the full set of criteria for supporting tailored and gameful physical and cognitive rehabilitation. With the lack of MCI frameworks available, which at best are quite narrow or only target the screening stage, there is a need for a serious game framework such as *MCI-GaTE* which is specifically targeted at MCI players.

7.5 Conclusion

The chapter demonstrated the usability testing process and evaluations on *A-go!* which has been appraised by the OTs. The interview data overall has shown positive results which verified that *A-go!*, a tailored serious game containing appropriate therapeutic elements, core gaming elements and motivational elements, may potentially be one of the motivational assistive training tools for the MCI player. However, the OTs have also given several improvements on interface design, such as the realism of kitchen setting and instant feedback after each of the small tasks. Comparison with similar rehabilitative game frameworks confirms that it contributes a full set of criteria for supporting tailored and gameful physical and cognitive rehabilitation. The next chapter will conclude all the research findings for further research topics, taking into consideration research limitations and future works.

8 Chapter Eight – Conclusion

This chapter summarises the research findings and contributions of this interdisciplinary research project and draws some final conclusions. Each chapter of the thesis is summarised and concluded with suggestions for leading to further research directions. Limitations and strengths are also discussed based on the project outcomes and deliverables.

8.1 Summary of the Research Project and Outcomes

The thesis comprises chapter contributions seeking insights in literature and clinical settings that are relevant to gaming technologies and clinical tools in aiding MCI patients in order to exploit serious games within a particular healthcare sector, namely those with MCI during rehabilitation. The current user interaction and gaming technological approaches were found to be lacking in means in tackling the MCI group. However, there is great potential in promoting serious games as an assistive training tool to resolve the issues arising from traditional training platforms, such as paper-and-pen, which decrease patient's motivation and engagement and lead to inaccuracies in detecting the patient's needs. This research entails the development of an innovative serious game framework (*MCI-GaTE*) where the techniques are derived from the secondary data (i.e. literature and GNH data) and primary data (i.e interview data). To demonstrate the use of *MCI-GaTE*, *A-go!* has been designed, an immersive and gesture-based serious game targeted at an MCI player and their OT, realised as an interactive high-fidelity prototype.

8.2 Summary of Thesis

Chapter One – Introduction was concerned with the positioning of digital games in the market linking with current healthcare demands, introducing state-of-the-art serious game techniques in aiding the MCI patients to undertake the rehabilitation. Research aim and objectives were presented to outline the direction of the research project. The methodology was illustrated as a number of stages: literature research, data collection from nursing home and interviews, design and realisation, and usability testing and evaluation.

Chapter Two – Literature Survey on Serious Game in Healthcare and Initial *MCI-GaTE* began with exploring existing examples of computerized cognitive training including the relevant serious games. It was found that, overall, they do not extensively use the pertinent playful and gameful components to optimize the use of serious game in the rehabilitative context. A set of highly relevant literature was then selected to explore methods through a diverse range of techniques inductively for assembling the themes to construct an initial *MCI-GaTE*, a serious game framework for MCI patients, alongside the use of thematic approach, encompassing gameful cognitive rehabilitation, gameful physical rehabilitation and playful experiences for all ages. The initial *MCI-GaTE* was structured from three main theme groups: *therapeutic elements*, *core gaming elements* and *motivational elements*.

Chapter Three – Data Analysis of Resident Profiles from GNH and Initial *MCI-GaTE* started with the data collection of GNH resident patient records that were fully documented by healthcare specialists, then presented the GNH data analysis to identify the key features, i.e. *player background*, *player physical* and *cognitive capabilities*, of the MCI patients, and the clinical daily basis, such as *therapeutic tasks* and *scenarios*. The findings were mainly to create *MCI player profile* for *MCI-GaTE* to offer a tailored gaming experience for the MCI player to attempt the rehabilitation. *MCI player profile* was also used in design modelling stage (Chapter 5) to construct the personas (*Foon Lee* and *Ching Lau*).

Chapter Four – Data Analysis of Interview and Final *MCI-GaTE* presented the complete version of *MCI-GaTE*, the first research contribution of this thesis. This chapter brought together previously selected themes to finalise *MCI-GaTE* through the in-depth semi-structured interviews with OTs, a qualitative data collection. The OTs discussed and identified the MCI patients' crucial characteristics and needs to mainly provide the additional themes for *MCI player profile*, *therapeutic element* and *motivational elements* to build upon the initial *MCI-GaTE.* Two research hypotheses were also formulated based on the research findings from Chapter 2 to Chapter 4 to further investigate the effectiveness of the *MCI-GaTE* in Chapter 7.

Chapter Five – Design of *A-go!*: a Serious Game based on *MCI-GaTE* used *MCI-GaTE* which served as a design reference to generate user models, i.e. personas, scenarios and journey map designs, illustrating MCI player (*Foon Lee*) and OT's (*Ching Lee*) initiation into the training. *A-go!* was designed according to key path scenarios with UX&UI designs which are derived from the user models.

Chapter Six – Realisation of *A-go!* as an Interactive High-fidelity Prototype demonstrated the use of *MCI-GaTE* through facilitating *A-go!*, the second research contribution, which may serve as an effective means for physical and cognitive rehabilitation for the players with MCI. *A-go!* is an immersive serious game targeted at an MCI player and their OT, where the architecture served to represent an intended implemented environment, while the high-fidelity prototype conformed with the architecture through an interactive, responsive high-fidelity prototype running on an iPad alongside an *InVision Studio* application.

Chapter Seven – Serious Game Usability Testing and Evaluation presented the procedure of *A-go!* usability testing and evaluations, which has been appraised by the OTs through semi-structured interviews and deductive thematic analysis to respond to the research hypotheses, which were formulated in Chapter 4. The findings have been qualitatively confirmed and overall have shown that *A-go!* can potentially produce a tailored, engaging and motivational training tool to support the MCI players according to *MCI player profile* which links with adaptive user interactions, gaming elements and therapeutic contents. Comparison against existing framework revealed that *MCI-GaTE* is currently the only serious game framework that accommodates the full set of criteria for supporting tailored and gameful physical and cognitive rehabilitation specifically targeted at MCI players. To further validate the effectiveness of *A-go!*, a standardised screening tool was recommended to be used in the future.

8.3 Research Contributions

The construction of the serious game framework is presented together with the designs of personas, scenarios and journey maps for those with mild cognitive impairment. The proposed serious game framework, *MCI-GaTE*, and *A-go!* are particularly designated to provide a potential solution in addressing MCI with unique data, i.e. from GNH and interviews with sophisticated specialists. There are two main contributions of this thesis as follows.

8.3.1 *MCI-GaTE*

In the face of a high prevalence of dementia in the population, serious games play an important role with providing meaningful ways beyond pure entertainment. The traditional programmes led by OTs have been shown to be obsolete. Studies concerning people with dementia or AD only became a popular research topic in the last decade. Even with the more recent studies, there is high heterogeneity between the location settings, demographics of patients, intervention qualities and conditions, etc. Even though there has been a reasonable amount of evidence-based studies looking into a specific way to support the patients with MCI providing serious game approach as a solution, these studies failed to give clear recommendations when regarding the type or optimal measure of gameful elements implemented that would be most beneficial to patients with MCI. There is no literature documenting a framework particular in addressing MCI in combining the holistic research on MCI, usefulness of therapeutic elements and gamefulness. Therefore, *MCI-GaTE* is constructed with a comprehensive tailored approach including MCI player profile, therapeutic, core gaming and motivational elements to optimise the use of serious game for MCI players.

MCI-GaTE produced a comprehensive and tailored gameful approach for MCI players starting with the integration of physical and cognitive capabilities that is derived from the *MCI player profile.* The profile offers a standard for examining MCI players' qualities in using *A-go!*, obtaining inclusive features in accordance with the holistic research supported by the nursing home and interview data. It therefore serves as a novel contribution in bridging serious game technology with the MCI context via the optimization of goal-directed design processes. Depending on the *MCI player profile* criteria, a range of adaptive gaming approaches including gamefulness, playfulness and user interaction are employed, resulting in intuitive and accessible therapeutic gaming experience. The proposed multidimensional layers are intended to be responsible for particular stages throughout the intervention. *MCI player profile* encompasses a stack of MCI player's features that aids more efficient identification of the players to ensure the suitability. It has potential to serve as a screening tool to discern MCI patients based on all designated hand gestures deriving from the nursing home daily training, where these are manageable for MCI patients. *Therapeutic elements* comprised of all conventional daily training bases to provide an all-round training environment to satisfy the player's needs and training purposes. The incorporation of the replicated clinical data and research findings presented in this thesis leads to industrial usage of the gameful rehabilitation, making use of the therapeutic game scenes along with other attributes of the tailored interaction and design considerations in different scenarios. It also entails the common methods that have been employed in traditional training platform, such as paper-and-pen training, which is known for its inability to produce a high-quality and interactive content generation to the player. This layer also works with *core gaming* and *motivational elements* to overcome its mediocre and monotonous training platform to enhance MCI player's motivation and engagement. *Core gaming elements* offer a useful gaming approach to support and motivate the MCI players in completing the tasks, while included external and internal factors provided from *motivational elements* can advance the MCI player's substantial interest throughout the intervention journey. These elements have constituted and summarised the insights pertaining to MCI player's background information and cognition in order to efficiently enable them to access the game tasks. The underlying contribution is the interplay of multidimensional layers in *MCI-GaTE* which serves as a comprehensive designing reference for digital designers and healthcare sector professionals related to MCI to design and evaluate the training content.

The existing serious game frameworks have been extensively compared with *MCI-GaTE*, which contributes a full set of criteria for aiding tailored and gameful physical and cognitive rehabilitation. Researchers and healthcare specialists may use the framework in several ways: as a set of comprehensive and established criteria by which a serious game for MCI may be evaluated, as a basis for developing frameworks for other rehabilitative domains, and as a means for proposing rehabilitative serious games for MCI patients.

8.3.2 *A-go!*

Today, the elderly (65+) is turning to digital technologies which indicates that the number of elderlies in accepting digital platforms as therapeutic methods is expected to escalate dramatically in the future. Serious games can be an intervention method to ease the healthcare burden by executing repeated exercise and training on digital platforms, thereby improving the quality of intervention through cost-effective services. Providing serious games as an intervention solution can mitigate for the high frequency of traditional training methods which require a long period of observation by OTs. This indicates the need of *A-go!*, a proof-of-concept immersive serious game, that is targeted at an MCI player and their OT to demonstrate the use of *MCI-GaTE*. The visual form of *MCI-GaTE* was presented along with UX&UI designs to match the MCI player's touchpoints and emotions. The artefact is introduced to OTs to eliminate the unwanted materials and improve the design elements to favour the MCI player throughout the game. *A-go!* has been designed to enable an MCI player to improve their memory capacity through repeated training supervised by an OT and demonstrates the potential of the framework in designing and implementing therapeutic experiences. Evaluation with OTs revealed that it may be more engaging and effective than traditional training tools for MCI. However, further assessment should be undertaken, and the addition of enhanced features explored, which will be the basis of future research.

8.3.3 Empirical Findings

The two forms of empirical findings arising from this research serve as a further contribution. The first is the nursing home resident data that were measured and documented by the OTs, which were then analysed and initiated in constructing *MCI-GaTE*. This uncovered the structural clinical settings in assessing those with cognitive impairments (i.e. dementia), ranging from physical to cognitive abilities to reveal the traditional assessment tools within typical nursing homes. These data allow researchers to ascertain whether or not the proposed MCI player profile is evidently supported by the clinical data, and may be utilised to further develop the research in other areas, such as advanced physical-oriented cognitive training, using lower limbs, and a full set of game accessibility features according to individual needs. The second is the interview data. It may be possible to use such OT recommendations to build various serious games aiding the MCI context through maximising beneficial outcomes. For example, multi-sensory elements and a collaborative environment are suggested for enhancing the player's gaming experience and engagement in future development. These empirical findings revealed the possibilities and future directions in health technology, assisting the game developers and designers to produce goal-directed applications for MCI players to undergo intervention in nursing homes, hospitals and other elderly care centres.

8.4 Limitations

Several limitations of this proposed project have been identified. The sample of participants (*n*=4) was not fully representative of the diverse population of OTs. Moreover, obtaining the resident profile data (*n*=31) from two branches of a nursing home and associating with several OTs for professional advice limits how much of the actual phenomena arising in general clinical settings and culture is reflected in the data. Furthermore, the methods in designing interventions for the residents are limited to the particular nursing home's settings (i.e. those of GRACE). For example, the packages of intervention were customized to meet the needs of individual residents, the assessment form mentioned in Section 3.6.1 was not undertaken for all residents and thus there was an inequality in the number of participants between the assessment form and individual care plan. Therefore, it would be ideal to target more branches of the nursing home in different districts to enlarge the data cluster such that a variety of packages provided to residents could be investigated. This would further support the consolidation of generalisation. The data is also restricted to Hong Kong Chinese and so the data results of other nursing homes worldwide may slightly vary whereby some of the culturally relevant data would not generalise. The number of residents (*n*=31) is also relatively small. A larger number of residents may provide more varied results and enhance accuracy and generalisation. The prominent MCI player's features may also be more detailed and support improved persona construction. Additionally, the results were not assessed with actual MCI players and tested with standardized screening tools, but rather by proxy via healthcare professionals, thus results in the field may differ. Consequently, the efficacy of the proposed approach, such as interaction design via *Leap* and in-depth usability for MCI players in practice, is not empirically known. Furthermore, a limitation to the current high-fidelity prototype pertains to the utility of the natural user interface control via *Leap*. Although it conforms with the designed architecture, it is nevertheless a prototype that omits the underlying logic and processing for the intended contactless gesture controller in practice. As such, its effectiveness is limited for determining if the controllability of *A-go!* is satisfactory for the MCI player's physical constraints towards the game objects. In addition, interview responses revealed that tactile functions can be potentially implemented in *A-go!* by which a clear sensory message can be transmitted to the MCI player to offer a further enhanced serious gaming experience. Unfortunately, there is a constraint on hardware and the current platform could not offer this type of haptic feedback. Consequently, a fully implemented game may produce fuller and perhaps less inhibited results.

8.5 Implications

There is a lack of gamified solutions for MCI patients that combine physical and cognitive therapy, despite the prevalence of MCI diagnoses within the global population. Through secondary and primary research that surveyed related research literature, analysed nursing home resident profiles, and undertook in-depth interviews with a number of OTs, this research established a set of themes which were organised into a serious game framework for MCI, *MCI-GaTE*. The framework targets players with MCI so that it may serve as an effective means for physical and cognitive rehabilitation, and thus incorporates an MCI player profile with core gaming, therapeutic, and motivational elements. *A-go!* is a proof-of-concept immersive serious game that was developed using the framework. It enables an MCI player to undertake physical and cognitive therapy through gestures. Given the rise in dementia among the elderly and the advantages that digital forms of rehabilitation offer, such as freedom from geographic locations, customised training programmes, and greater engagement, such frameworks and serious games are becoming vital for supporting conventional rehabilitation needs. The global pandemic (Covid-19) has changed people's interactions and routines which led to social distancing and staying-at-home. Most of the daily training in the nursing homes has been drastically affected which can increase the intervention dropout rate. However, the serious game approach can redress this through offering a repeated training for the outpatients at their homes. The framework may also serve as a set of comprehensive and established criteria by which a serious game for MCI may be evaluated. Potentially, the game can be one of the screening tools to discern the MCI group, thus further assisting the healthcare system.

8.6 Future Research and Development

MCI-GaTE was developed inductively through several stages of thematic analysis which enabled successive refinements. It was then verified by the OTs during the interviews, where they were asked to review a close-to-final iteration of the framework, which fed into final refinements, e.g. consolidating some elements. However, future work will seek to undertake further validation. *A-go!* is a persona-based artefact to specifically cater for

MCI players. It has been designed to enable an MCI player to improve their memory capacity through repeated training supervised by an OT and demonstrates the potential of the framework in designing and implementing therapeutic experiences. Evaluation with OTs revealed that it may be more engaging and effective than traditional training tools for MCI. However, further assessment should be undertaken, and the addition of enhanced features explored, which will be the basis of our future research.

The construction of *MCI-GaTE* which is exemplified by the gaming artefact (*A-go!*) can be a sensible rehabilitative training tool. This research area will lead to the redesign of the current rehabilitation culture through interactive platforms which promote tailored serious games to MCI players via a series of gameful elements that can highly improve the MCI player's motivation and engagement. However, the optimization in user interaction and game contents can be further improved. The implementation of the serious game (*A-go!*) could be used to detect the progression of MCI which maps to the player's scores and level through a clinical trial with an extended period. Implementation of a full version of *A-go!* according to the aforementioned findings could subsequently be tested with the MCI players to validate the research approach.

Further research into the extension of *MCI-GaTE* to accommodate other healthcare areas is another research direction, such as physiotherapy, sports science, and other physical/cognitive-related contexts. There is also much research that can be done to investigate the design and application of collaborative serious games consisting of multiple MCI players. The contributions to the state of the art of serious game technology can further offer a solution for the delivery of home-based patients to engage in rehabilitative practices. Relating to Covid-19, a recent situation, and potential future pandemics, where the elderly is restricted to go to the nursing home or hospital to undertake their training, there is an urgent need for research into digital training solutions to serve remote patients, such as those at home.

References

[1] Entertainment Software Association, "2020 Essential Facts About the Video Game Industry," Washington, DC, USA, 2020. [Online]. Available: https://www.theesa.com/esa-research/2020-essential-facts-about-the-video-game-industry/.

[2] S. Egenfeldt-Nielsen, J. Heide Smith, and S. Pajares Tosca, *Understanding Video Games: The Essential Introduction*. New York, NY, USA: Taylor and Francis, 2008.

[3] M. Ma, "Introduction to serious games development and applications," *Entertainment Computing*, vol. 2, no. 2. pp. 59–60, 2011.

[4] M. Ulicsak and B. Williamson, "Computer games and learning: A Futurelab Handbook," Futurelab, London, UK, June 2010. [Online]. Available: https://www.nfer.ac.uk/computer-games-and-learning-handbook.

[5] T. Marsh, "Serious games continuum: Between games for purpose and experiential environments for purpose," *Entertainment Computing*, vol. 2, no. 2. pp. 61–68, 2011.

[6] P. A. Rego, P. M. Moreira, and L. P. Reis, "Serious games for rehabilitation: A survey and a classification towards a taxonomy," in *5th Iberian Conference on Information Systems and Technologies*, Santiago de Compostela, Spain, 16-19 June 2010, pp. 1–6.

[7] World Health Organization and Alzheimer's Disease International, "Dementia: a public health priority," Geneva, Switzerland, 2012. [Online]. Available: https://www.who.int/mental_health/publications/dementia_report_2012/en/.

[8] World Health Organization, "Global action plan on the public health response to dementia 2017-2025," Geneva, Switzerland, 2017. [Online]. Available: https://www.who.int/mental_health/neurology/dementia/action_plan_2017_2025/en/.

[9] S. A. Eshkoor, T. A. Hamid, C. Y. Mun, and C. K. Ng, "Mild cognitive impairment and its management in older people.," *Clinical interventions in aging*, vol. 10, pp. 687–93, 2015.

[10] R. Roberts and D. S. Knopman, "Classification and epidemiology of MCI.," *Clinics in geriatric medicine*, vol. 29, no. 4, pp. 753–72, November 2013.

[11] R. C. Petersen, B. Caracciolo, C. Brayne, S. Gauthier, V. Jelic, and L. Fratiglioni, "Mild cognitive impairment: a concept in evolution.," *Journal of internal medicine*, vol. 275, no. 3, pp. 214–28, March 2014.

[12] S. Gauthier, B. Reisberg, M. Zaudig, R. C. Petersen, K. Ritchie, K. Broich, S. Belleville, H. Brodaty, D. Bennett, H. Chertkow, J. L. Cummings, M. de Leon, H. Feldman, M. Ganguli, H. Hampel, P. Scheltens, M. C. Tierney, P. Whitehouse, and B. Winblad, "Mild cognitive impairment," *Lancet*, vol. 367, no. 9518, pp. 1262–70, April 2006.

[13] R. S. Wilson, E. Segawa, P. A. Boyle, S. E. Anagnos, L. P. Hizel, and D. A. Bennett, "The natural history of cognitive decline in Alzheimer's disease," *Psychology and Aging*, vol. 27, no. 4, pp. 1008–1017, December 2012.

[14] J. Gaugler, B. James, T. Johnson, K. Scholz, and J. Weuve, "2016 Alzheimer's disease facts and figures," *Alzheimer's and Dementia*, vol. 12, no. 4, pp. 459–509, April 2016.

[15] L. M. Allan, C. G. Ballard, D. J. Burn, and R. A. Kenny, “Prevalence and Severity of Gait Disorders in Alzheimer’s and Non-Alzheimer’s Dementias,” *Journal of the American Geriatrics Society*, vol. 53, no. 10, pp. 1681–1687, October 2005.

[16] C. G. Blankevoort, M. J. G. van Heuvelen, F. Boersma, H. Luning, J. de Jong, and E. J. A. Scherder, “Review of Effects of Physical Activity on Strength, Balance, Mobility and ADL Performance in Elderly Subjects with Dementia,” *Dementia and Geriatric Cognitive Disorders*, vol. 30, no. 5, pp. 392–402, 2010.

[17] J. E. Gaugler, S. Duval, K. A. Anderson, and R. L. Kane, “Predicting nursing home admission in the U.S: a meta-analysis,” *BMC Geriatrics*, vol. 7, no. 1, p. 13, December 2007.

[18] A. F. Pettersson, E. Olsson, and L.-O. Wahlund, “Motor Function in Subjects with Mild Cognitive Impairment and Early Alzheimer’s Disease,” *Dementia and Geriatric Cognitive Disorders*, vol. 19, no. 5–6, pp. 299–304, 2005.

[19] A. Mora, C. González, J. Arnedo-Moreno, and A. Álvarez, “Gamification of cognitive training,” in *Proceedings of the XVII International Conference on Human Computer Interaction - Interacción ’16*, New York, NY, USA, 13-16 September 2016, pp. 1–8.

[20] G. L. West, B. R. Zendel, K. Konishi, J. Benady-Chorney, V. D. Bohbot, I. Peretz, and S. Belleville, “Playing Super Mario 64 increases hippocampal grey matter in older adults.,” *PLoS One*, vol. 12, no. 12, p. e0187779, 2017.

[21] S. Lee, Y. Baik, K. Nam, J. Ahn, Y. Lee, S. Oh, and K. Kim, “Developing a cognitive evaluation method for serious game engineers,” *Cluster Computing*, vol. 17, no. 3, pp. 757–766, September 2014.

[22] Y. Zhao, H. Feng, X. Wu, Y. Du, X. Yang, M. Hu, H. Ning, L. Liao, and H. Chen, “Effectiveness of exergaming in improving cognitive and physical function in people with mild cognitive impairment (MCI) or dementia: A systematic review.,” *JMIR Serious Games*, vol. 8, no. 2, October 2019.

[23] S. McCallum and C. Boletsis, “A Taxonomy of Serious Games for Dementia,” in *Proceedings of the 3rd european Conference on Gaming and Playful Interaction in Health Care on Games for Health*, Wiesbaden, Germany, 2013, pp. 219-232.

[24] S. P. Walz and S. Deterding, *The gameful world : approaches, issues, applications*. The MIT Press, 2014.

[25] J. Schell, *The Art of Game Design*. Massachusetts, MA, USA: Morgan Kaufmann, 2008.

[26] D. Daylamani-Zad, M. C. Angelides, and H. Agius, “Lu-Lu: A framework for collaborative decision making games,” *Decision Support Systems*, vol. 85, pp. 49-61, May 2016.

[27] K. S. Tekinbaş and E. Zimmerman, *Rules of Play: Game Design Fundamentals*. Cambridge, Massachusetts: The MIT Press, 2003.

[28] A. Marczewski, “52 Gamification Mechanics And Elements,” Gamified UK, United Kingdom, 2017. [Online]. Available: https://gamified.uk/user-types/gamification-mechanics-elements/.

[29] R. Hunicke, M. Leblanc, and R. Zubek, “MDA: A Formal Approach to Game Design and Game Research,” 2004. [Online]. Available:

https://www.researchgate.net/publication/228884866_MDA_A_Formal_Approach_to_Game_Design_and_Game_Research#fullTextFileContent.

[30] M. Sicart, *Play matters*. Cambridge, Massachusetts : The MIT Press, 2014.

[31] E. L. Glisky, *Changes in Cognitive Function in Human Aging*, Boca Raton (FL): CRC Press/Taylor & Francis, 2007.

[32] World Health Organization., *International statistical classification of diseases and related health problems.*, 2nd ed., vol. 3. Geneva, Switzerland: World Health Organization, 2004.

[33] G. Smith, "Is mild cognitive impairment bridging the gap between normal aging and Alzheimer's disease?," *Journal of Neural Transmission. Supplementa*, no. 62, pp. 97–104, 2002.

[34] M. D. C. Díaz-Mardomingo, S. García-Herranz, R. Rodríguez-Fernández, C. Venero, and H. Peraita, "Problems in Classifying Mild Cognitive Impairment (MCI): One or Multiple Syndromes?," *Brain sciences*, vol. 7, no. 9, September 2017.

[35] M. P. Mattson, "Pathways towards and away from Alzheimer's disease," *Nature*, vol. 430, no. 7000, pp. 631–639, August 2004.

[36] R. C. Petersen, "Mild cognitive impairment: transition between aging and Alzheimer's disease.," *Neurologia* , vol. 15, no. 3, pp. 93–101, March 2000.

[37] B. J. Kelley and R. C. Petersen, "Alzheimer's disease and mild cognitive impairment.," *Neurologic clinics*, vol. 25, no. 3, pp. 577–609, v, August 2007.

[38] C. N. Harada, M. C. Natelson Love, and K. L. Triebel, "Normal cognitive aging.," *Clinics in geriatric medicine*, vol. 29, no. 4, pp. 737–52, November 2013.

[39] A. Perera, "Fluid vs Crystallized Intelligence," *Simply Psychology*, December 14, 2020. https://www.simplypsychology.org/fluid-crystallized-intelligence.html.

[40] CogniFit Research, "Attention," *CogniFit Research*, 2021. [Online]. Available: https://www.cognifit.com/attention.

[41] A.-M. Kirova, R. B. Bays, and S. Lagalwar, "Working memory and executive function decline across normal aging, mild cognitive impairment, and Alzheimer's disease," *BioMed research international*, vol. 2015, p. 748212, 2015.

[42] M. Antoniou, G. M. Gunasekera, and P. C. M. Wong, "Foreign language training as cognitive therapy for age-related cognitive decline: a hypothesis for future research," *Neuroscience and biobehavioral reviews*, vol. 37, no. 10 Pt 2, pp. 2689–98, December 2013.

[43] E. Heerema, "The Trail Making Test Part A and B for Dementia," *Verywell Health*, January 04, 2020. https://www.verywellhealth.com/dementia-screening-tool-the-trail-making-test-98624.

[44] D. Bruno and S. S. Vignaga, "Addenbrooke's cognitive examination III in the diagnosis of dementia: A critical review," *Neuropsychiatric Disease and Treatment*, vol. 15, pp. 441–447, 2019.

[45] A. Burns, C. Brayne, and M. Folstein, "Key Papers in Geriatric Psychiatry: mini-mental state: a practical method for grading the cognitive state of patients for the clinician. M.

Folstein, S. Folstein and P. McHugh, Journal of Psychiatric Research, 1975,12, 189-198.," *International Journal of Geriatric Psychiatry*, vol. 13, no. 5, pp. 285–294, May 1998.

[46] "Simple Reaction Time (SRT)," *Cambridge Cognition*. http://www.cambridgecognition.com/cantab/cognitive-tests/simple-reaction-time-srt/.

[47] G. L. Iverson, "Go/No-Go Testing," in *Encyclopedia of Clinical Neuropsychology*, New York, NY, USA: Springer New York, 2011, pp. 1162–1163.

[48] S. Merilampi, A. Sirkka, M. Leino, A. Koivisto, and E. Finn, "Cognitive mobile games for memory impaired older adults," *Journal of Assistive Technologies*, vol. 8, no. 4, pp. 207–223, December 2014.

[49] G. Y. Lee, C. C. K. Yip, E. C. S. Yu, and D. W. K. Man, "Evaluation of a computer-assisted errorless learning-based memory training program for patients with early Alzheimer's disease in Hong Kong: a pilot study," *Clinical interventions in aging*, vol. 8, pp. 623–33, 2013.

[50] Hongmei Chi, E. Agama, and Z. G. Prodanoff, "Developing serious games to promote cognitive abilities for the elderly," in *2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH)*, Perth, WA, 2-4 April 2017, pp. 1–8.

[51] M. S. Chen and C. N. Wang, "The effects of memory cue and Memory Aid on prospective memory in older and younger adults," in *2010 IEEE International Conference on Industrial Engineering and Engineering Management*, Macao, 7-10 December 2010, pp. 832–836.

[52] D. Dong, L. K. Wong, Z. Luo, and C. Quan, "A novel approach for assessing prospective memory using immersive virtual reality task," in *2016 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, Qingdao, China, 3-7 December 2016, pp. 1888–1893.

[53] H. Lin, J. Hou, H. Yu, Z. Shen, and C. Miao, "An Agent-Based Game Platform for Exercising People's Prospective Memory," in *2015 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT)*, Singapore, 6-9 December 2015, pp. 235–236.

[54] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, 2006.

[55] J. Saldana, *The Coding Manual for Qualitative Research*, Arizona State, USA: SAGE Publications, 2015.

[56] S. Valladares-Rodríguez, R. Pérez-Rodríguez, L. Anido-Rifón, and M. Fernández-Iglesias, "Trends on the application of serious games to neuropsychological evaluation: A scoping review," *Journal of Biomedical Informatics*, vol. 64, pp. 296–319, December 2016.

[57] V. F. A. Pereira and L. S. S. Valentin, "The MentalPlus® Digital Game Might Be an Accessible Open Source Tool to Evaluate Cognitive Dysfunction in Heart Failure with Preserved Ejection Fraction in Hypertensive Patients: A Pilot Exploratory Study.," *International journal of hypertension*, vol. 2018, p. 6028534, 2018.

[58] S. Valladares-Rodriguez, M. J. Fernández-Iglesias, L. Anido-Rifón, D. Facal, and R. Pérez-Rodríguez, "Episodix: a serious game to detect cognitive impairment in senior adults. A psychometric study," *PeerJ*, vol. 6, p. e5478, 2018.

[59] S. Grau, D. Tost, R. Campeny, S. Moya, and M. Ruiz, "Design of 3D Virtual

Neuropsychological Rehabilitation Activities," in *2010 Second International Conference on Games and Virtual Worlds for Serious Applications*, Braga, Portugal, 25-26 March 2010, pp. 109–116.

[60] V. Vallejo *et al.*, "Evaluation of a new serious game based multitasking assessment tool for cognition and activities of daily living: Comparison with a real cooking task," *Computers in Human Behavior*, vol. 70, pp. 500–506, May 2017.

[61] M. N. A. van der Kuil, I. J. M. van der Ham, and J. M. A. Visser-Meily, "Game technology in cognitive rehabilitation of spatial navigation impairment," in *2017 International Conference on Virtual Rehabilitation (ICVR)*, Montreal, Canada, 19-22 June 2017, pp. 1–2.

[62] A. E. Alchalcabi, A. N. Eddin, and S. Shirmohammadi, "More attention, less deficit: Wearable EEG-based serious game for focus improvement," in *2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH)*, Perth, WA, 2-4 April 2017, pp. 1–8.

[63] M. J. Rodriguez-Fortiz, C. Rodriguez-Dominguez, P. Cano, J. Revelles, M. L. Rodriguez-Almendros, M. V. Hurtado-Torres, and S. Rute-Perez, "Serious games for the cognitive stimulation of elderly people," in *2016 IEEE International Conference on Serious Games and Applications for Health (SeGAH)*, Orlando, FL, USA, 11-13 May 2016, pp. 1–7.

[64] T. Mondéjar, R. Hervás, E. Johnson, C. Gutierrez, and J. M. Latorre, "Correlation between videogame mechanics and executive functions through EEG analysis," *Journal of Biomedical Informatics*, vol. 63, pp. 131–140, October 2016.

[65] G. Savulich, E. Thorp, T. Piercy, K. A. Peterson, J. D. Pickard, and B. J. Sahakian, "Improvements in Attention Following Cognitive Training With the Novel 'Decoder' Game on an iPad," *Frontiers in behavioral neuroscience*, vol. 13, p. 2, January 2019.

[66] R. Baranyi, R. Perndorfer, N. Lederer, B. Scholz, and T. Grechenig, "MyDailyRoutine - a serious game to support people suffering from a cerebral dysfunction," in *2016 IEEE International Conference on Serious Games and Applications for Health (SeGAH)*, Orlando, FL, USA, 11-13 May 2016, pp. 1–6.

[67] T. Tong and T. Sieminowski, "Case Study: A Serious Game for Neurorehabilitation Assessment," *Procedia Computer Science*, vol. 69, pp. 125–131, January 2015.

[68] A. Lopez-Martinez, S. Santiago-Ramajo, A. Caracuel, C. Valls-Serrano, M. J. Hornos, and M. J. Rodriguez-Fortiz, "Game of gifts purchase: Computer-based training of executive functions for the elderly," in *2011 IEEE 1st International Conference on Serious Games and Applications for Health (SeGAH)*, Braga, Portugal, 16-18 November 2011, pp. 1–8.

[69] I. Laskowska *et al.*, "A serious game – a new training addressing particularly prospective memory in the elderly," *Bio-Algorithms and Med-Systems*, vol. 9, no. 3, pp. 155–165, January 2013.

[70] A. Dan, "EEG-based cognitive load of processing events in 3D virtual worlds is lower than processing events in 2D displays," *International Journal of Psychophysiology*, vol. 122, pp. 75–84, December 2017.

[71] S. Jessen, J. Mirkovic, and C. M. Ruland, "Creating Gameful Design in mHealth: A Participatory Co-Design Approach.," *JMIR mHealth and uHealth*, vol. 6, no. 12, p. e11579, December 2018.

[72] R. N. Madeira, L. Costa, and O. Postolache, “PhysioMate - Pervasive physical rehabilitation based on NUI and gamification,” in *2014 International Conference and Exposition on Electrical and Power Engineering (EPE)*, Iași, Romania, 16-18 October 2014, pp. 612–616.

[73] M. Alimanova *et al.*, “Gamification of Hand Rehabilitation Process Using Virtual Reality Tools: Using Leap Motion for Hand Rehabilitation,” in *2017 First IEEE International Conference on Robotic Computing (IRC)*, Taichung, Taiwan, 10-12 April 2017, pp. 336–339.

[74] Y. Shi and Q. Peng, “A VR-based user interface for the upper limb rehabilitation,” *Procedia CIRP*, vol. 78, pp. 115–120, January 2018.

[75] Y. Qiu, K. M. Li, E. C. Neoh, H. Zhang, X. Y. Khaw, X. Fan, and C. Miao, “Fun-Knee™: A novel smart knee sleeve for Total-Knee-Replacement rehabilitation with gamification,” in *2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH)*, Perth, WA, 2-4 April 2017, pp. 1–8.

[76] I. Ayed, A. Ghazel, A. Jaume-i-Capo, B. Moya-Alcover, J. Varona, and P. Martinez-Bueso, “Fall Prevention Serious Games for Elderly People Using RGBD Devices,” in *2016 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES)*, Barcelona, Spain, 7-9 September 2016, pp. 1–3.

[77] C. L. Hee, T. H. Chong, D. Gouwanda, A. A. Gopalai, C. Y. Low, and F. A. binti Hanapiah, “Developing interactive and simple electromyogram PONG game for foot dorsiflexion and plantarflexion rehabilitation exercise,” in *2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Jeju, South Korea, 11-15 July 2017, pp. 275–278.

[78] T.-Y. Pan, Y.-X. Wong, T.-C. Lee, and M.-C. Hu, “A Kinect-based oral rehabilitation system,” in *2015 International Conference on Orange Technologies (ICOT)*, Hong Kong, 19-22 December 2015, pp. 71–74.

[79] J. Thomson *et al.*, “Aspira: Employing a serious game in an mHealth app to improve asthma outcomes,” in *2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH)*, Perth, WA, 2-4 April 2017, pp. 1–7.

[80] T. B. Pasqual, G. A. P. Caurin, and A. A. G. Siqueira, “Serious game development for Ankle rehabilitation aiming at user experience,” in *2016 6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob)*, Singapore, 26-29 June 2016, pp. 1007-1012.

[81] A. A. Foletto, M. Cordeiro d’Ornellas, and A. L. Cervi Prado, “Serious Games for Parkinson’s Disease Fine Motor Skills Rehabilitation Using Natural Interfaces.,” *Studies in health technology and informatics*, vol. 245, pp. 74–78, 2017.

[82] M. Csikszentmihalyi, *Beyond boredom and anxiety*. San Francisco: Jossey-Bass, 1975.

[83] J. Eriksson, “Playful Method for Seniors to Embrace Information Technology,” in *International Conference on Human Aspects of IT for the Aged Population*, Vancouver, Canada, 9-14 July 2017, pp. 429–446.

[84] G. Perugia, M. Díaz Boladeras, E. Barakova, A. Català Mallofré, and M. Rauterberg, “Social HRI for People with Dementia,” in *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction - HRI ’17*, New York,

NY, USA, 6-9 March 2017, pp. 257–258.

[85] A. A. Salah, B. A. M. Schouten, S. Göbel, and B. Arnrich, "Playful interactions and serious games," *Journal of Ambient Intelligence and Smart Environments*, vol. 6, no. 3, pp. 259–262, January 2014.

[86] R. Tieben, J. Sturm, T. Bekker, and B. Schouten, "Playful persuasion: Designing for ambient playful interactions in public spaces," *Journal of Ambient Intelligence and Smart Environments*, vol. 6, no. 4, pp. 341–357, January 2014.

[87] P. Marti, "Bringing playfulness to disabilities," in *Proceedings of the 6th Nordic Conference on Human-Computer Interaction Extending Boundaries - NordiCHI '10*, Reykjavik, Iceland, 16-20 October 2010, p. 851.

[88] H. H. Lund and C. B. Nielsen, "Modularity for modulating exercises and levels - observations from cardiac, stroke, and COLD patients therapy," in *2011 8th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*, Incheon, South Korea, 23-26 November 2011, pp. 253–258.

[89] J. D. Jessen and H. H. Lund, "Playful home training for falls prevention," in *2015 IEEE International Conference on Advanced Intelligent Mechatronics (AIM)*, Busan, South Korea, 7-11 July 2015, pp. 311–317.

[90] X. Wang, K. S. Niksirat, C. Silpasuwanchai, Z. Wang, X. Ren, and Z. Niu, "How skill balancing impact the elderly player experience?," in *2016 IEEE 13th International Conference on Signal Processing (ICSP)*, Chengdu, China, 6-10 November 2016, pp. 983–988.

[91] H. Davis, F. Vetere, M. Gibbs, and P. Francis, "Come play with me: designing technologies for intergenerational play," *Universal Access in the Information Society*, vol. 11, no. 1, pp. 17–29, March 2012.

[92] L. Angelini, M. Caon, N. Couture, O. A. Khaled, and E. Mugellini, "The multisensory interactive window," in *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers - UbiComp '15*, Osaka, Japan, 7-11 September 2015, pp. 963–968.

[93] S. Jacoby, G. Gutwillig, D. Jacoby, N. Josman, P. L. Weiss, M. Koike, Y. Itoh, N. Kawai, Y. Kitamura, and E. Sharlin, "PlayCubes: Monitoring constructional ability in children using a tangible user interface and a playful virtual environment," in *2009 Virtual Rehabilitation International Conference*, Haifa, Israel, 29 June - 2 July 2009, pp. 42–49.

[94] A. Moraiti, N. Moumoutzis, M. Christoulakis, A. Pitsiladis, G. Stylianakis, Y. Sifakis, I. Maragoudakis, and S. Christodoulakis, "Playful creation of digital stories with eShadow," in *2016 11th International Workshop on Semantic and Social Media Adaptation and Personalization (SMAP)*, Thessaloniki, Greece, 20-21 October 2016, pp. 139–144.

[95] S. Jamshed, "Qualitative research method-interviewing and observation," *Journal of basic and clinical pharmacy*, vol. 5, no. 4, pp. 87–8, September 2014.

[96] A. Cooper, R. Reimann, D. Cronin, and C. Noessel, *About face : the essentials of interaction design*, 4th ed. Indianapolis, Indiana: John Wiley & Sons, Inc., 2014.

[97] "Color wheel," *Canva*, Perth, Australia, [Online]. Available:

https://www.canva.com/colors/color-wheel/.

[98] "Game accessibility guidelines – Full list," [Online]. Available: https:/gameaccessibilityguidelines.com/full-list/.

[99] "Game accessibility guidelines – Use symbol-based chat (smileys etc)," [Online]. Available: https:/gameaccessibilityguidelines.com/use-symbol-based-chat-smileys-etc/.

[100] "Game accessibility guidelines – Provide pre-recorded voiceovers for all text, including menus and installers," [Online]. Available: https:/gameaccessibilityguidelines.com/provide-full-internal-self-voicing-for-all-text-including-menus-and-installers/.

[101] K. Procci, C. A. Bowers, F. Jentsch, V. K. Sims, and R. McDaniel, "The Revised Game Engagement Model: Capturing the subjective gameplay experience," *Entertainment Computing*, vol. 27, pp. 157–169, August 2018.

[102] J. Nielsen, "Why You Only Need to Test with 5 Users," 2000. https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/.

[103] L. W. P. Peute, N. F. de Keizer, and M. W. M. Jaspers, "The value of Retrospective and Concurrent Think Aloud in formative usability testing of a physician data query tool," *Journal of Biomedical Informatics*, vol. 55, pp. 1–10, June 2015.

[104] A. Mills, G. Durepos, and E. Wiebe, "Thematic Analysis," in *Encyclopedia of Case Study Research*, California, USA: SAGE Publications, Inc., 2013.

[105] V. Fernandez-Cervantes, E. Stroulia, and B. Hunter, "A grammar-based framework for rehabilitation exergames," in *International Conference on Entertainment Computing*, Wien, Austria, 28-30 September 2016, vol. 9926 LNCS, pp. 38–50.

[106] J. K. Lin, P. H. Cheng, Y. Su, J. J. Luh, S. Y. Wang, H. W. Lin, H. C. Hou, W. C. Chiang, S. W. Wu, and M. J. Su, "Augmented reality serious game framework for rehabilitation with personal health records," in *2011 IEEE 13th International Conference on e-Health Networking, Applications and Services, HEALTHCOM 2011*, Columbia, MO, 13-15 June 2011, pp. 197–200.

[107] I. Afyouni, F. U. Rehman, A. M. Qamar, S. Ghani, S. O. Jussain, B. Sadiq, M. A. Rahman, A. Murad, and S. Basalamah, "A therapy-driven gamification framework for hand rehabilitation," *User Modeling and User-Adapted Interaction*, vol. 27, no. 2, pp. 215–265, June 2017.

[108] D. Avola, L. Cinque, G. L. Foresti, and M. R. Marini, "An interactive and low-cost full body rehabilitation framework based on 3D immersive serious games," *Journal of Biomedical Informatics*, vol. 89, pp. 81–100, January 2019.

[109] X. Qian, W. Dai, R. Xu, and H. Ling, "One intelligent framework for screening and intervention of Mild Cognitive Impairment (MCI)," *The Journal of Engineering*, vol. 2020, no. 13, pp. 422–425, 2020.

[110] K. Gutenschwager, R. Shaski, R. Mc Leod, and M. Friesen, "A Framework for Utilizing Serious Games and Machine Learning to Classifying Game Play Towards Detecting Cognitive Impairments," *Global Journal of Aging & Geriatric Research - GJAGR*, vol. 1, no. 1, 2019.

[111] E. A. Alcover, A. Jaume-I-Capó, and B. Moyà-Alcover, "PROGame: A process framework for serious game development for motor rehabilitation therapy," *PLoS One*, vol. 13, no. 5, 2018.

[112] D. Holmes, D. Charles, P. Morrow, S. McClean, and S. McDonough, "Rehabilitation Game Model for Personalised Exercise," in *2015 International Conference on Interactive Technologies and Games*, Nottingham, UK, 22-23 October 2015, pp. 41–48.

[113] M. S. Hossain, S. Hardy, A. Alamri, A. Alelaiwi, V. Hardy, and C. Wilhelm, "AR-based serious game framework for post-stroke rehabilitation," *Multimedia Systems*, vol. 22, no. 6, pp. 659–674, November 2016.

[114] I. T. Paraskevopoulos, E. Tsekleves, A. Warland, and C. Kilbride, "Virtual reality-based holistic framework: A tool for participatory development of customised playful therapy sessions for motor rehabilitation," in *2016 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games)*, Barcelona, Spain, 7-9 September 2016, pp. 1-8.

A. Appendix A

Table A-1 Interview Questions, Responses and Themes for *MCI-GaTE*

Questions	Participant Responses	Themes
Question 1: ***To what extent do you agree that patients with MCI are interested in using computer-based rehabilitation/therapy? What makes them interested or uninterested (both initially and during the rehabilitation/therapy)?***	*P1 - "I think the interest of any patient depends on their education level because it will determine whether they understand or know the functionality of the computer … maybe around 30%-40% of them who are relatively smarter and have a higher education level would be more interested…"* **-** *"If the game or the task requires the use of the mouse, the patients might not want to participate, or may just ignore you. Several patients might still want to try to use new technologies, maybe the touch-screen…* *P2 - "As long as they are willing to learn the computer or new things, they would be interested…"* **-** *"From my working experience in a healthcare centre, generally those with visual or hearing impairment… the very mild cases or MCI patients without visual and hearing impairment were more likely to learn new skills. They*	i. Education (***P1-P4***) ii. Controllability (***P1***) iii. Potential Impairment: Visual and Hearing Impairment (***P2***) iv. Supervision & verbal encouragement (***P4***) v. Tangible Tools (***P1, P3***) vi. Attention Support (***P1, P4***)

	probably would have more interest than the impaired group." *P3 - "I think in this century, many of them do not know how to use the computer… but if it could provide them with some tangible tools, it would be easy for them to pick up the computer and develop their interest in it…"* *P4 - "If their education level is high, they can be keenly interested, and easily initiated into the computer-based rehab…"* **-** *"…the relationship between the carer and patient is important for motivating them and building trust, because we understand their living styles and they would be willing to listen and follow our instructions…"* **-** *"I suggest that the content should be similar to their daily routines, then they could understand the given information and engage with it much more…"*	
Question 2: ***What can increase a patient's attention and motivation during cognitive rehabilitation/therapy? What tools are used during the rehabilitation?***	*P1 - "It is hard to provide training that is tailored to each of them. Grading is needed, for example, assigning the easy level to match the beads to the columns; the intermediate level to classify the different coloured beads in the corresponding coloured columns, and so on…gradually increasing or decreasing the level according to their abilities."*	i. Levels (***P1-P4***) ii. Personalisation (***P1***) iii. Flow (***P1-P2***) iv. Potential Impairment: Visual and Hearing Impairment (***P4***) v. Supervision & Verbal Encouragement (***P1***)

	- *"Assistants or carers can provide verbal encouragement. Sometimes, the participants would need us to play with them or just watch them do the tasks for a few minutes."* *P2 - "What I suggest is that the game or task should not be too hard or too easy, …if it is too hard, they will not be able to manage the difficulty level; and if it is too easy, they might easily get bored and drop out of the task. So, I will adjust the tasks with regard to their cognitive level"* - *"There is an example in my centre using a real object, maybe a towel, to do some daily life activities, such as cleaning movements…"* *P3 - "During the training, I will keep upgrading and downgrading the level of the task according to the participants, so the results and effectiveness of the training end up fitting them."* *P4 - "In real life cases, because most of the elderly would have visual and hearing disabilities, it is common in training to adjust the image size in order to draw their attention."* - *"Errorless learning is commonly used during the training… We will just ignore all the errors during the task, and ask them to be focus on what they are doing."*	vi. Tangible Tools (***P2***) vii. Learning Approach (***P4***)

	- *"…adjusting the level during the rehab can increase the motivation…"*	
Question 3: ***In general, how long does an intervention usually take? How do you know it is working based on the patient's capability? What is the minimum duration for it to be effective? Is there a maximum duration?***	*P1 - "To assign different tasks to them, each task is around 15mins. We won't only provide one task, but several tasks in a row."* *P2 - "The pre- and post- recorded medical history and results which they have achieved helps us assess whether the training is working for them. Normally, we will use the scoring to evaluate it."* *- "One session is around one hour…"* *P4 - "The period of intervention depends on their ability. If they have high motivation, they can last for 30-45 mins. Some cases can exceptionally last for one hour, and they are at the very mild stage and highly motivated. But, the worst cases can only last for around 15 mins."* *- "When we want to train a certain cognitive domain of the patient, we'll just check their profile from pre- and post- test results, then address their weak areas."*	i. Levels (***P4***) ii. Duration (***P1, P2, P4***)
Question 4: ***What basic level of physical movements (especially***	*P1 - "Basically, most of the MCI's upper limbs are flexible. They can do all the basic physical movements if they have no other physical injuries, like stroke. Stroke may make*	i. Co-ordination (***P2***) ii. Physical functional tasks: upper and lower limbs (***P1-P4***)

arms/hands/fingers) are patients with MCI able to manage? Please give some examples.	*it difficult for them to perform the movements, but they can still do the basic tasks because they still have another limb to do it… Thumb opposition is the hardest one among all the hand functions. If they can perform this gesture, all other basic gestures are not a problem to them.”* *P2 - “Generally, MCI can perform all basic physical movements. Co-ordination will always be involved, like using both hands to do the tasks, which mainly requires co-ordination and not just a simple physical movement. For example, picking up certain coloured objects with the co-ordination of the eyes and fingers.”* *P3 - “MCI are still at the very mild stage or onset of dementia, so they can perform a lot of basic physical movements.”* *P4 - “MCI who do not have fractures, stroke or other physical conditions can perform all the basic movements. I would prefer to choose functional tasks for the patients, such as frying, clapping and reaching gestures.”*	
Question 5: ***From the beginning to the end of the cognitive rehabilitation/therapy, which sessions or aspects are cognitively challenging for the patients? Please give some examples,***	*P1 - “Working memory and attention could be the challenging part among the cognitive domains involved in cognitive rehab.”* *P2 - “The sensory registration is important… using colours or some other visual*	i. Attention (***P1, P2, P4***) ii. Attention Support (***P2, P3***) iii. Duration (***P3***)

e.g. attention, interactions, external/internal factors affecting them, etc. What factors might help make these sessions or aspects less challenging?	*elements to stimulate them visually, and avoid providing too much descriptive content for them"* *P3 - "I'll try to keep the rules or instructions very simple for them to understand the given tasks. The language or communication should be very clear…"* *- "The worst situation is that a sudden medical change happens during the middle of rehab, because the patients might need to be sent to the hospital and the intervention would be interrupted."* *P4 - "To initiate them into the rehab at the beginning would be the most challenging, because it requires their attention and right mental state to perform the tasks. Sometimes, they will blame themselves and feel stigmatized…"*	
Question 6: ***From your experience and observations, do you think computer-based rehabilitation/therapy can potentially contribute to patients with MCI more effectively than the traditional training platform? How? In what areas?***	*P2 - "Nowadays, the elderly is gradually learning how to use the computer. I know that integrating the computer into the therapeutic environment can bring diverse and various modes to the patients."* *P3 - "Seems that the computer can provide more elements and choices, such as board games and VR reminiscence. If the carers have no confidence in the patients going out for outdoor activities, the computerized*	i. Autonomy: Freedom of Choice (***P2-P4***)

	training can help them to build up some basic skills first." *P4 - "The cases who would like to try to use the computer could achieve good results or offer positive feedback because the computer can change into different modes and provide more variety to match their preference."*	
Question 7: ***Can you show me some examples of cognitive rehabilitation with/without technological support? In your experience, what is the main difference between them? What are the positive and negative effects on the patients?***	*P1 - "When we are monitoring or observing a patient who is undergoing the tasks or a challenge, we can instantly spot out the subtle mistakes… technology might not be as accurate as our analysis."* *- "The technological support can help us to measure the range or capability of patients; and for safety concerns, technology can reduce the potential risks because it can provide trials or test prior to the tasks.* *P2 - "Several cases in my centre would use the "platform-based" rehabilitation which provides a board inscribed with geometric shapes, like circles and triangles, and get the patients to match the shapes accordingly."* *- "One-on-one (therapist and patient) training can increase the quality and effectiveness of the training."* *- "There is no verbal reinforcement provided by technological support. The support of the*	i. Supervision & Verbal Encouragement (***P1-P3***)

	OT can sometimes motivate the patients to do the tasks." *P3 - "I'm sure that technology can provide accurate measurement, and it is good for data recording, but I don't think that technology can replace the jobs of OT because we can provide concise analysis of our patients."* *- "It can reduce the risks and our workload, then we can focus on other issues."* *P4 - "Some home-based clients may not have a chance to use the technology because it is hard for us to carry the equipment to their home to carry out the training."*	
Question 8: ***What type of memory training have you used with patients (including currently) and why? What are the differences/benefits between them?***	*P1 - "Reality Orientation, we named it R.O., is a very common type of training for the patients to strengthen their memory. R.O. provides orientation information, like the weather, time and date or something related to that person. They would need to understand and adapt to the given environment and respond to some questions… and IADLs are provided to get the patients to focus on the complex skills… to see if they can remember a series of steps to complete the task."* *P2 - "Working memory, or you may say short-term memory, will always be involved in*	i. ADLs (***P1-P3***) ii. IADLs (***P1-P3***) iii. Reminiscence (***P1-P4***) iv. Reality Orientation (***P1-P4***)

	any task. What I'll do is ask them to list out the objects that I've shown them a few secs ago." *P3 - "Reminiscence, ADLs and IADLs are good for training the short-term and long-term memory. I'll also ask them to remember the activity instructions…"* *P4 - "Short-term and long-term memory in MCI can still remain functional, but their short-term memory will gradually deteriorate because of aging. I've employed R.O., reminiscence and long-term memory training…long-term memory training supports them by getting them to recall information on familiar objects. I've also used the rehabilitative approach of providing hints, notifications and sometimes an alarm to remind them of the following actions".*	
Question 9: ***Do you think patients with MCI are sufficiently competent to manage the basic functionality of a digital game? What are the common restrictions to be aware of? What range of interactions and range of physical movements do you think patients could manage? Using which parts of their body?***	*P1 - "I think most of the MCI have the common sense to understand the basics and manage the functionality of a digital game. But, if it requires them to learn some new skills or receive new information, they might need more time."* *- "I would recommend either using upper limbs or lower limbs for one training session."* *P4 - "Digital game may be a topic that they are not familiar with… but if they like it, they would put in more effort and spend more*	i. Controllability (***P1, P4***) ii. Physical Functional Tasks: Upper and Lower Limb Tasks (***P1, P4***)

	time to listen to you and follow the instructions. If they do not like it, it can be a barrier for them, for instance, they may not be familiar with a mouse and keyboard." *- "Table tasks are good for them… sitting in front of the table and using the upper limbs to perform the tasks can enhance their attention by reducing physical limitation with a steady position."*	

B. Appendix B

Table B-1 Foon Lee's Context Scenario and Key Path Scenario

Context Scenario	Data Elements	Functional Elements	Key Path Scenario
a. **Early Wednesday morning, *Foon* is getting ready to join the training programme in the care home. This is the very first time she is going to the care home, so her grandchild, *Yuet*, is to accompany her to the centre, to help *Foon* get used to the new surroundings during the programme.**	• A full version of diagnostic document (with background information	• Prepare the diagnostic document	Early Wednesday morning, *Foon* is getting ready and **preparing a full version of a diagnostic document that comprises all the background information in detail** to join the training programme in the care home. This is the very first time she is going to the care home, so her grandchild, *Yuet*, is to

			accompany her to the centre, to help *Foon* get used to the new surroundings during the programme.
b. ***Foon* and *Yuet* arrive at the care home and check in at the reception. The centre assigns an OT (*Ching*) to *Foon* and set up a personal care plan in accordance with her diagnosis and abilities.**	● Booking record ● Availability of OT ● Diagnosis of MCI with intact physical ability, i.e. no fracture and stroke ● Personal care plan profile	● The centre checks the reservation record and availability of OT ● Hand in the diagnosis document to OT (*Ching*) ● Set up the personal care plan	*Foon* and *Yuet* arrive at the care home and check in at the reception. The centre **checks *Foon*'s booking** and **assigns an available OT** to her to follow up her case. *Foon* **submits the diagnosis document** for *Ching* **to set up a personal care plan** in accordance with her diagnosis and abilities. *Ching* has to ensure that *Foon* is part of the **MCI group** and **has an intact physical abilities** with no fracture or stroke.
c. ***Ching* introduces the game-based training programme to *Foon* and asks *Yuet* to be with her throughout the entire programme. The training is set around 30 to 45 minutes. *Foon* looks at the monitor and places both hands upon the motion capture device. *Foon* cannot see the contents clearly and asks *Ching* for help. *Ching* adjusts**	• Game-based training programme • Visual instructions • Duration: 30 to 45 minutes for entire training • Monitor for displaying the game scene	• Look at the monitor and check the virtual hands in the game scene • Calibrate *Foon*'s both hands with the motion capture device to the monitor • Adjust the gaming contents in game	*Ching* introduces the **game-based training programme visually** to *Foon* and asks *Yuet* to be with her throughout the entire programme. The training is set for around **30 to 45 minutes**. *Foon* **looks at the monitor** and **places**

the content size to suit *Foon*'s vision quality, and then continues.	• Motion capture device for detecting *Foon*'s upper limb movements • Clearness of the training contents for *Foon* • Adjustable gaming objects	settings for the sake of adaptability	**both hands upon the motion capture device to calibrate the hand movements**. The virtual hands are displayed in the game scene. *Foon* cannot see the contents clearly and asks *Ching* for help. *Ching* **adjusts the content size from the menu bar at the top right corner** to suit *Foon*'s vision quality, so as to improve the adaptability, and then continues.
d. ***Foon* follows *Ching*'s instructions and starts to do a set of interactions which will be used during the training. The practice is around 5 to 10 minutes. *Foon* constantly checks with *Ching* if she is doing the movements correctly.**	• A number of demonstration tasks • A set of upper limb gesture inputs • Game objects, e.g. boxes • Duration: 5 to 10 minutes for demonstration	• Observe *Ching*'s hand movements on the monitor • Practise the hand functions: (i)opposition, (ii)fist, (iii)grasp and release, (iv)pinching and (v)co-ordination; and other upper limb functions: (i)pressing/tapping, (ii)pulling and (iii)translating • Interact with the given game objects	*Foon* observes and follows *Ching*'s instructions pertaining to **a set of hand movements** which will be used during the training. It includes**: (i)opposition, (ii)fist, (iii)grasp and release, (iv)pinching and (v)co-ordination; and other upper limb functions: (i)pressing/tapping, (ii)pulling and (iii)translating**. *Foon* practices the hand movements for around **5 to 10 minutes**, trying to

			perform the gestures with the given game objects and constantly checks with *Ching* if she is doing them correctly.
e. ***Foon* has completed all the given tasks and begin the game-based cognitive training. She looks at the game menu on the computer monitor and picks one of the preferred training contexts provided. She selects cooking as the training theme as it is the familiar to her.**	• A number of completed tasks • The level settings • A list of preferred training contexts	• The system shows the completion of demonstration • Set the appropriate game level • Look at the game menu • Choose one of the preferred training contexts from the game menu by doing thumbs up for 3 seconds	*Foon* has completed all the given tasks and **the monitor displays the completion of the demonstration**. By showing the "**thumbs up" hand gesture** to the monitor **for 3 seconds,** *Foon* is able to go to the "**game levels" page**. *Ching* **sets the level** for *Foon* to begin the game-based cognitive training by showing **thumbs up for 3 seconds to enter the desired level**. *Foon* **looks at the game menu** and picks one of the **preferred training contexts provided (i.e. cooking scene) by showing thumbs up for 3 seconds**. The chosen training context is familiar to her.

f. ***Foon* explores the cooking scene and tries to understand the game context. She uses the upper limb gestures which she practiced during the previous stage. When she lacks sufficient attention and working memory, the training system automatically provides the attention support and gameful components to guide her in accomplishing the level.**	• Memory recalling of practiced gestures • Amount of attention and working memory functioning supports • Gameful components	• Explore the game scene with the set of practised gestures • Respond to the given tasks • The system provides attention and working memory supports with gameful visual elements	*Foon* **explores the cooking scene with hand movements** and tries to understand the game context. She uses the upper limb gestures which she practiced during the previous stage to **respond to the tasks**. When she lacks sufficient attention and working memory, the training system automatically **provides the attention support and gameful components** to guide her in accomplishing the level.
g. **Sometimes, she needs to ask *Ching* for further explanation of the game context, then *Ching* will walk through some of the steps with her.**	• Further explanation from *Ching* • Verbal guidance with hand movements	• Ask *Ching* for explaining the particular context • Demonstrate the hand movements	Sometimes, she needs to **ask *Ching* for further explanation** of the game context, then *Ching* will walk through some of the steps with **hand movements**
h. ***Foon* is able to finish the level without being distracted.**	• No errors are displayed throughout the training • System detection	• The system hides and records all the errors • The system detects *Foon*'s inputs	*Foon* is able to finish the level without being distracted by errors because the training system **will not**

			display errors which demotivate her.
i. **After the training, *Foon* tells *Ching* about her experience in using the game-based training. The game ends with results.**	• Experience comments • Full record of *Foon*'s interaction	• Reveal the feelings of participating the game-based training to *Ching* • The system records all of the interaction inputs • The system reviews the results	After the training, *Foon* **tells *Ching* about her experience** in using the game-based training. The game-based training **has recorded and scored every single interaction** that she has made. The system **displays *Foon*'s results** on the monitor.

Table B-2 Ching Lau's Context Scenario and Key Path Scenario

Context Scenario	Data Elements	Functional Elements	Key Path Scenario
a. **On an early Wednesday morning, *Ching* receives a new case (*Foon*) at the reception. She sets up the player's profile for *Foon*.**	• Diagnosis of MCI • Personal care plan for setting up player's profile	• Evaluate *Foon*'s diagnosis • Ensure that *Foon* is MCI case • Set up MCI player profile on the system by inserting the background information	On an early Wednesday morning, *Ching* receives a new case (*Foon*). She **evaluates *Foon*'s medical report and ensures that she is accurately diagnosed with MCI**. She **sets up the player's profile by inserting the**

			data into the system.
b. ***Ching* understands that *Foon* is illiterate and has visual impairment which has been fully recorded in her medical report. In this case, *Ching* needs to provide appropriate materials in game settings for *Foon* to do the training.**	• *Foon*'s capabilities • Visual contents • Size of the training elements • Calibration with the motion capture device and monitor	• Assign the appropriate physical and cognitive functions in game settings • Enlarge and adjust the visual elements for *Foon* • Calibrate the hand movements	*Ching* understands that *Foon* is illiterate and has visual impairment which has been fully recorded in her medical report. In this case, *Ching* **needs to display several training contents** on the monitor to gauge her visual ability. She activates **a set of physical and cognitive functions** in game settings and **enlarges the size of the training elements by sliding the menu bar button with a pinching gesture** for *Foon* to clearly see the images. Then, they proceed to **calibrate the hand movements**.
c. ***Ching* demonstrates the tasks with *Foon* before the game-based cognitive training. She observes how *Foon* interacts and ensures that she can apply all the hand gestures. Then, *Ching* motivates *Foon* complimenting her passing all the given tasks. She then**	• A set of designated hand gestures • Game objects in cooking scene • Adaptability in using hand gestures • Verbal encouragement	• Demonstrate each of the hand gestures: hand functions and other upper limb functions • Interact with the game objects with appropriate gestures	*Ching* demonstrates and **practices a set of designated hand gestures (see *F-d.*)** with *Foon* before the game-based cognitive training. She **observes how *Foon* interacts with the**

moves on to the game-based training.		• Make sure *Foon* can complete all the assigned tasks • Tell *Foon* that she accomplished all the given tasks in order to motivate her to start the game-based training	**game objects** and ensures that she can apply all the hand gestures. Then, *Ching* **motivates *Foon* by reviewing the completion of the demonstration stage complimenting her passing all the given tasks.** She then moves on to the game-based training.
d. ***Ching* patiently introduces the game scene with *Foon*.**	• Game menu • Functionality of the system	• Provide the game menu on the monitor • Demonstrate/walk through some functionalities of the system, e.g. painting the bread	*Ching* **displays the game menu on the monitor** and patiently introduces and **walks through some of the functionalities** of the game with *Foon.*
e. **Sometimes, *Foon* seems confused with the action and context while trying to respond to the task. Meanwhile, *Ching* needs to record and discern the difficulties that *Foon* is encountering.**	• A list of *Foon*'s difficultie	• Record and anticipate *Foon*'s problem	Sometimes, *Foon* seems confused with the action and context while trying to respond to the task. Meanwhile, *Ching* needs to **record and discern the difficulties** that *Foon* is encountering.
f. ***Ching* motivates *Foon* to carry on with hints and verbal encouragement when *Foon* is**	• Verbal encouragement	• Give some hints to motivate *Foon* to continue the game	*Ching* motivates *Foon* to carry on **with hints** and

inattentive or unmotivated during the training.			**verbal encouragement** when *Foon* is inattentive or unmotivated during the training.
g. **Finally, *Foon* relates her experience during the game-based training to *Ching. Ching* documents *Foon*'s comments and records the touchpoints, emotions, thoughts and level of personal engagement during the training.**	• Review of the gaming experience • Results of the training	• Jot down *Foon*'s attitudes and feelings toward the game	Finally, *Foon* **relates her attitudes and feelings** during the game-based training experience to *Ching. Ching* documents *Foon*'s **comments** and **records** the touchpoints, emotions, thoughts and level of personal engagement during the training.
h. ***Ching* analyses all the collected data of *Foon* for the next training.**	• Data analysis and findings • Game levels in settings	• Analyses the data through reviewing the score from the system	*Ching* **analyses all the collected data and findings using the scoring system** to determine the suitable game level for *Foon* in the next training.

Table B-3 Functional Requirements for MCI Player

Scenario	Contexts	Functional Requirements
F-a.	i. *Foon* needs to prepare the files of diagnosis	i. The diagnosis is stated as MCI group
F-b.	i. The staff can check the reservation record and availability of OT from the database, and then assign an OT(*Ching*) to *Foon.* ii. The OT (*Ching*) inserts *Foon*'s diagnosis to the system and sets up the personal care plan for her.	i. Secondary requirement: view the reservation record and the availability of OT on database. ii. Set up the personal care plan by inserting the diagnosis information.
F-c.	i. *Foon* can place her hands above the motion capture device. If her hands are detected, the monitor will display her virtual hands in the play area. ii. Once her virtual hands are displayed, *Foon* can start to move her hands within the play area to calibrate the device from the device panel. iii. *Ching* can help *Foon* to adjust the gaming contents via the size adjustment button (with a slider) from the side bar menu. The size of the monitor can be changed from range 50% to 150%. iv. Doing thumbs up gesture for 3 seconds to confirm the size of the monitor.	i. Display virtual hands in play area after automatic recognition of *Foon*'s hands. ii. Calibrate the device from the device panel. iii. Slide the size adjustment button (with a slider) from the bar menu is within range 50% to 150%. iv. 3-second thumbs up gesture confirmation.
F-d.	i. *Foon* should practise eight of the designated gestures: (i)opposition, (ii)fist, (iii)grasp and release, (iv)pinching, (v)co-ordination,	i. Eight of the designated gestures: (i)opposition, (ii)fist, (iii)grasp and release, (iv)pinching, (v)co-ordination, (vi)pressing/tapping, (vii)pulling and

	(vi)pressing/tapping, (vii)pulling and (viii)translating, one by one. *Foon* needs to respond to the given tasks in accordance with the side bar at the left. When *Foon* the current task is completed, the next task will be shown, and required her to complete, and so forth. ii. When all the gestures are completed, "mission complete!" will be shown and direct to the Completion of Demonstration page.	(viii)translating, are displayed accordingly on side bar. ii. "Mission Complete!" is displayed when eight of the designated gestures are completed. The interface will direct to the Completion of Demonstration page.
F-e.	i. Eight of the completed gestures are listed on the Completion of Demonstration page. ii. *Foon* needs to do the thumbs up for 3 seconds to leave the page and enter to Game Levels page. iii. *Ching* can choose the game level for *Foon.* By doing thumbs up on the button for 3 seconds to confirm the game level. Then, the system will direct to the Game Menu. iv. Four game scenes are provided on Game Menu. *Foon* can select one of the game scenes by doing thumbs up for 3 seconds on the button. Then, the selected game will be released.	i. Completion of Demonstration page displays the completed tasks. ii. 3-second thumbs up gesture confirmation to exit the current page and enter to Game Levels page. iii. Select the game level button with 3-second thumbs up confirmation. The system directs to the Game Menu. iv. Four game scenes are provided. 3-second thumbs up confirmation to select the game scene.
F-f.	i. Game Scene – Cooking	i. The gameful elements to support the player
F-g.	i. Verbal guidance with hand movements (This interaction will be using the same screen as in *F-d.* or *F-f.,* e.g. *Foon* might be confused or forgot to use the designated hand gestures, so that *Ching* would need to guide her with the hand movements.)	i. *Ching'*s verbal guidance with hand movements will be provided.

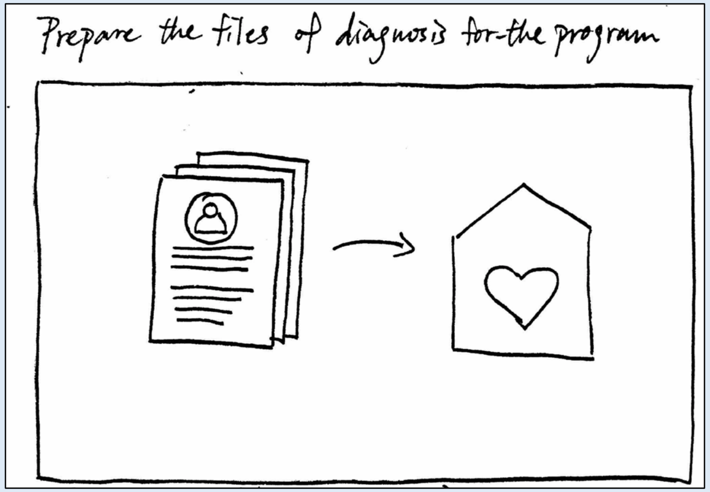
F-h.	Results i. The results will reveal the scores and errors in a form of list.	i. The results are revealed in a form of list with scores and errors at the end.

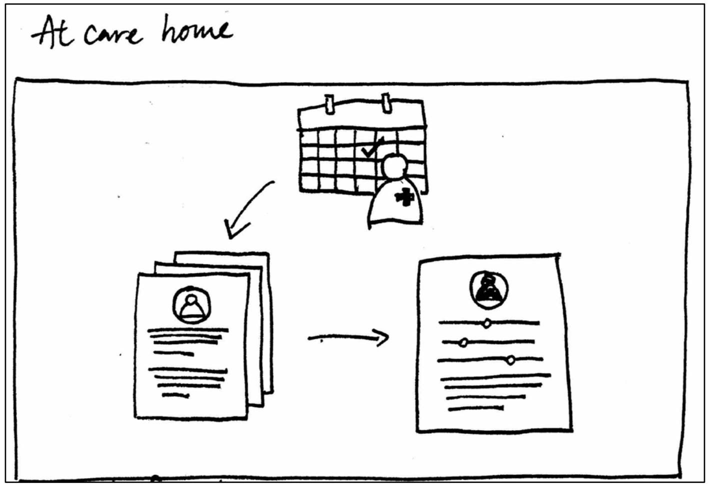
Table B-4 Functional Requirements for Occupational Therapist

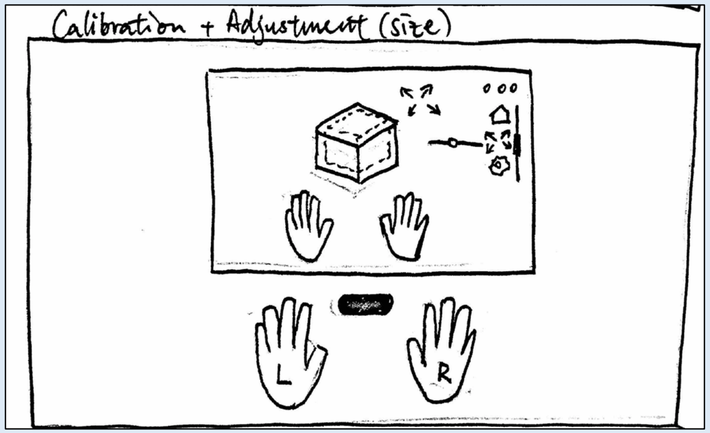
Scenario	Contexts	Functional Requirements
C-a.	i. *Ching* can insert the background information and *Foon*'s physical capabilities into the player profile page as the personal care plan.	i. Insert the MCI player information on profile page.
C-b.	i. *Ching* can calibrate *Foon*'s hand movements from the device panel. ii. *Ching* can enlarge or adjust the gaming contents from the menu bar. She can slide the adjustment button to enlarge or reduce the game objects within range 50% to 150%.	i. Calibrate the device from the device panel. ii. Slide the size adjustment button (with a slider) from the bar menu is within range 50% to 150%.
C-c.	The functional requirements of demonstration will be worked the same as in *F-d.*	

C-d.	The functional requirements of Game Menu will be worked the as in *F-f* when *Ching* is needed to demonstrate/walk through some of the gaming functionalities to *Foon.*
C-e.	These scenarios i.e. *C-e.* to *C-h.* do not involve any interaction with the game. i. Listing out *Foon*'s difficulties ii. Record and anticipate *Foon*'s problem
C-f.	i. Verbal encouragement ii. Give some hints to motivate *Foon* to continue the game
C-g.	i. Experience comments ii. Jot down *Foon*'s attitudes and feelings toward the game
C-h.	i. Data analysis ii. Analyses the data through reviewing the score from the system

Table B-5 Low-fidelity UI Sketches for Foon Lee

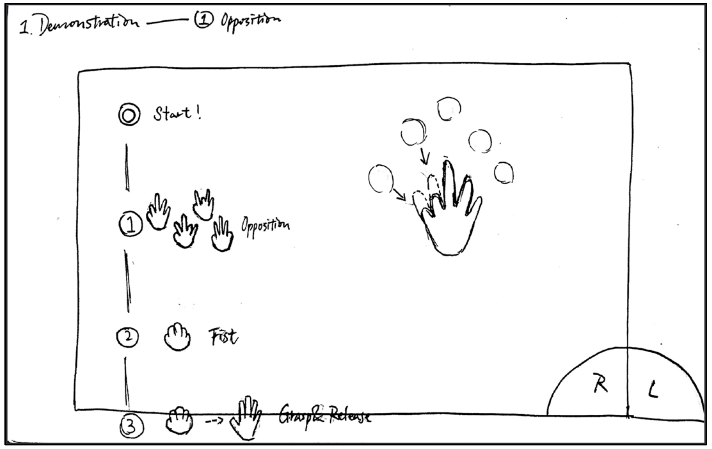
Low-fidelity UI Sketches



At care home

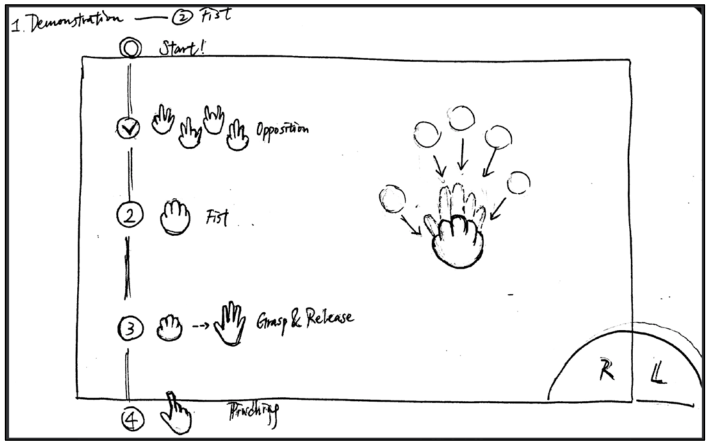

Calibration + Adjustment (size)
L
R

Demonstration

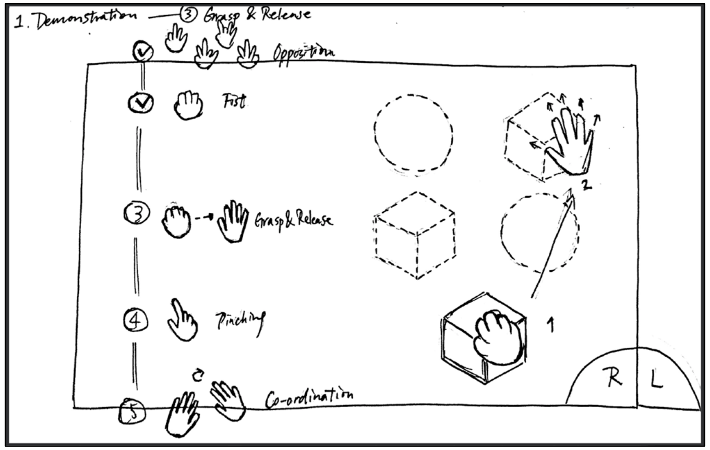
i. **Opposition**



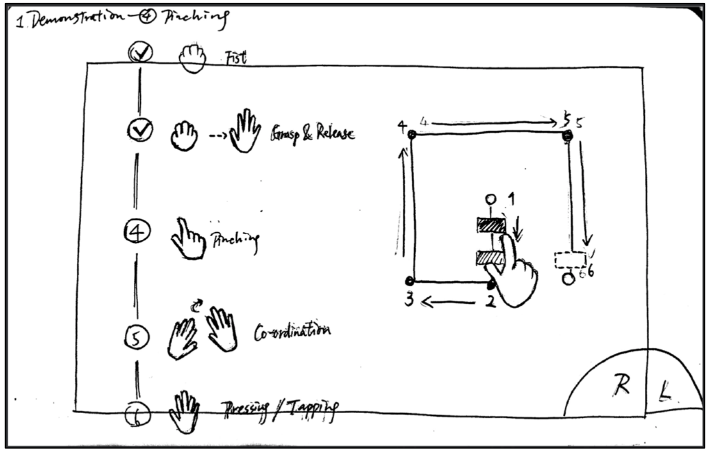
ii. **Fist**



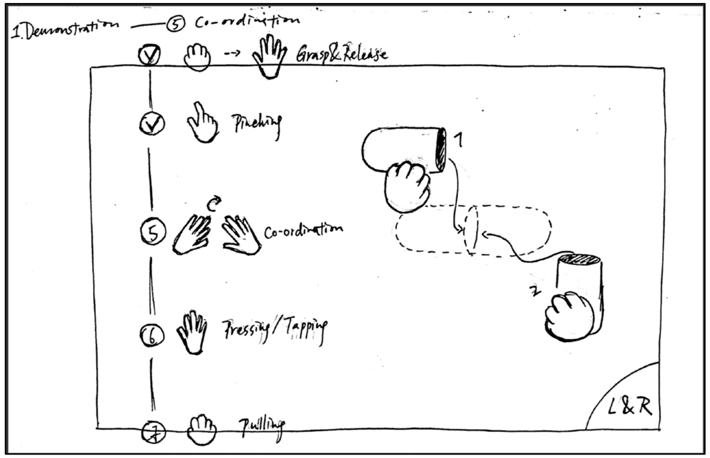
iii. **Grasp and Release**



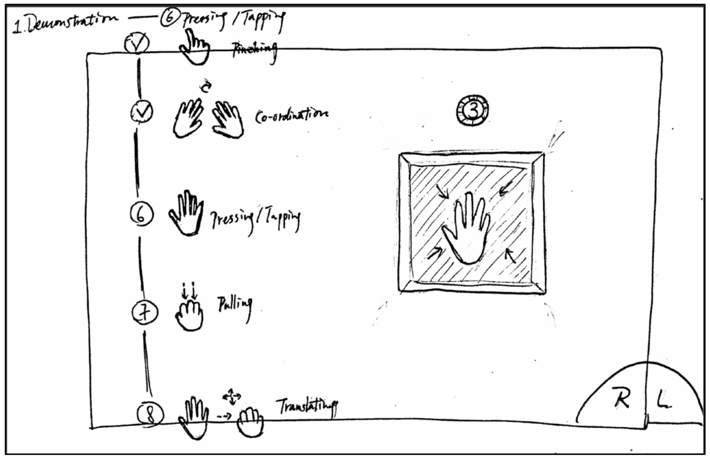
iv. **Pinching**



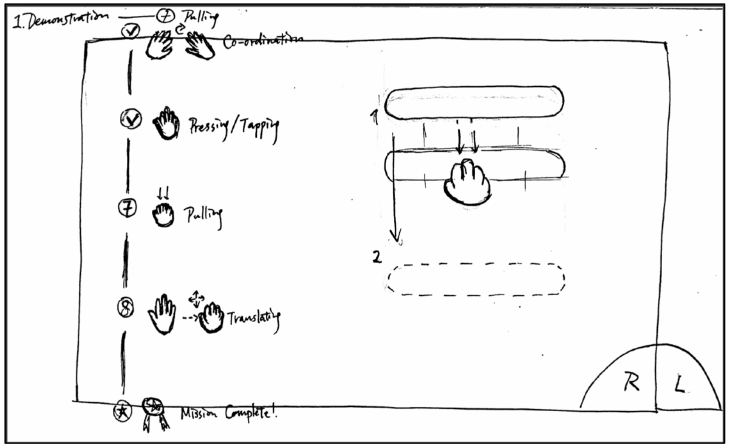
v. **Co-ordination**



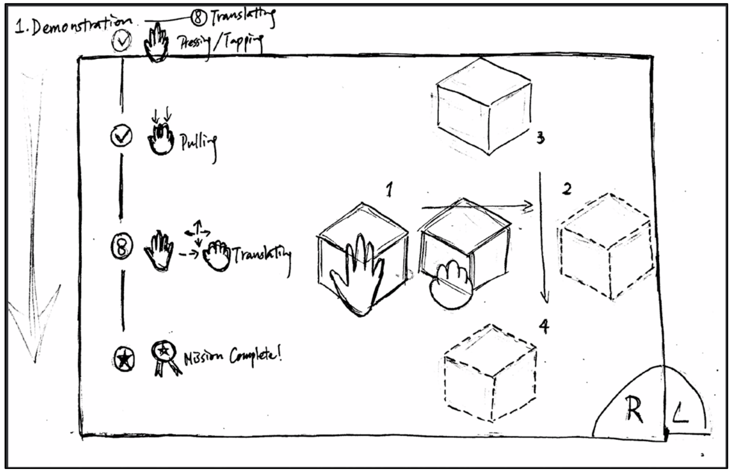
vi. **Pressing / Tapping**



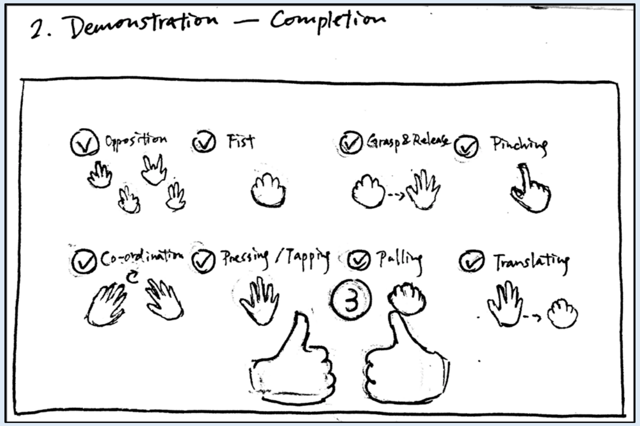
vii. **Pulling**



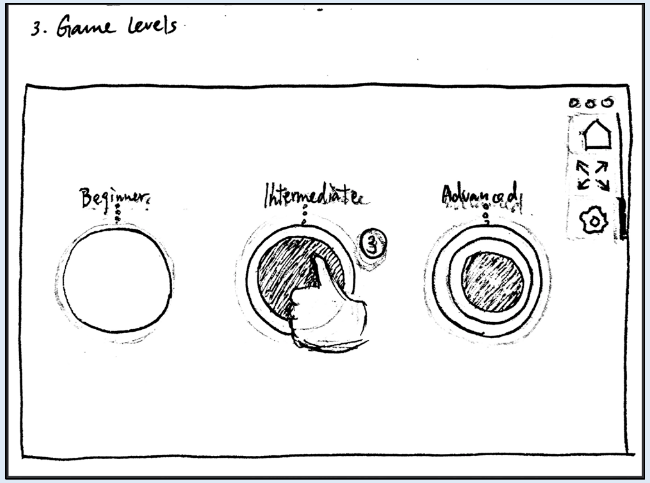
viii. **Translating**



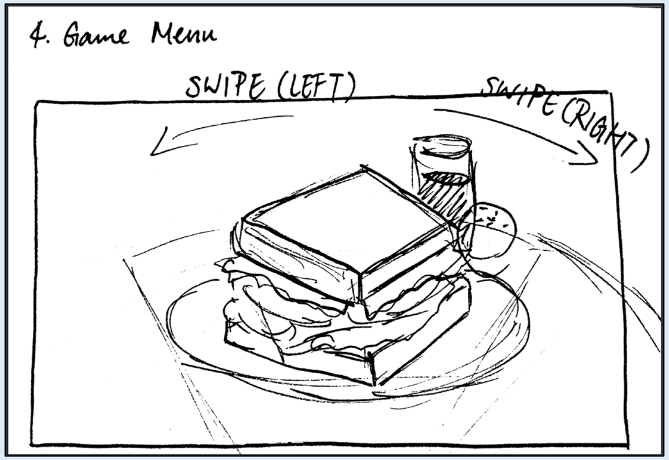
Completion of demonstration



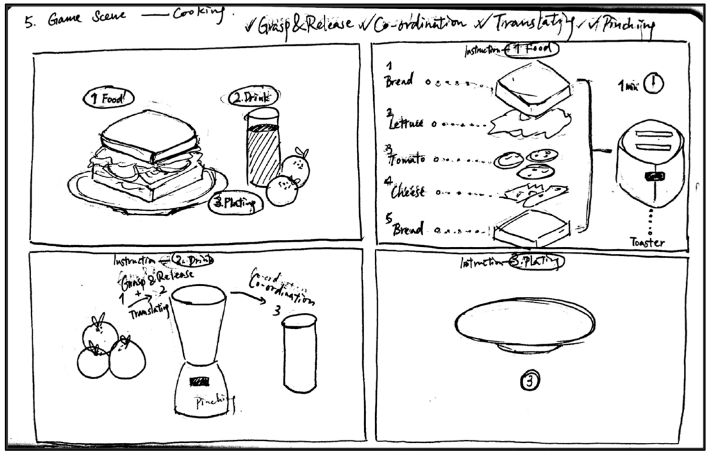
Game Levels

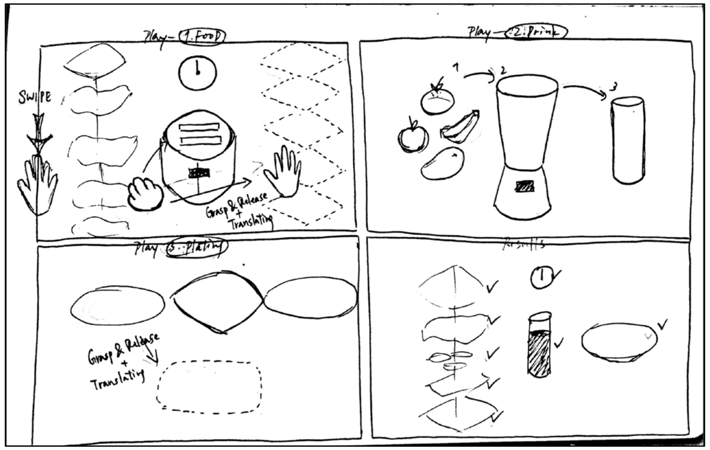


Game Menu



Game Scene - Cooking





Verbal guidance with hand movements (This interaction will be using the same screen as in *F-d.* or *F-f.,* e.g. *Foon* might be confused or forgot to use the designated hand gestures, so that *Ching* would need to guide her with the hand movements.)

Results

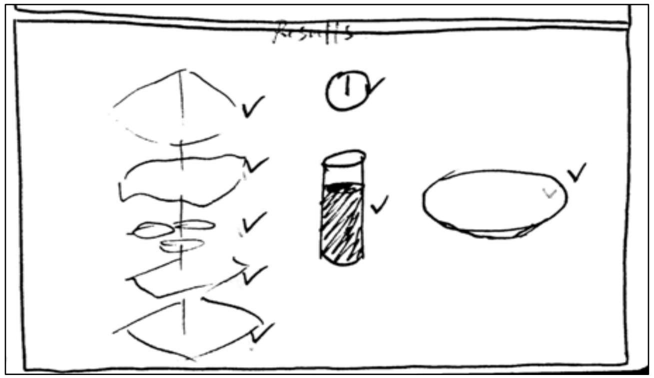
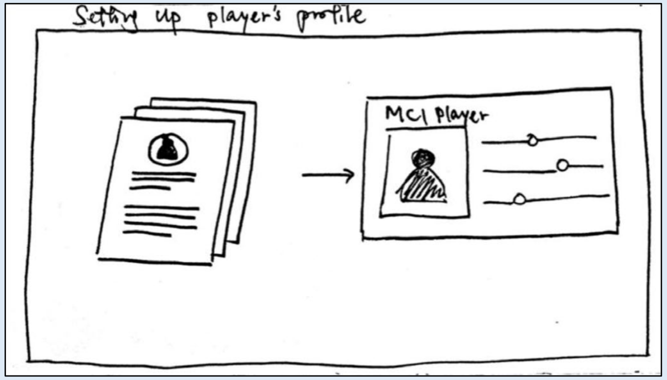
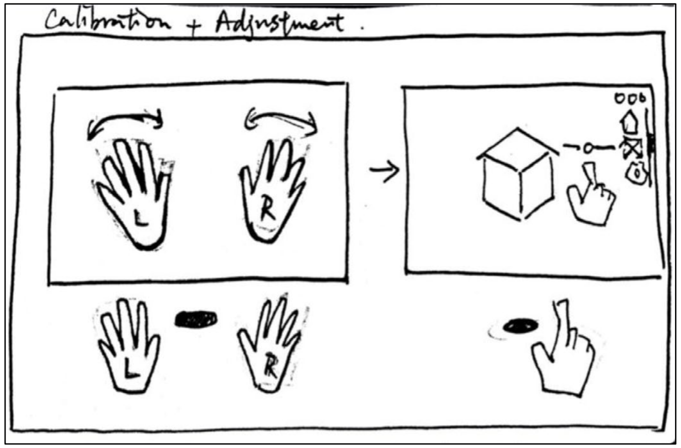
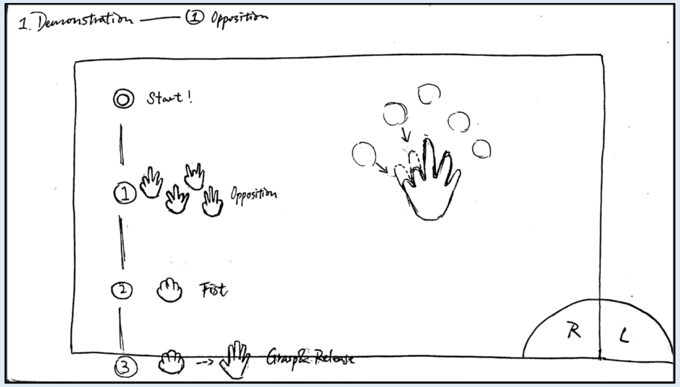


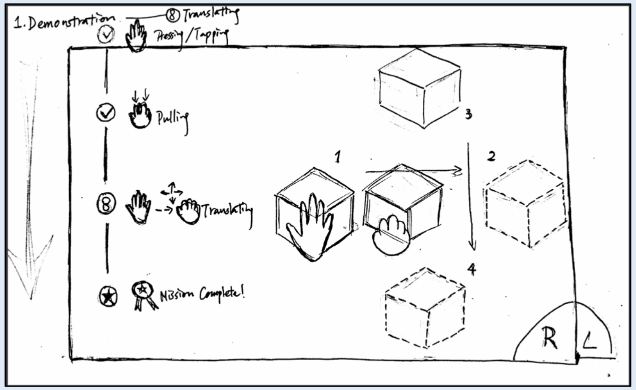
Table B-6 Low-fidelity UI Sketches for Ching Lau

Low-fidelity UI Sketches



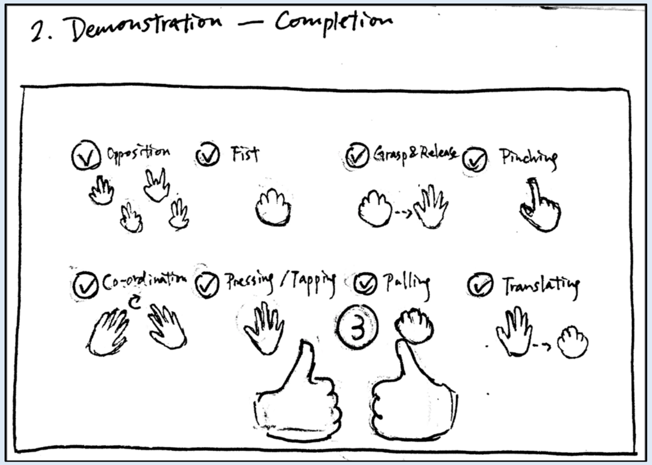
a. **Opposition to viii. Translating**



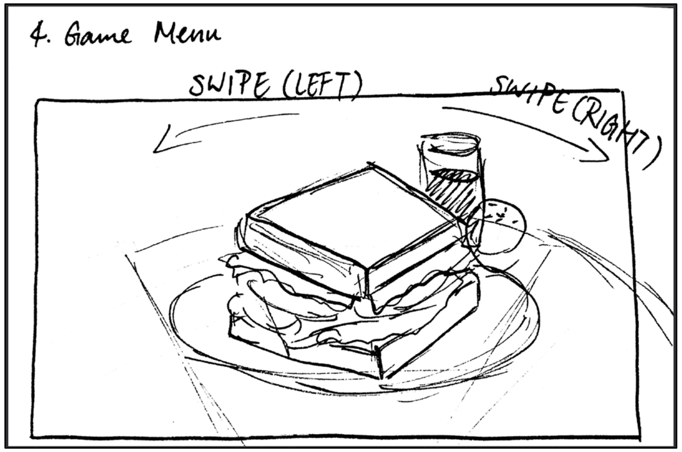
…



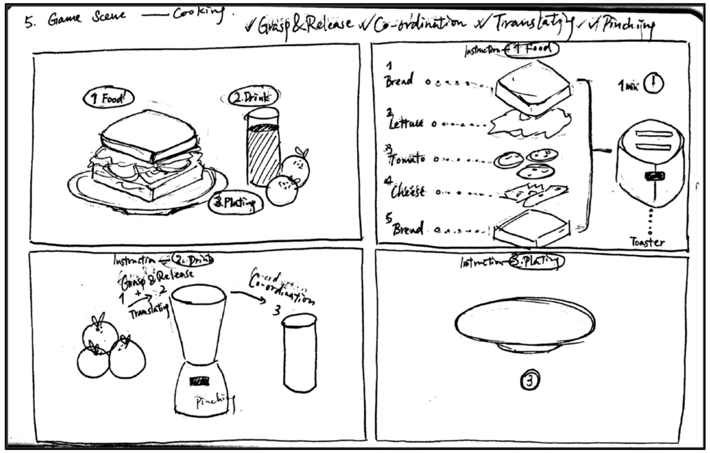
Completion of demonstration

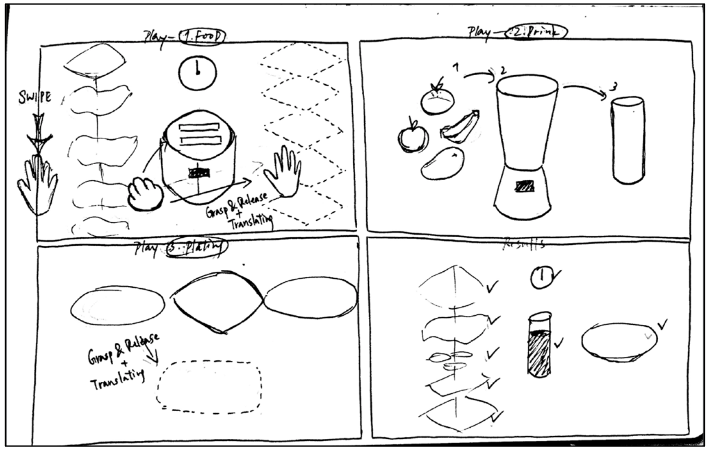


Game Menu



Functionality of the system (Game Scene – Cooking)




These scenarios i.e. *C-e.* to *C-h.* do not involve any interaction with the game. **Listing out *Foon*'s difficulties**
Verbal encouragement
Experience comments
Data analysis

C. Appendix C

The verbatim transcripts of the interviews have been translated from Cantonese into English and are presented in the below table.

Table C-1 Interview Questions and Responses for Evaluations

Questions	Responses
Question 1: ***Which stage(s) of the proposed serious game do you believe that MCI players would need further explanation from you, e.g. demonstration, utility of the game, new environment, etc.?***	*P1 - "Normally, most of us will demonstrate the game once to the patient when it is introduced to them for the first time. After the first demonstration, the patient should know how to play, unless they are too resistant to accept the game or do not want to play it alone."* *- "We would use "treatment" or "training" and avoid using the word "game" to describe the tasks to the patient because we want to emphasize the purpose of coming to the centre."* *P2 - "When the patient first encounters the game interface, we need to explain the operation and rules of the game to ensure that they understand clearly before starting the game."* *- "As long as the demonstration has been provided to the patients, they will be able to understand because those are easy gestures. But if you want them to apply those gestures correctly during the game, we will need to carefully observe their progress during the game"* *P3 - "If they are playing the game for the first time, we will need to explain the game content and functionality in detail to them. The player also requires more time to understand the relationship between the computer and themselves. To provide sufficient time for this, we should determine the cause of their difficulties, whether it is due to their inadequate capabilities or their lack of understanding of the game functionality."*

	P4 - "We would need to go through the patient's profile to study their previous training experience and some medical conditions, such as visual and auditory problems, to determine whether they would need further explanation. Their cognitive ability and education level are decisive in their acceptance of the game and a new platform. Before getting into the game content, it is important to let the MCI players understand the purpose of the game by telling them that it is for sustaining their memory capacity and improving their fine motor skills. This aims to enhance their acceptance and motivation in by allowing them to be aware of their goals. Not only is our explanation important to them, but the game itself should clearly show the instructions and translation of the interfaces so that players can instantly understand what the computer wants them to do. The support of the tutorial or animation can help them in understanding the actions required during the game, but they require sufficient attention span to read the messages shown on screen.
Question 2: ***What signs immediately tell you that it may be necessary to support MCI players during the game? Do you think players can understand the UI designs easily?***	*P1 - "They might be misusing the equipment or inattentively doing the tasks which may lead them to take a long pause. However, they may achieve better results when we are next to them. It is because our role image works as an external factor which motivates them to carry on. The UI is understandable but if it were more realistic, it would be more accessible. I would recommend that the demonstration only provide a few gestures at a time, because they cannot remember all the gestures. The game hints in the toasting scene should be more exaggerated with greater contrast."* *P2 - "Usually, the patient will stop playing or they will ask more questions. Sometimes they will just look at us and do nothing, then we will guide them back to the task."* *- "We usually need to know their level of understanding to predict the problems they may encounter during the game. The UI is understandable, but demonstration is a significant factor to ensure that the players understand the essential functionality of the game. Extra time will be given to the players to try*

	understanding the interface by themselves first, before we assist them throughout the game. *P3 - "The patient may want to give up. They will want to play the previous game which they are already familiar with. Or they may use the wrong functions when performing the tasks."* *- "It would better if the hands and the game objects are more realistic. Then they will be able to instantly understand the images and designs."* *P4 - "The UI is understandable, but we need to pay attention to whether they can see or hear clearly or not. It is also easy to check whether they have the ability to control their movements. For example, if they keep asking the same question, they most likely have memory or attention issues which should be highlighted."*
Question 3: ***Should any elements/features in the game be removed or added in order to improve the training (cognitively and physically)?***	*P1 - "A 3D background should be added to the Sandwich Making setting because it provides the visual cue which allows the players to understand the environment - kitchen. The hint on the toaster should be more exaggerated."* *P2 - "Physical elements should be considered, such as adding more sensory elements to further stimulate their cognitive functions. The setting can be more realistic which can increase their engagement and enhance their understanding."* *P3 - "Extend the duration - I would suggest training 2 times a week as it will aid their progress."* *P4 - "Add "good job!" as feedback to let them know they have accomplished the tasks."* - *"Need to specify that the training is to support their cognitive functions, then they will put in more effort during the training."*

Question 4: ***To what extent do you think the proposed serious game can improve MCI players' motivation and engagement through the gameful elements? Why?***	*P1 - "It can improve their motivation and engagement through the game, but some of the players may not know how to operate the toaster. The demonstration of using the toaster should be fully shown to the players. The instant feedback, which normally cannot be provided through other non-computerized platforms, can increase their motivation and engagement."* *P2 - "They will be interested in a novel game because of their curiosity. If they have played the game before, the game theme should be slightly changed in order to maintain their curiosity, otherwise they will feel bored after several attempts. UI designs, variety of themes and levels are the motivators to increase their liking for the game, which keeps them motivated and engaged.* *P3 - "If the game is specifically for patients in Hong Kong, they would rather choose something more closely related to their lifestyles or culture, e.g. mahjong can be one of them. Making sandwiches may be more suitable for western culture. But it is good for making food or cooking to be one of the training options due to safety concerns. Their family may not allow them to touch the hob or toaster, but the game can overcome this restriction.* *P4 - "The game can improve the player's motivation and engagement through several elements. First, the given objects or training content should be related to their culture. Second, the patient's personality – there are different reactions between male and female. Females are relatively willing to try new things. Third, their previous experience - some of them may refuse to use the computer because they do not want to learn something unfamiliar. In this case, we may not assign another training session to them. Lastly, social elements which offer cognitive stimulation. The OT, carer or friend(s) can be a motivator to stimulate them during the group-based training. The interactivity will be increased."*
Question 5: ***What advantages and disadvantages does the proposed serious game have compared to the traditional training method?***	*P1 - Advantage - "A variety of themes and personalization can be promoted through this kind of novel platform. Using the game in training can reduce the time spent on explaining each training task compared with other traditional training involving a bunch of equipment and setup."*

	- Disadvantage - "They have a preference for traditional training because it requires less effort to learn since they are already familiar with it." *P2 - Advantage - "To some extent, it can technically reduce their upper limb competence limitation. The variety of the scenarios is better than the few usual ones in the traditional paper-and-pen training. It is portable for outpatient use (home-based individual). The instant feedback can help the OT to calculate the results"* *- Disadvantage "Not all MCI clients can instantly accept the novel platform at their age. New technology can be a pressure to them."* *P3 – Advantage "It is possible to apply the skills learnt in the game to everyday life. It can reduce the preparation time which the OT spends on setup and scheduling. It is immersive.*" *P4 – Advantage "I can easily see the effect of controlling objects in 3D space. Not much preparation is needed because only a screen and a small device are required. Comparing the computerized platform to the traditional training method, the latter requires more time to schedule and setup the equipment, especially for outpatient cases.* **-** *Disadvantage "It is only a simulation and we will still need to assess them in a real scenario. There are some limiting factors, such as the virtual hands do not have haptic feedback and cannot entirely transmit a clear sensory message to the player. However, theoretically the player tends to be a normal person, and is relatively smarter and easier to manage."*
Question 6: ***In terms of a-MCI, do you think the game can potentially sustain MCI players' (episodic)***	*P1 – "We cannot tell the actual outcomes because we need to assess their cognitive level especially the memory aspect through standardized screening tools."*

memory capacity after a certain period of training? To what extent and why or why not?	*P2 – "The training result may not be negative and may even slow down the decay of memory capacity, but we will need to use various assessments and real trials to assess the patient. Normally, we will do the pre- and post- assessment, e.g. MOCA, Pre-assessment, to check their progress and scores. Potentially, the game can be one of the assistive tools to train the patient."* *P3 – "A constant form of memory training can possibly support the patient's memory capacity. We will employ assessment tools to assess the patient's cognitive capability."* *P4 – "Yes, the game can potentially bring positive effects, but the training duration should be at least twice a week. After 4-6 weeks, you will be able to see their progress."*