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DEPARTMENT OF REHABILITATION SCIENCES

An intelligent rehabilitation system for cognitive rehabilitation

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to my best knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

________________________ (Signed)

Yip Chi Bun (Name of student)

DEDICATION

To my dearest parents, wife, and children for their endless support.

ABSTRACT

Prospective memory (PM) failure is one of the most disabling forms of cognitive impairment in people with acquired brain injury (ABI). To date, there is a paucity of research on effective treatment strategies for PM deficits. In the present study, an innovative PM treatment combining modern computer technologies with artificial intelligence (AI) and virtual reality (VR) was proposed. Combining the simulated training environment provided by VR and the individualized feedback provided by AI, an optimal training environment could thus be created for people with ABI. This "intelligent virtual reality prospective memory" (IVRPM) training programme could be a cost-effective means to offer PM training content which is considered ecologically valid for the living environment of people with ABI. In order to investigate the effectiveness of this novel IVRPM training programme, another non-AI version, a "virtual reality prospective memory" (VRPM) training programme was developed for comparison purposes.

A single-blinded, pre-test/post-test randomized controlled trial was adopted. Fifty-six subjects were successfully recruited. They were randomly assigned to an IVRPM treatment group, a VRPM treatment group, or a control group. Subjects who were assigned to the two treatment groups were provided with ten sessions of training in the respective programmes. Subjects'

PM performance, retrospective memory performance, frontal lobe functioning, level of community integration, and self efficacy were assessed before and after the training.

The results showed that subjects in the IVRPM group performed significantly better in PM functioning, level of community integration and self-efficacy. It may suggest that the subjects in the IVRPM group not only learnt better, but also showed better transference of skills to the real environment. Finally, the findings showed that the AI system could help to establish subjects' self efficacy and hence it improved their perception of their level of community integration as compared with the control group. To conclude, the findings from the present study showed that the combination of AI and VR can be a feasible and successful treatment strategy for PM rehabilitation of people with ABI. Further application of the present training model to other groups of patients should be encouraged.

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TABLE OF CONTENT

Chapter 1

Introduction

1.1. Overview of the study

Acquired brain injury (ABI) is a well known condition that may cause long-term cognitive impairments and disabilities, and demands active intervention (Gouvier, Ryan & O'Jifle, 1997; Lezak & O'Brien, 1990). Among different cognitive impairments which sufferers may face, memory impairment is one of the most commonly reported symptoms (Shum, Valentine & Cutmore, 1999). One disabling form of memory impairment is prospective memory impairment (Brooks, Rose, Potter, Jayawardena & Morling, 2004). Prospective memory (PM) refers to the ability to *"remember to perform an intended action at a particular point in the future"* (Martin, Kliegel & McDaniel, 2003). Several studies had pointed out the importance of PM in successful everyday life (Ellis & Kvavilashvili, 2000; Roche, Moody, Szabo, Fleming, Shum, 2007; Zollig, West, Martin, Altgassen, Lemke & Kliegel, 2007). Increasing research interest in PM in people with brain injury has developed since last decade. Unlike retrospective memory (RM), on which rehabilitation strategies had been extensively studied, most studies on PM are focused on basic understanding, such as the underlying processes (McDaniel & Einstein, 2000). Rehabilitation of PM, however, is still in its infancy stage. Most of the treatment strategies reported use routine scheduling and cueing devices (Fish et al., 2007; Fleming, Shum, Strong & Lightbody, 2005). Treatment strategies that can be effective in providing direct remedial effect and that focus on everyday PM tasks are much needed.

To achieve an additional goal in developing an ecologically valid (i.e., relevant in real life) PM training programme with a high generalization effect, the use of advanced computer technology was proposed in the present study. Virtual reality (VR) is one of the possibilities. VR had been reported to have promising training and generalization effects in cognitive rehabilitation studies, such as memory (Brook & Rose, 2003), executive functioning (McGeorge et al., 2001) and community living skills (Lam, Tam, Man & Hui-Chan, 2003; Yip & Man, 2009). A dynamic, three-dimensional, virtual environment offers a simulated environment which is relevant to the user's daily life. This corresponds with one of the characteristics of PM. VR has also proved effective in activating the neural substrates just like a real environment (You et al., 2005). This may further indicate the possible use of VR in providing direct remedial effects in PM functioning itself or its related cognitive attributes.

In order to enhance the training effect of the VR-based training programme, another advanced computer technology was suggested, artificial intelligence (AI). Although AI is seldom used in providing direct treatment in cognitive rehabilitation, it has long been demonstrated to be an effective technology for teaching and learning in education (Kim, Ryu, Hwang & Kim, 2006; Kinshuk & Russell, 2002; Westera, Hommes, Houtmans & Kurvers, 2003). With its excellence in capturing and analyzing behaviors and giving immediate individualized feedback to users, AI can target the weaknesses of each individual and gave appropriate challenges to users, such as the ABI subjects in the present study. This may also reduce frustration during training, which is believed to be a factor that can reinforce the training effects further.

The two abovementioned computer technologies have been combined to form an innovative training strategy, called intelligent virtual reality (IVR) in this study. The VR environment can provide an ecologically valid training environment while AI provides therapist-like, timely judgment in modifying the content of training and grading of training difficulty in accordance with the patient's needs. These two main characteristics are considered important in PM rehabilitation. PM is highly related to community living, and the VR technology provides a chance for patients to receive PM training in a simulated environment which is very meaningful to their daily life. In chapter 2, it will be made clear that PM is not a single cognitive process, but involves multiple processes. Different patients may have different problems with one or more of these processes leading to their ultimate PM deficits. The AI component in the IVR-based training programme can offer an important feature in identifying this individual variability and possibly providing suitable training content according to the individual's needs. These adaptabilities have made the IVR-based training programme stand out from the traditional computer-assisted training programmes. In the past, the contents of training in computer-assisted training programmes were structured during programme development. The training content and level of difficulty could not easily and quickly be adapted according to users' needs. Even if a user was unable to keep up, they might be forced to receive the training at a particular level of difficulty that was too high for them. Thus some patients would be demotivated from participating and this would be detrimental to the effectiveness of their training and even their self efficacy.

In short, through this proposed IVR-based training, it was believed that the beneficial effect of PM training for people with ABI could be raised to a higher level. In the present study, the cognitive rehabilitation programme in PM training for people with ABI has been developed in two different versions: an intelligent virtual reality

(IVR)-based version and a virtual reality (VR)-based version. The two programmes are designed to be similar in training environment and content. In the IVR-based version, the AI component is further embedded to control the choice of training contents and their level of difficulty according to the patient's performance. In the VR-based version, the training contents and levels of difficulty are rigidly structured. No variation can be made throughout the training period. The effectiveness of IVR technology will be evaluated through group comparisons of PM-related outcome measures.

1.2. Statement of purpose

1 To develop an intelligent virtual reality-based (IVRPM) and a virtual reality-based prospective memory (VRPM) programme targeted at training everyday prospective memory for people with acquired brain injury (ABI).

2 To evaluate the effectiveness of the intelligent virtual reality-based prospective memory (IVRPM) programme by comparing prospective memory performance, evaluated in both laboratory-based and real life environments, self efficacy and global cognitive performance with a virtual reality-based training group and a control group.

1.3. Organization of chapters

There are seven chapters in this thesis. Chapter 2 will provide a literature review which outlines the background information. It will ultimately support the development of the conceptual framework to be adopted in the present study. This includes the description of ABI, common cognitive rehabilitation strategies and approaches, and the application of advanced computer technology for improving the effectiveness of rehabilitation. Detailed illustrations of PM functions and dysfunctions and approaches to rehabilitation are also discussed. Chapter 3 will present the conceptual framework of the proposed IVRPM rehabilitation model and explain how it works. Specific research questions, hypotheses and the significance of this study will be elaborated in Chapter 4. The study methodology, which states the research design, sampling methods, instrumentation and implementation, will be discussed in Chapter 5. The Results and Discussion chapters follow, with conclusions set out in the final chapter.

Chapter 2

Literature review

This chapter covers the background knowledge that has contributed to the present study. A general picture of problems associated with acquired brain injury (ABI), cognitive rehabilitation theories and related treatment approaches and the use of advanced technology in cognitive rehabilitation will be outlined. A description of prospective memory (PM), its dysfunction and approaches to rehabilitation will be presented subsequently.

2.1. Characteristics of people with acquired brain injury

Acquired brain injury (ABI) is damage to the brain after birth. ABI is one of the major causes leading to long-term disability (Khan, Baguley & Cameron, 2003). This not only affects suffers themselves, but also their carers and society at large. Cognitive deficits rarely occur in isolation, they may also come along with emotional, social, and behavioral problems (Wilson, 2002). Different types of injuries or sites of injury will lead to different clinical pictures.

Many different pathophysiological reasons may result in injuries to the brain. The etiology could be divided into two main categories; traumatic and non-traumatic.

Traumatic brain injury (TBI) can be caused by accidents, falls or assaults etc. Non-traumatic brain injury may be due to stroke, brain tumour, infection, poisoning, hypoxia, ischemia or substance abuse. Most definitions of ABI exclude neurodegenerative disorders. According to Cicerine et al. (2000), TBI and stroke are the two major sources of brain injuries that result in disabilities in adults.

2.1.1. Epidemiology of Traumatic Brain Injuries (TBI)

According to statistics from the US Centers for Disease Control and Prevention (CDC, 2007), at least 1.4 million Americans survive a TBI each year and approximately 80,000 to 90,000 people are left with a permanent disability. As a result, an estimated 5.3 million people are living with a permanent TBI-related disability in the US today. According to the latest research in the US, US$ 60 billion was lost in 2000 due to direct medical costs and other indirect costs, such as loss of productivity (Finkelstein, Corso, & Miller, 2006). With advances in medical care, the survival rate of TBI is increasing. Of those who suffer TBI, 20% are classified as severe and moderate and the remainders are in the mild grade (Sohlberg & Mateer, 2001). The most common mechanisms of injury are motor vehicle accidents, falls, violence and recreational activities. Motor vehicle accidents accounted for 50% of TBI cases. The second leading cause is falls, which contributed about 20–30% of the injuries. The most common age groups are under 5 years old and over 75 years old (Jay, 2000). Older people are more prone to falls that result in TBI. The incidence of TBI is about double for women after the age of 60. Young adults are more likely to be injured in motor vehicle accidents while young men are most likely to suffer from sports-related TBIs (Bushnik, Hanks, Kreutzer, & Rosenthal, 2003).

2.1.2. Epidemiology of Cerebrovascular Accident (CVA)

Cerebrovascular accident (CVA) is the third leading cause of death in the US and around 700,000 American people suffered from a first time or recurrent stroke in 2004 (American Heart Association, 2006). In Hong Kong, it ranked fourth in annual causes of death (Department of Health, Hong Kong, 2004). For survivors, it causes long-term physical and neurological disabilities in most cases. Stroke is either caused by cerebral infraction or hemorrhage, with infraction causing about 75% to 80% of CVA cases (Bogousslavsky & Caplan, 2001). The underlying pathology of cerebral infraction is either thrombosis in or embolism to cerebral arteries, while hemorrhage is mainly due to rupture of primary intracerebral or subarachnoid arteries (Ebrahim & Harwood, 1999).

2.1.3. Impact of cognitive deficits after ABI

Cognition is not a single function. Cicerone and colleagues (2000) defined it as "the process of knowing", which includes the discrimination between and the selection of relevant information, the acquisition of information, understanding and retention, and the expression and application of knowledge in the appropriate situation. Therefore, any damage to the brain would induce a wide range of physical, cognitive, emotional, social and behavioral problems (Wilson, 2002) or even psychiatric disorders (Miller, Burnett & McElligott, 2003). Impairment to one or more cognitive processes, in terms of losing efficiency or reduction in cognitive functions, would be regarded as cognitive deficits (Wilson, 1989).

The presentation of cognitive deficits after ABI varies between individuals. The severity, type and site of lesion may affect the clinical picture. But no matter what the extent of the cognitive deficit, people with cognitive impairment would experience reduced normal interaction with their surrounding environment (Rose et al., 2001). Furthermore, the relationship between cognitive deficits and community-related functioning has been established (Kendall & Terry, 1996; Wood & Rutterford, 2006), where attention and memory (Cattelani, Tanzi, Lombardi, & Mazzuchi, 2002; Dawson, Levine, Schwartz & Stuss, 2004; Fleming, Tooth, Hassell & Chan, 1999;

Guise, Leblanc, Feyz, Lamoureux, 2005; Sherer et al., 2002; Sohlberg, Todis, Fickas, Hung & Lemoncello, 2005) are the two main cognitive attributes that are well documented as predictors of functional outcomes after brain injury.

2.2. Prospective memory and prospective memory deficits in people with acquired brain injury

Memory problems are commonly reported in people with ABI (Lim & Alexander, 2009; Majid, Lincoln & Weyman, 2000; Shum, Fleming & Neulinger, 2002). To date, the nature of memory impairment and rehabilitation strategies for memory impairment have been extensively studied, and most of the studies have focused on retrospective memory (RM) (Roche et al., 2007). RM is commonly referred to as people's ability to remember and recall events that happened in the past or were presented previously (Dalla Barba, 1993). Although RM is an important cognitive attribute and has its importance in maintaining daily functions, many daily tasks do not involve RM alone. Instead, people have to remember to perform tasks in the future. This specific form of memory is generally known as prospective memory (PM).

Prospective memory and its related cognitive functions

Prospective memory (PM) refers to the ability to “remember to perform an intended action at a particular point in the future” (Martin, Kliegel, & McDaniel, 2003). According to Shum, Valentine and Cutmore (1999), PM can be divided into three sub-types, namely time-based PM, event-based PM and activity-based PM. Different types of PM required the execution of an intended action in a different situation. For time-based PM, the intended action should be performed at a specific time, such as attending a meeting at 3 pm. For event-based PM, the intended action should be performed when an external cue appears, e.g., passing a message to Tom when you see him. Lastly, activity-based PM is similar to event-based PM, but it does not involve interruption of ongoing tasks. An everyday example involves locking the door after leaving the room.

PM consists of a series of phases. Ellis (1996) stated that successful PM was *“a processing that supports the realization of delayed intentions and their associated actions”*. These processes are closely linked to one another. A failure in one phase leads to failure of the whole process. Ellis divided PM into five phases: formation and encoding of intention and action; retention interval; performance interval; initiation and execution of intended action; and evaluation of outcome.

Intentions have to be stored and retrieved before being executed at a later time (Einstein & McDaniel, 1990; Ellis, 1996; Mathias & Mansfield, 2005). Therefore many researchers classify these processes further into two components, a retrospective component and a prospective component. The retrospective component contains information about what and when the intended action has to be performed, while the prospective component is to remember to perform the intended action when a suitable moment occurs (Einstein & McDaniel, 1996).

It is quite clear that PM is not a unitary cognitive process. Firstly, different phases contributing to PM functioning have been identified. However, realizing the supporting cognitive abilities for these phases is even more important. RM is one of the cognitive processes found to be important for PM. As mentioned, RM is to remember what needs to be done. It is assumed that RM is related to PM functioning (Kim, Craik, Luo & Ween, 2009). This assumption is further supported by a significant correlation between PM and RM testing performance in people with TBI (Groot, Wilson, Evans & Watson, 2002; Knight, Harnett & Titov, 2005). In addition, a positron emission tomography (PET) study showed activation of brain regions which were believed to be responsible for episodic memory while performing PM tasks (Burgess, Quayle & Frith, 2001).

Besides the strong evidence showing the relationship between RM and PM, executive function (EF) is another cognitive ability which has been found to be related to PM performance. Both EF (Duncan & Owen, 2000) and PM functioning are supported by frontal lobe functioning (Burgess, Quayle & Frith, 2001). Many studies have shown that people who perform poorly in EF tasks also perform poorly in PM tasks, especially in time-based tasks (Kinch & McDonald, 2001; Martin, Kliegel, & McDaniel, 2003; McDaniel, Glisky, Rubin, Guynn & Routhieaux, 1999). Moreover, inhibition is one of the EFs important to PM performance (Cockburn, 1995; Groot et al., 2002; Shum, Valentine, & Cutmore, 1999). As interruption of ongoing activities is needed for successful PM, people with EF deficits were found to be less likely to stop at the appropriate moment to execute the time-based tasks and relay the event-based tasks when a cue was encountered (Kinch & McDonald, 2001). These authors pointed out the importance of EF in the inhibition of ongoing activities and the execution of intention during time-based and event-based tasks.

PM deficits in people with ABI

Looking at the pathological characteristics of people with TBI and stroke, the medial temporal lobe and frontal lobe were found to be the most frequent sites of injury. EFs are significantly impacted in stroke. Therefore, memory and EF deficits are commonly seen in people with ABI (Bigler, 2000; Kim, Craik, Luo & Ween, 2009). This affects their PM performance, whether during the acquisition and retention of intention (Kliege, Eschen & Thone-Otto, 2004) or in the initiation and execution of an intended action (Roche et al., 2007). The importance of PM in successful everyday life was also highlighted (Ellis & Kvavilashvili, 2000; Roche et al., 2007; Zollig et al., 2007). It is not surprising that PM is the most reported memory problem (Mateer, Sohlberg & Crinean, 1987) and one of the most disabling forms of memory impairment experienced by people with brain injury (Brooks et al., 2004).

2.3. Review of cognitive rehabilitation theories and approaches in managing cognitive deficits

Cognitive rehabilitation is one of the non-pharmaceutical treatment approaches to tackle cognitive deficits. It can be defined as *"any intervention strategy or technique which intends to enable clients or patients, and their families, to live with, manage, by-pass, reduce or come to terms with cognitive deficits precipitated by injury to the brain"* (Wilson, 1997). Owing to the rapid development of neuropsychology in the last few decades, understanding the relationship between neural structure and cognitive functions has become much clearer. More theories have been developed based on both animal and human models, such as neuroplasticity, environmental enrichment (EE) etc. Many cognitive rehabilitation approaches were developed eventually too (Rizzo, Schultheis, Kerns & Matter, 2004). The major theories and approaches related to the present study will be outlined in the subsequent sub-sections.

2.3.1. Neuroplasticity

Neuroplasticity refers to "the capacity of a system to achieve new functions by transforming, on a long-term basis and under environmental constraint, either its constituting elements or its internal connectivity network" (Will, Galani, Kelche & Rosenzweig, 2004). Before 1960, research seldom supported that the phenomenon of neuroplasticity could happen. The brain was believed by the majority of scientists to be immutable, and subject only to genetic control (Diamond, 2001). To date, more and more evidence has been gathered to show that the brain has plasticity, both in animal models (Albensi, Schwerizer, Rarick, & Filloux, 1998) and in people with brain injury (Page & Levine, 2003). Animal models simulating the pathological conditions in human TBI (Albensi, 2001) had shown behavioral improvement on both motor and cognitive aspects, for example, after certain training was given to mice with brain injury. Synaptic plasticity is believed to contribute to behavioral changes after injury to the brain (Albensi & Janigro, 2003; Kolb, 1999). With modern neuroimaging technology, fMRI can also demonstrate the changes in neural activities after rehabilitation (Matthews, Johansen-Berg & Reddy, 2004). Factors that affect the degree of neuroplasticity include age of onset (Kolb, Forgie, Gibb, Gorny & Rowntree, 1998), type and location of lesion, environmental factors, and duration and types of training (Will et al., 2004). The nature of plasticity within the nervous system enables intensive cognitive training to speed up nervous "regeneration" and thus return of functions.

2.3.2. Environmental enrichment (EE)

Studies investigating recovery from brain injury have shown the importance of environmental effect. From animal models, Kolb (1999) stated that rats raised in a relatively complex and stimulating environment had better results from training than those situated in a relatively impoverished environment in terms of cognitive performance. This is known as environmental enrichment (EE). EE has been documented as having beneficial effect in neurochemistry, neurophysiology and neurogenesis in healthy mice (Johansson, 2004). Furthermore, positive effects were also shown in mice with various kinds of neural diseases (Will et al., 2004). As animal models of brain injury are assumed to simulate human pathology, the contributions of EE are also believed to be effective in human subjects. Thus, careful selection, design and structuring of training environments may have crucial effects on the training outcomes in persons with ABI.

2.3.3. Contextualized learning (CL)

According to Gordon, Cantor, Ashman and Brown (2006), contextualized learning (CL) means the learning that takes place when encountering day-to-day problems in real life situations. It has been found to be more effective than learning isolated cognitive skills that are not clearly related to the performance of functional tasks. Stuss and Benson's model (1986) of cerebral organization also supported the use of a top-down approach in learning functional tasks, which was in contrast to those bottom-up approaches focusing on repetition exercise and drills in basic cognitive attributes. Thus, it may hint that if persons with ABI could receive training in an ecologically valid environment and with everyday task scenarios, it might be more beneficial and effective than training isolated cognitive functions alone.

2.3.4. Process approach

In the process approach (Bracy, 1983), complex functioning is considered to consist of many basic processes. Change in behavior is the result of the disruption of the basic processes which affect these complex functioning systems. Bracy, therefore, argued that rehabilitation efforts must be directed at the specific interrupted brain processes that contribute to this complex cognitive functioning.

In summary, the development of various cognitive rehabilitation approaches helps the development of better treatment strategies. Neuroplasticity has set the foundation for cognitive rehabilitation as it has been shown that intense cognitive training can bring changes to the nervous system and lead to return of functions. A stimulating environment and training content focused on real life may make the training more effective. Finally, training in complex cognitive functions may be delivered better through breaking them down into basic, meaningful, cognitive processes.

2.4. Rehabilitation of PM deficits

To date, most publications have been concerned with a basic understanding of PM, such as its underlying processes (McDaniel & Einstein, 2000) and neural correlates (Zollig et al., 2007). There is a paucity of research studies reporting rehabilitation strategies for PM (Shum, Fleming & Neulinger, 2002). In the early days, PM rehabilitation focused on a direct retraining approach. Sohlberg, White, Evans and Mateer (1992) reported the effect of PM training on two subjects with PM deficits after TBI. The training programme required the subject to perform a certain action after a designated time. The time delay between the instruction given and performance increased gradually with the aim of improving the ability to store information for longer periods of time. Although the time span for successful PM execution was increased, the generalization to other new skills and PM tasks was limited.

With better understanding of the nature of PM, some successful attempts to strengthen the RM component in PM training programmes have been reported. For instance, Camp, Foss, Stevens and O'Hanlon (1996) and Kixmiller (2002) reported the use of applying learning techniques, such as spaced retrieval and errorless learning, in PM training in people with Alzheimer's disease. Chasteen, Park and Schwarz (2001) reported an improvement in PM performance in older people through rehearsing the explicit intention, aiming at strengthening the linkage between cue and target action and also increasing the likelihood of noticing the cue. As laboratory-based tasks were adopted and only event-based tasks were involved in that study, generalization to a real-world environment is still questionable.

Lastly, recent studies have tried to utilize cueing devices to help individuals compensate for PM deficits in daily life. Fleming, Shum, Strong and Lightbody (2005) also reported a rehabilitation programme which incorporated the use of a customized cueing system together with reviewing individual organizational strategies in pursing prospective memory tasks, such as participant's daily routines, home and work environments. In addition, positive effects were reported by Fish and colleagues (2007) who also used a cueing device to compensate for the lost cognitive functions which lead to failure in PM. Although both studies from Fleming et al. (2005) and Fish et al. (2007) were conducted in the participants' living environment, the former involved just three participants, while the latter study involved just one telephone task as the target action. The findings reflected that compensatory strategies, such as routine re-scheduling and cueing devices, may have a beneficial effect on PM performance. However, Wilson and Watson (1996) pointed out the difficulties in applying compensatory strategies for people with brain injury. Furthermore, the effect of cueing devices varies according to individuals' EF and the use of the cueing devices would last for a long period of time. EF training and phasing-off training were needed (Fish, Manly, Emslie, Evans & Wilson, 2008).

Thus, although a few cognitive rehabilitation approaches had been tried in PM rehabilitation, a specific kind of training strategy which could both improve an individual's PM performance and possess high generalization effect has not yet been established. The development of a new training approach is considered necessary.

2.5. Technology used in cognitive rehabilitation

Computer-assisted training had been used in cognitive rehabilitation since the mid 1980s (Bracy, 1983; Chute, Conn, DiPasquale, & Hoag, 1988) and had been used in the retraining of attention, concentration and visual scanning (Gianutsos & Kitzner, 1981; Lynch, 1982). During this period, the software used was actually video games that were commercially available. In the 1990s, training programmes based on task-specific and hierarchical approaches were developed (Chan, Thomas, Glueckauf & Bracy, 1997). However, these earlier programmes were criticized for poor transfer of training effects to daily living. Due to the rapid development in computer technology, other types of computer-based cognitive rehabilitation programmes had started to demonstrate equivalent or even better training effects than traditional treatments in people with brain injury (Dou, Ou, Zheng, Man, & Tam, 2006; Gontkovsky et al., 2002; Tam & Man, 2004). Delivery in a tele-communication mode, i.e., without face-to-face contact during the intervention (Soong, Tam, Man & Hui-Chan. 2005; Tam et al, 2003) was also reported. The advantages of computer-assisted training had been documented, including its cost effectiveness and training effectiveness. Also, the characteristics of accurate recording of patients' performance and the flexibility of use of multimedia, such as text, video, graphics and sound, were also appreciated (Bergman, 2002). In recent years, two advanced computer technologies have begun to show their efficacy in medical and rehabilitation fields; namely virtual reality (VR) and artificial intelligence (AI).

2.5.1. Virtual reality

Background of virtual reality

Virtual reality (VR) is one of the new computer technologies that has been applied to rehabilitation in recent years. VR originated from a visual coupled system (Kalawksy, 1993) which formed the basis of the first flight simulator. VR is a computer-generated environment, based on computer simulation and real-time visual, auditory and touch feedback (Katz et al., 2005). Schultheis and Rizzo (2001) defined VR as a way for humans to visualize, manipulate and interact with computers and extremely complex data. VR can be viewed as an advanced form of human–computer interface that allows users to “interact” with and become “immersed” in a computer-generated environment in a naturalistic fashion.

There were three main types of VR technologies which had been applied in computer-assisted rehabilitation. They were immersive type VR, non-immersive type desktop-based VR and non-immersive type video capture VR. In immersive

VR, the computer displays a range of sensory modalities, with high-fidelity resolution of a panoramic visual view, where the user's physical reality is shut out (Slater & Wilbur, 1997). A head mounted display, data gloves or body suit are always used. In the non-immersive forms of VR, the virtual environment is generated and displayed by computer and other multimedia peripherals, for example, wide LCD monitors, and speakers. Users perceive stimuli as comparable to real world objects and events (Weiss, Naveh & Katz, 2003). The difference between desktop-based and video capture VR was equipment needed and the mode of control. Instead of using a desktop computer, chroma key backdrop, large video display and video camera were used video capture VR. Users control the programme through natural movements.

Through the use of VR, a dynamic three-dimensional, ecologically valid and highly controllable environment can be created. This could be very helpful in assessment and training (Rizzo & Kam, 2007). It may be very difficult for some patients to perform the required tasks in “real life” situations due to their sensory, motor and cognitive disabilities. Besides the environmental advantage, users’ behavioral performance can be recorded accurately (Rizzo et al., 2001). Not only can performance within the virtual environment be recorded, but users’ body movements, like head and eye movement, postural deviations and limb kinematics can also be recorded. The characteristics of the virtual environment and advancement in recording users' performance represent another option for rehabilitation assessment and training which traditional techniques cannot offer (Schultheis & Rizzo, 2001; Tsirlin, Dupierrix, Chokron, Coquillart & Ohlmann, 2009). The advantages of VR are widely agreed. For instance, VR technology is used in cognitive rehabilitation of memory (Rose, Attree, Brooks & Johnson, 1998), executive dysfunction (Mcgeorge et al., 2001), topographical orientation (Bertella, Marchi & Riva, 2001) and for training of daily living skills (Lam, Man, Tam & Weiss, 2006; Yip & Man, 2009; Zhang et al., 2003).

Mechanism of virtual reality rehabilitation

The training effectiveness of VR in cognitive rehabilitation may be explained by the cognitive rehabilitation approaches (EE and CL), as mentioned earlier. In adopting the EE approach, it is believed that environmental effect is very important to patients' recovery from brain injury. A relatively complex and stimulating environment has a better training effect than an impoverished environment (Kolb, 1999). VR offers rich and vivid visual and auditory stimulations. Better training effects are expected as compared with other training strategies which do not focus on the application of visual and auditory stimulation. The naturalistic training environment created by VR matches the principle of CL, too. The focus on training in real life situations and day-to-day problems has been found to be more effective than training isolated cognitive skills (Gordon, Cantor, Ashman & Brown, 2006). While real life training may impose potential hazards for both patients with ABI and therapists, a virtual environment is a good substitute. Many studies have demonstrated that training in a virtual environment yields a training effect equivalent to training in a real environment (Brooks, McNeil, Rose, Greenwood, Attree & Leadbetter, 1999). Lastly, modern functional imaging technology has shed light on the effect of VR on the human central nervous system. One aspect which has been widely studied is the activation of the hippocampus under functional imaging during virtual navigation (Astur, St. Germain, Baker, Calhoun, Pearlson & Constable, 2005). This means that a virtual environment or tasks may produce a stimulation of the corresponding neural structure similar to the real environment. Another control experimental study used a VR-based programme to conduct motor training of affected upper limb in people with hemiparetic stroke. Functional improvements in the affected limb were found in the VR group, but not in the control group. Furthermore, cortical reorganization was found in the primary sensorimotor cortex under fMRI examination (Jang et al., 2005).

This evidence supports the effect of VR exposure as not being limited to functional gains but also affecting activities within the nervous system.

Possible application of VR in PM rehabilitation

Based on the assumption of neuroplasticity and EE, repeated training may bring changes in neural activities (Matthews, Johansen-Berg & Reddy, 2004) and exposure to rich environmental stimulations will lead to better training effect (Kolb, 1999). Therefore, VR provides training opportunities in an environment rich in audio and visual stimulation for PM, which is a demanding cognitive function.

Secondly, studies have demonstrated that VR can contribute not only to the functional improvement for which it is intended, but also to the supporting cognitive functions underlying the functional task. For instance, Yip and Man (2009) found improvement in subjects' memory function in VR-based training in community living skills for people with ABI. Significant improvements in visual spatial and visual scanning were also found in people with stroke who received VR-based street crossing training (Katz et al., 2005).

As mentioned earlier, PM consists of a series of phases to which different cognitive functions contribute. RM and EF are the two important cognitive functions contributing to PM. Deficits in these two cognitive functions are commonly seen in people with ABI (Bigler, 2000; Kim, Craik, Luo & Ween, 2009), which may affect the acquisition and retention of intention (Kliege, Eschen & Thone-Otto, 2004), and the initiation and execution of intended action (Roche et al., 2007) during performance of PM tasks. Therefore, it is believed that through careful design of training contents and training scenarios in a VR-based training programme, users' RM and EF can be effectively and even optimally stimulated. This in turn could lead to improvement in the related PM process, such as acquisition and retention of intention, and the initiation and execution of intended action in the long run.

Finally, PM is highly related to people's daily living. With the CL approach, training in real life situations and day-to-day problems has been found to be more effective than training in isolated cognitive skills (Gordon, Cantor, Ashman & Brown, 2006). Furthermore, Stuss and Benson's model (1986) of cerebral organization supported the use of a top-down approach in learning functional tasks, instead of focusing on repetition exercises and drills in basic cognitive attributes. By using VR technology, a simulated environment which is relevant to the user's daily life can be created. This offer a life-like scenario for users to practise PM skills directly. This top-down approach is believed to offer stimulation to underlying cognitive functions, such as RM and EF.

2.5.2. Artificial intelligence

<u>Background to the development of AI</u>

Artificial intelligence (AI) can be defined as the “simulation of human intelligence on a machine, so as to make the machine efficient to identify and use the right piece of 'knowledge' at a given step of solving a problem” (Russell & Norvig, 2003). That means the machine can act “rationally” after learning enough “facts” from the real world (Konar, 2000). The first paper that documented machine intelligence using a modern computer was written in 1950 by the British mathematician Alan Turing (Luger, 2005a). But it was not until the 1970s that the AI technique began to have some success. Expert systems and other AI software and languages appeared. In the 1980s, neural networks became popular. Nowadays, AI is very popular and widely used in different areas of the world (Russell & Norvig, 2003), such as image and signal processing, pattern recognition, financial system, data mining and so on (Schalkoff, 1997).

<u>Application of AI in education</u>

AI technology is frequently applied in education, providing direct teaching to students. This is usually known as an intelligent tutoring system (ITS) or adaptive learning material. While traditional computer-aided teaching only provides specially organized information to students in a static way (Wenger, 1987), the use of AI has radically changed the nature of computer training programmes. The AI system enriches the programme with the capacity for “cognitive diagnosis” and “adaptive remediation” (Shute & Psotka, 1994). That means the programme can use built-in knowledge dynamically, according to students’ needs (Wenger, 1987). This facilitates users’ learning by giving them an optimal learning environment for every session (Wasson, 1993). In order to achieve this, several important steps are needed in the AI system. Firstly, the AI system has to reason about users’ knowledge and difficulties. Then, it finds the best strategy and available contents for the users and finally comes up with adaptive learning material tailor-made for users’ individual needs (Wasson, 1997). Three different modules – an expert module, a student module and an instruction module – are needed in the AI system of a typical ITS to handle these tasks. The expert module contains a large amount of knowledge in a specific domain derived from specialists in the field. The student module is the data or knowledge structure which describes the students’ current understanding or status in the domain. The instruction module contains knowledge on selecting the appropriate teaching materials, responding to students' questions and determining when the students may need help (Burns & Capps, 1988).

Studies have shown promising effects in adopting ITS in education in a variety of subjects, such as computer programming, medical diagnosis and geometry (Anderson, Corbett, Koedinger, & Pelletier, 1995; Servan-Schreiber & Binik, 1989). The improvement is not limited to learning outcomes and effectiveness. Users' motivations were also promoted. Rebolledo, du Boulau and Luckin (2006) reported that students with low motivation could be motivated to make more effort, becoming more independent and more confident under an ITS, which can alter the mode of feedback given during and after each session according to the student's performance.

Application of AI in rehabilitation

Although AI has been applied in education for decades, to date the use of AI in rehabilitation has still been quite limited. Most of its application has been in assisting medical diagnosis (Innocent, John & Garibaldi, 2005), or decision making (Becker, Thull, Käsmacher-Leidinger, Stemmer, Rau, Kalff & Zimmermann, 1997). Several attempts at integrating AI technology into direct patient treatment have yielded positive effects and experiences. Most of them borrowed from the experience of ITS.

Servan-Schreiber and Binik (1989) investigated the use of ITS principles in designing AI-based sex therapy. Through answering the questions generated by the AI-based treatment programme, users' sexual dysfunctions could be evaluated and the possible causes identified. An individualized treatment plan could be set at the end of the session. Positive feedback was received from the programme users, who felt that the programme was "smart" and seemed to understand their needs. The researchers concluded that AI had the advantage of being highly individualized in analyzing users' behavior and providing immediate objective feedback. Users were taking the comments from the programme seriously.

Another study applied AI technology in treatment of aphasia (Masson & Quiniou, 1990). The successful development of an AI-based programme could provide a cost-effective treatment for patients with aphasia who required long-term intensive rehabilitation. The AI-based programme in this study evaluated the patients' impairments through grammatical exercises in the first two sessions, followed by individualized rehabilitation strategies and exercises. The development of the treatment programme followed the design of ITS where the three basic modules of domain model, patient model and pedagogue in the AI system were constructed. Unfortunately, no clinical trial was implemented.

The studies mentioned above provide preliminary support for the use of AI in rehabilitation. It was agreed that AI has advantages in providing individualized feedback and treatment strategies according to users' performance. The "optimal learning environment" (Wasson, 1993) was considered to be cost effective and a possible way to offer long-term therapist-intelligent-based treatment no matter where the users were.

2.6. Summary of literature review

ABI survivors live with long-term disability and their situations also affect their carers, the healthcare system and society. Among many deficits and difficulties they may face, memory deficits are commonly reported. Retrospective memory (RM) has been extensively studied. Another form of memory, prospective memory (PM), is considered to be important to people's everyday lives. Studies related to PM are just beginning. There is limited literature reporting the rehabilitation of PM deficits. Thus the development of effective cognitive rehabilitation strategies for PM deficits is important to this group of people. Due to advancements in basic neuroscience and neuropsychology, several theories have been developed to explain the underlying mechanisms for cognitive rehabilitation, for example, neuroplasticity, environmental enrichment (EE) and contextualized learning (CL). These theoretical inputs are very useful in guiding new rehabilitation practice. The traditional cognitive rehabilitation approach, which focused on repeated exercises and drilling on specific cognitive functions, might fail to address the functional outcome or the generalization of training effects to the real life situation. The use of advanced computer technology was thus proposed. Virtual reality (VR) enables the use of vivid visual and auditory stimulations and naturalistic training environments. The application of VR in rehabilitation can match the training approach supported by EE and CL, where a simulating environment and real life training scenarios are believed to yield better training effectiveness. Research has also demonstrated that the training effect of VR-based programmes can be highly transferable to real life situations.

It is widely agreed that PM is not a unitary cognitive process but is supported by other cognitive functions, such as RM and EF. Repeated practicing of PM skills in a virtual environment may not yield optimal training effects. The Process approach relies on the importance of remedy the basic cognitive functions that contribute to complex cognitive processes. Knowing that the characteristics of people with ABI vary, in the symptoms and their severity, artificial intelligence (AI) was proposed to combine with VR to tackle this complex situation. With its strength in analyzing users' difficulties from captured behavior, providing individualized training materials and appropriate feedback, it is believed that this could give additional training effect to existing VR-based cognitive rehabilitation strategies.

Chapter 3

Conceptual framework

This chapter sets out the development of an innovative cognitive rehabilitation model which has guided the development of two newly developed computerized programmes. The proposed model was named the Intelligent Virtual Reality-based Prospective Memory (IVRPM) Rehabilitation Model. It was developed by incorporating the strengths of two types of advanced computer technology; AI and VR. Both AI and non-AI VR-based training programmes were designed to offer PM training to people with acquired brain injury. They had problems in PM functioning which hindered their everyday life in the community. The proposed IVRPM rehabilitation model will be described in two ways. One is a structural model, which demonstrates the interactions between the therapeutic environment (VR environment and AI component), and the real environment where people with ABI actually live. The second is the process model which shows how the training programme actually works. The following sections would elaborate the conceptual framework of this model in more detail.

3.1. Background of proposed IVRCR model

As mentioned in the previous chapter, PM deficits are commonly found in people with ABI. As PM functioning is closely related to everyday life, PM has been reported to be one of most disabling forms of memory impairment and it hinders community participation for people with ABI.

Research has shown that a stimulating environment is essential for the re-learning of motor and cognitive skills. This belief is advocated by environmental enrichment (EE) philosophy. The effect of EE is widely documented in terms of the effect on behavior, neural anatomy and neuro-activity. Although most of the research is based on animal models, it is believed that the human brain would perform similarly. While basic cognitive functioning could be enhanced with the input of EE, functional improvement required another training approach, the contextualized learning (CL) approach. The CL approach emphasizes training in functional tasks and in an ecologically valid environment. The top-down approach is usually encouraged, i.e., the activation of basic cognitive components through training in direct functional tasks rather than repeated drilling of cognitive components and expecting the transfer of improved cognitive skills to functional performance (bottom-up approach). With the use of VR technology, a naturalistic training environment with rich visual and auditory stimulation allows a training programme to integrate the EE and CL approaches at the same time.

According to the process approach, complex functional skills are composed of basic cognitive abilities. Therefore, basic cognitive abilities should be addressed in the rehabilitation of complex functional skills. When applied to the present study, RM and inhibition should be addressed in the PM rehabilitation programme, as PM was found to be supported by RM and affected by inhibition. This process approach was used as a complement to the CL approach. By combining these two approaches, a holistic training programme (which addressed both PM as a top-level functional skill, and the bottom-up supporting cognitive abilities: RM and inhibition) was thus developed. However, the cognitive profile of people with ABI varies from one to another. Putting all functional training and its related cognitive skills training together would result in a very lengthy training programme. The redundant training content would also demotivate the users. Therefore, AI technology was applied to tackle this situation.

AI has strengths in capturing and analyzing users' real-time behavior and providing individualized feedback. This enables training appropriate to different users with different cognitive profiles, rather than just following pre-structured training procedures and content. This technology has proved to be effective in teaching students. It was believed it would produce a similar effect in enhancing the learning of target skills in people with ABI.

3.2. The conceptual framework of the Intelligent Virtual Reality-based Prospective Memory (IVRPM) Rehabilitation Model

3.2.1. Intelligent Virtual Reality-based Prospective Memory (IVRPM) Rehabilitation Model (Structural Model)

Figure 1 shows the structural model of the proposed intelligent virtual reality-based prospective memory (IVRPM) rehabilitation model. As the name implies, this model is constructed from two main components; AI component and VR component. The VR component is the training environment and the interface with which the users interact. The AI component is conceptualized as a “virtual therapist”, which is responsible for adjusting the programme parameters, such as selection of training content and adjustment of training difficulties. Such adjustments would be made after diagnosing users’ deficits from the behavioral and performance data collected at the end of each session. Thus, individualized training can be given continuously within the course of treatment.

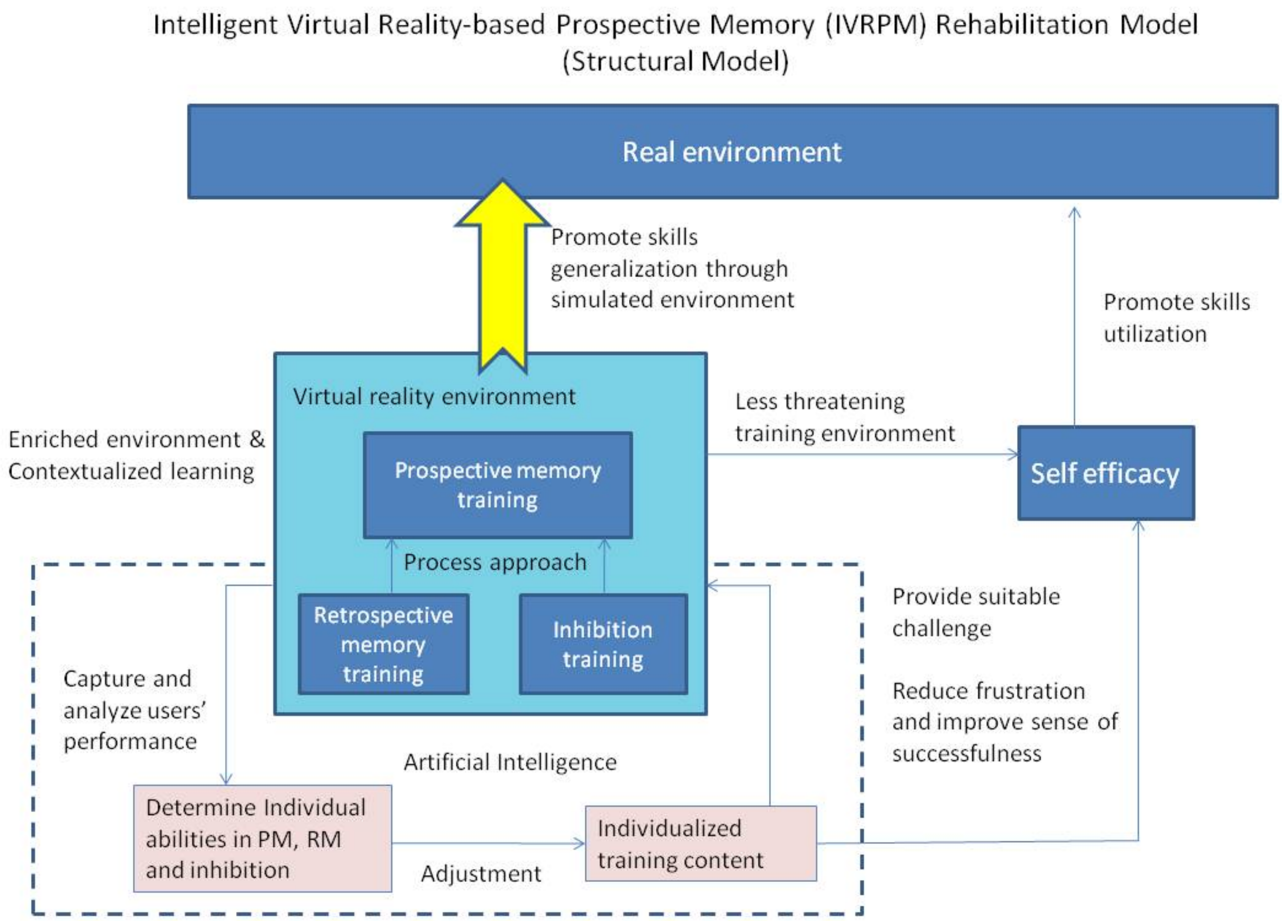

Figure 1. Intelligent Virtual Reality-based Prospective Memory (IVRPM) Rehabilitation Model (Structural Model)

The aim of the IVRPM rehabilitation model is to improve users' PM functioning and to promote generalization of the improved function to the real environment. As shown, PM training is the core training component. From the literature review, the importance of RM and inhibition in PM functioning was supported. By adopting the process approach (indicating the necessity of training in basic cognitive abilities), RM training and inhibition training were developed.

PM, RM and inhibition training had been developed by using VR technology. As mentioned in the previous chapter, the EE and CL approaches were applied in the use of rich visual and auditory stimulations and a simulated environment in the VR-based training. Furthermore, the simulated and meaningful environment serve the purpose of filling the gap between the ability deficits in people with ABI and the demands of the real environment by making the training environment very close to a real life environment. This has acted like a bridge, bringing the improved PM function towards the real environment. This also improved users' self efficacy by providing a familiar and less threatening training environment.

Instead of adopting a structured training content and process, the AI component was added to facilitate the learning process further, and is conceptualized as a "virtual therapist". Just as a real therapist would do, it collects data on the user's performance and analyzes the data with its existing knowledge. After the diagnostic process, it can choose the appropriate training tools (PM, RM and inhibition training) with a suitable level of difficulty. This process will keep looping after the end of each training session. With this capture-analysis-adjust process, individualized training can be provided to suit individual users' needs.

Besides the effects in improving the effectiveness of treatment, this kind of individualized training is believed to be able to improve users' self efficacy. According to Bandura (1994), self efficacy is “people's beliefs about their capabilities to produce designated levels of performance”. This belief would affect one's motivation, how much effort one makes and how one responds to difficulties. This is achieved by providing appropriate levels of difficulty to offer enough challenge or to reduce the sense of frustration. Knowing that self efficacy is commonly affected after ABI (Rutterford & Wood, 2006), the presence of AI is considered important.

3.2.2. Intelligent Virtual Reality-based Prospective Memory (IVRPM) Rehabilitation Model (Process Model)

Figure 2 shows the process model of the intelligent virtual reality-based prospective memory (IVRPM) rehabilitation model. It explains the underlying process of the IVRPM rehabilitation model. When people with ABI received IVRPM rehabilitation in the present study, they engaged in the virtual environment generated by a computer through an interface. The interface contained computer input and output devices, such as LCD monitor, stereo headset, keyboard and pointing device. Through this interface, the training environment of the IVRPM was presented to its users. At the same time, the users responded to the training environment in a process of human–machine interaction (HMI). After each time the user interacted with the training environment through the interface, the programme would capture the users' responses, such as number of errors, domain of errors, accuracy and efficiency etc. The captured parameters would then be sent to the AI component of the IVRPM programme.

The AI component consists of four major parts, namely (1) programme generator, (2) patient model (3) expert model and (4) pedagogue. The patient model collects and stores the user's performance at the end of each training session. Afterwards, it forms a representation of the user's ability and passes the information to the expert model for further analysis.

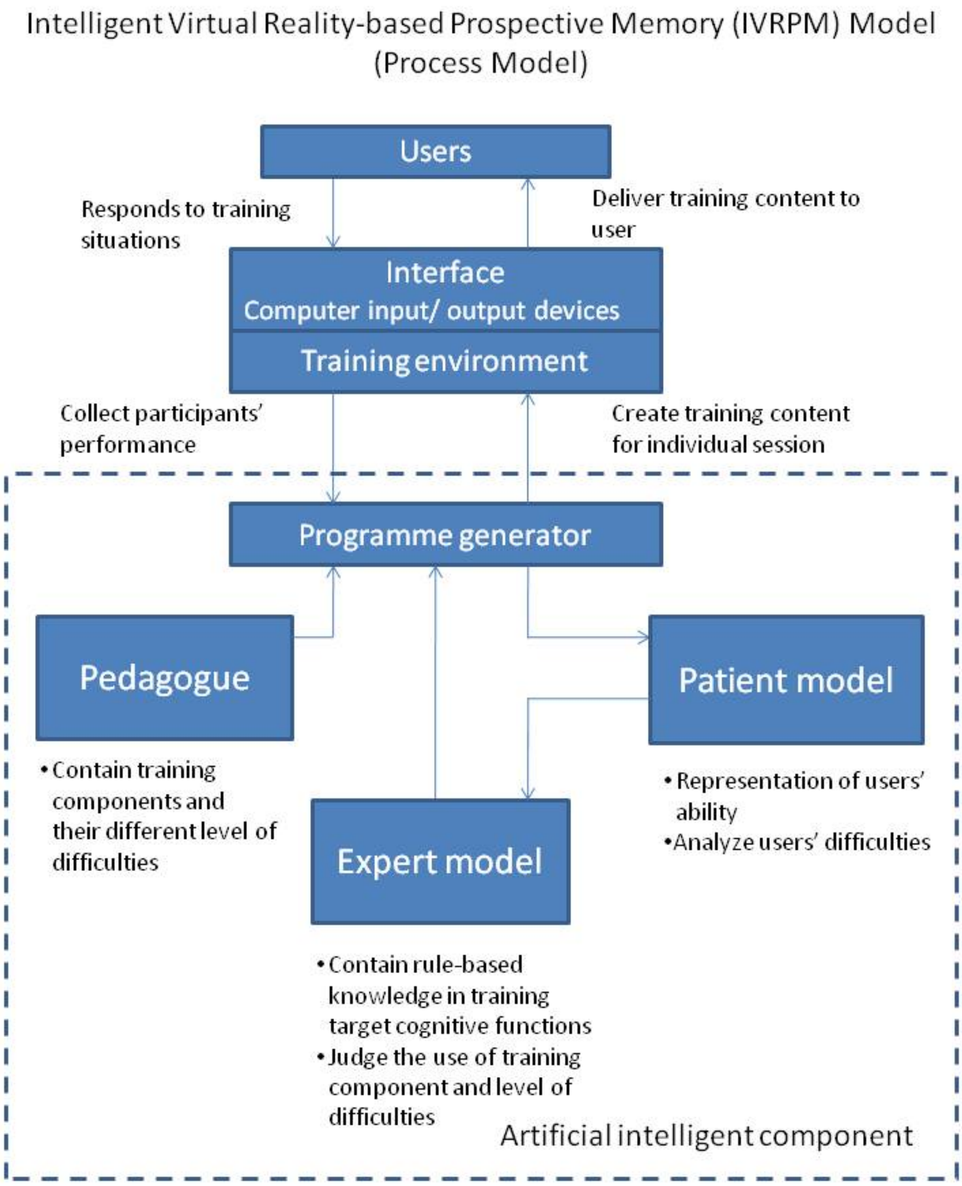

Figure 2. Intelligent Virtual Reality-based Prospective Memory (IVRPM) Rehabilitation Model

(Process Model)

A rule-based expert system was adopted in the expert model of the present IVRPM training programme. The expert system could be constructed to solve a wide range of problems; one of the functions was to give a diagnosis, which means to "determine the cause of malfunctions in complex situation based on observed symptoms" (Luger, 2005b). This function fitted the needs of the present study. The expert system finally came up with the user's difficulties in RM or inhibition. After apprehending the user's difficulties, the pedagogue would be responsible for choosing the appropriate training content and determining the level of difficulty. The final outcome would be then sent to the programme generator, where training sessions are constructed and displayed to the user through the computer interface.

Chapter 4

Research questions and hypotheses

This chapter will describe the research questions and hypotheses set for testing in the present study.

4.1. Research questions

1. Did the incorporation of artificial intelligence and virtual reality technologies (intelligent virtual reality, IVR) in computer-assisted rehabilitation produce a training effect in enhancing prospective memory (PM) performance for people with acquire brain injury (ABI)?

    i. What would be the effect of IVR in enhancing PM processes in terms of encoding of intention, and execution of intention in people with ABI?

    ii. Would the subjects be able to transfer the training effects to real environment?

    iii. Would there be any significant differences in self efficacy on everyday PM tasks?

2. Were there any significant differences between the two treatment groups (IVRPM and VRPM) and a control group in terms of PM performance, transfer of learnt skills, self efficacy, PM related cognitive attributes (i.e., retrospective memory, inhibition, divided attention, etc.) and the level of community integration?

4.2. Hypotheses

After the completion of the 10-session prospective memory training programme, it was hypothesized that the IVRCR group would have better learning effects than the VRCR group, and there would be no significant improvement in the control group, in the following aspects:

a. The performance of PM tasks, represented by the accuracy in encoding and execution of PM intentions, and duration in executing required PM intentions.

b. Transfer of training effects in PM performance in real environment, as represented by the accuracy in execution of intention in real environment.

c. The self efficacy in performing everyday PM tasks.

d. The performance of PM related cognitive functions, such as retrospective memory, inhibition and attention.

e. The level of community integration.

4.3. Operational definitions

1. Everyday PM function was defined by the ability in performing selected PM tasks chosen for the present study and conducted in a predefined place, i.e., a convenience store.
2. Self efficacy was defined as how much the subjects believed they could successfully perform the PM tasks listed in a self efficacy questionnaire.
3. Difficulties in RM and inhibition were defined as the extent that subjects' RM and inhibition hindered the performance of PM in the training programme at particular level of difficulty (usually when the level of difficulty in the PM training is not too high, the subjects will not expose the difficulties in RM and inhibition).

4.4. Implications and significance of the study

As outlined in chapter 2, extensive literature concerning PM has shown that people with ABI are widely affected by PM difficulties. These difficulties seriously hinder their community participation. Unfortunately, there is a paucity of research studies reporting rehabilitation strategies for PM. Several attempts which adopted a laboratory model or compensatory approach (Chasteen, Park and Schwarz, 2001; Fish and colleagues, 2007; Fleming, Shum, Strong and Lightbody, 2005) found it difficult to bring a solid functional improvement or a performance gain in peoples' daily life or their community participation.

The successful development of the IVRPM training programme could provide a cost-effective means to offer training which primarily targets improving PM functioning, but not by-passing it through compensatory approach, such as the application of cueing devices. This will bring new hope for people with ABI to experience improvement in their cognitive function. As the training content in the IVRPM training programme is highly relevant to the living environment of people with brain injuries, the performance gain may not be confined to users' cognitive performance, such as PM, RM and EF, but also to their functional performance and community participation.

In the present study, two training programmes were developed, namely the IVRPM and VRPM training programmes. They utilized one or two types of advanced computer technologies: AI and VR. VR had already been used in cognitive rehabilitation in recent decades and yielded positive training effects, such as in the rehabilitation of memory (Rose et al., 1998), executive dysfunction (McGeorge et al., 2001) and daily living skills (Yip & Man, 2009). These had proved that VR is effective in training target cognitive functions and promoting generalization to peoples' living environments. As said in previous chapters, PM is not a single construct and it is significantly affected by people's motivation and self efficacy. Solely adopting VR technology may not be the most effective means of PM rehabilitation for people with ABI having varying abilities. The capability of analyzing users' behavior, identifying their weaknesses and providing individualized feedback in AI were hypothesized to be the effective components in improving the training outcomes. Therefore, successful development and comparison of the two training programmes would contribute to the understanding of the strengths and weaknesses in the application of VR and AI. The application would not only be in PM rehabilitation, but also in the field of cognitive rehabilitation. This will shed light on developing innovative training programmes in the field of cognitive rehabilitation in the future.

Chapter 5

Methodology

The implementation of the present study was divided into two main phases, the pilot study and the main study. As the documentation concerning the application of VR technology in PM rehabilitation is very limited, a pilot study was very important for capturing information for the development of the training programme before the main study. The following sections describe the details of the two phases, including the aims, results and implications of the pilot study. Furthermore, the research design, training programme development and the outcome measures of the main study will also be presented.

5.1. Pilot study

Before the implementation of the main study on a larger scale, a pilot study was conducted to test the usability and effectiveness of a virtual reality (VR)-based training programme for people with ABI. This also served as an important means to capture relevant information, such as the rate of learning and generalization, the characteristics of the training effects and severity of simulator sickness suffered by the subjects, for the development of the training programme in the main study. This information would aid in designing the training content, choosing suitable training scenarios, determining the number of training sessions and training duration and adapting control devices. More importantly, the knowledge base of the artificial intelligence (AI) system in the intelligent VR-based training programme was constructed.

5.1.1. Methodology of the pilot study

A small-sample, pre- and post-quasi experimental design was adopted in the pilot study. Subjects were recruited by a convenience sampling method from a local rehabilitation centre according to the following selection criteria.

Inclusion criteria:

a. Had suffered a stroke or traumatic brain injury (TBI) and were medically stable.

b. Had subjective complaints of having one or more cognitive deficits that had affected their community integration (such as orientating in the community, using public transport and shopping).

Exclusion criteria:

a. Basic attention span of less than three minutes (such as the ability necessary to follow a day-to-day conversation).

b. Severe visual deficits (blindness, partial blindness or visual perceptual problems as reflected by scoring 1 S.D. below the mean in subtests of the Rivermead Perceptual Assessment Battery).

c. Impaired physical functions (which might inhibit the use of input devices), pre-morbid or post-morbid mental retardation or history of having other neurological disorders (such as epilepsy).

d. Received similar VR-based training previously.

In order to collect more information on the suitability of different training scenarios, three community living tasks which were reported to present difficulty for people with ABI were identified. These were; orientating in the community, using public transport, and shopping (Doig et al., 2001; Sohlberg et al. 2005). The training programme in the pilot study was thus developed to incorporate these three scenarios. In order to accomplish these tasks, the subjects were required to navigate in the virtual environment in a safe manner, locating the correct bus stop, identifying the correct bus to board, and alighting at the correct destination. After finishing the first task, subjects were then required to enter a nearby convenience store, shop for certain items according to a shopping list they were given, and pay at the check-out before leaving.

Both formative and summative assessment approaches were applied to capture the continuous and pre- and post- training outcomes. At the end of each training session, the training programme would record the time taken for completion of all tasks, the total distance travelled and the number of instances of dangerous behavior demonstrated. The changes in session-based outcomes reflected the acquisition of skills during the training period. Other important outcome measures, like the performance and self efficacy in applying these skills in the real environment, related cognitive abilities and functional independence, were taken before and after the treatment period. Finally, feedback on usability was collected through the observation of the subjects' behavior in using the training system by researcher and from brief interviews with the subjects.

The abovementioned assessments and training were delivered to each subject after written consent was obtained. During the treatment phase, subjects were provided with a total of ten sessions of virtual reality-based (VR) community living skills training at a frequency of three times per week.

5.1.2. Results of the pilot study

Four subjects (three male and one female, age ranged between 38 to 65) with ABI were recruited for the pilot study. Three of them suffered from CVA and one suffered from TBI. In all four cases, memory deficit was the major self-complaint that hindered their functioning in community living. Based on pre-training assessment results, they had a similar pattern of cognitive deficits.

The outcome measures of the pilot study demonstrated positive effects in several aspects. The results of this pilot study have been published (Yip & Man, 2009). A summary of the results is below:

a. Usability of the VR-based training programme:

   Usability interviews revealed that users perceived a lack of variety in the training content and in the levels of difficulty in the programme. Graphical resolution of the programme was also an important concern as subjects found it influenced their performance. One of the subjects developed symptoms of simulator sickness, which subsided after switching to a 15-inch LCD display (a 32-inch LCD display was used originally).

b. Skills acquisition in virtual environment:

All four subjects showed improvement in outcomes such as time taken and distance travelled to accomplish all the tasks. Three out of four subjects showed a decreasing trend in dangerous behaviour when crossing the road.

c. Transfer of learnt skills to real environment:

All four subjects showed improvements, from pre-test to post-test, in performing the simular community living tasks in the real environment.

d. Effects on related cognitive abilities and functional independence:

Three subjects showed dramatic improvement in related cognitive abilities, such as memory performance, and all subjects demonstrated improvement in their level of independence.

e. Self efficacy in performing related community living skills in real environment:

Three subjects showed improvement in their self efficacy score.

5.1.3. Implications for the main study

The pilot study provided preliminary support for the effectiveness of VR technology in cognitive rehabilitation of people with ABI. The finding is also in line with the findings set out above (Section 2.2). As the same as many studies to people with ABI (Lim & Alexander, 2009; Majid, Lincoln, Weyman, 2000; Shum, Fleming &

Neulinger, 2002), memory difficulties were demonstrated in this pilot study as reflected in self report and results from the outcome measure. Furthermore, their memory performance showed improvement in the post-test results, which concurred with Stuss and Benson's model (1986) of cerebral organization. Basic cognitive functions could benefit from a top-down functional training approach. This further supports the decision to target memory deficits as the training focus in the main study.

The subjects performed the best in the shopping task scenario, making few mistakes. They also scored the highest in their self efficacy evaluation in the shopping task, compared with the other two training scenarios. This contributed to our decision to choose the shopping scenario as the training scenario in the main study.

It seemed to be quite exhausting for the subjects to undergo training sessions three times a week. Therefore, in the main study, the frequency of training sessions was reduced to twice a week. Maintaining the total training sessions at ten was believed to be just sufficient to yield significant training effects.

Information from the usability interviews and the researcher's observations suggested the need for improvement of the resolution of the graphics of the training programme in the main study. The use of the computer display was standardized to a 17-inch LCD display in the main study, to minimize “simulator sickness” without impairing the sense of presence. Finally, the subjects experienced a lack of variety in the training content and the level of difficulty in the training programme. This may be one of the reasons for the limited improvement in the subjects’ self efficacy, and is also the grounds for the importance in adopting artificial intelligence in the training programme.

5.2. Main study

5.2.1. Research design

A single-blind, pre-test/post-test randomized control trial was adopted in this study. Assessors were blind to the allocation of individual subjects to treatment groups. Pre-training and briefing sessions were provided to assessors to standardize the procedures and enhance inter-rater reliability. The subjects were randomly assigned to an IVRPM- or a VRPM-treatment group or a control group by drawing lots.

5.2.2. Sampling

5.2.2.1. Sample size estimation

As ANOVA was used to test possible differences in the outcome measures of the three groups, the sample size was estimated according to the related literature (Cohen, 1977) and using the software "Power Analysis and Sample Size for Windows, v.6.0 (PASS) (Hintze, 1996). For ANOVA, using three groups, with an input of alpha=0.05, beta=0.2 (or power=0.8) and an estimated effect size of 0.4, the sample size for each of the groups was estimated to be 22. Thus a sample of 30 was recruited to avoid possible dropouts.

5.2.2.2. Subject recruitment

In this study, PM is the main training focus. As mentioned in previous chapters, PM is an advanced cognitive functioning and is supported by many basic cognitive attributes. Furthermore, PM is closely related to community integration, subjects are expected to utilize the learnt skills in their community living. Therefore, it is believed that the subject who will be benefited most, are those people with less cognitive impairment. They are living in the community and able to perform some PM tasks, despite facing some difficulties. With the help of the training programme, the underlying reason for their PM deficits can be identified and training can be given accordingly. But if subjects demonstrate serious cognitive impairment and cannot manage basic cognitive tasks, such as RM tasks or maintaining attention, PM rehabilitation should not be their training focus at the moment. One more important criterion is subjects' self-awareness. Literature had supported that self-awareness impairment could affect the treatment outcome in people with brain injury (Bach & David, 2006; Halligan, 2006). So, if a subject has deficit in self-awareness, he or she may not be motivated in participating in the training and thus affect the training outcome. Therefore, subjects selected in present study were those with less cognitive self-awareness impairment.

Subjects were recruited by a convenience sampling method from local self-help groups for stroke and brain injury and an out-patient unit of the Occupational Therapy Department of a general hospital. The inclusion and exclusion criteria were as follows:

Inclusion criteria:

a. Aged between 18 to 60 years.
b. Suffered from stroke or traumatic brain injury (TBI), at least three months post-injury and medically stable.

c. Complained (subjective or from main care-givers) of PM deficits or other cognitive deficits that hindered their community living (through initial intake interview).
d. Able to pass the three standardized screening tests (see Section 5.2.3.1).

Exclusion criteria:

a. Demonstrated a basic attention span of less than three minutes (for example, failing to follow day-to-day conversation).
b. Demonstrated severe visual deficits (blindness, partial blindness, visual perceptual problems as reflected by scoring 1 S.D. below the mean in subtests of the Rivermead Perceptual Assessment Battery).
c. Presented severe impairment in physical functions which might inhibit the use of input devices.
d. Pre-morbid or post-morbid mental retardation, other neurological or psychiatric disorders such as epilepsy or depression.
e. Received similar VR-based training previously.

5.2.3. Instrumentation

5.2.3.1. Screening tests

Mini Mental State Examination – Cantonese Version (MMSE–CV) (Appendix 1)

The MMSE, developed in 1975, is a widely used instrument for assessing cognitive functions. It consists of two sections. The first section requires vocal responses that cover orientation, memory, and attention, and the second section covers the ability to name objects, follow verbal and written commands, write a sentence, and copy a complex polygon. MMSE was translated into Cantonese (MMSE–CV) and validated in 1994, and this version was used in the study (Chiu, Lee, Chung & Kwong, 1994). The maximum total score is 30 and a cut-off point of 23/24 can discriminate patients with cognitive impairments from normal subjects (Folstein, Anthony, Parhad, Duffy & Gruenberg, 1985). In the present study, MMSE–CV was used to screen out those with severe cognitive impairment. Subjects who scored 18 or below were excluded.

Test of Nonverbal Intelligence, 3rd Edition (TONI –3) (Appendix 2)

TONI–3 was developed to be a non-verbal abstract/figural problem-solving test. Its content, instructions and responses do not require either verbal or written language. The test content includes only figural drawings and subjects can respond by gestures, such as pointing or even blinking their eyes (Brown, Sherbenou & Johnsen, 1997). As people with ABI might also have limited language ability, TONI–3 would be a suitable test for screening purposes. According to the examiner’s manual, a score of

70 or below would be classified as “very poor” (Brown, Sherbenou & Johnsen, 1997). Therefore, subjects who scored below 70 were excluded from the present study.

Self-Awareness of Deficit Interview – Chinese version (SADI–CV) (Appendix 3)

It is widely agreed that self-awareness impairment could affect the treatment outcome in people with brain injury (Bach & David, 2006; Halligan, 2006). SADI–CV (Cheung, 2005; Fleming, Strong & Ashton, 1996) was used to screen out those with severe self-awareness impairment. The SADI–CV is an interviewer-scored structured interview that assesses clients’ self-awareness in three areas: (1) self-awareness of deficits; (2) self-awareness of functional implications of deficits; and (3) ability to set realistic goals. A four-point scale (0–3) is used to rate each part of the interview. The higher the score, the more severe is the self-awareness impairment. There was no available literature suggested cut-off score. In the reliability test of SADI (Simmond & Fleming, 2003), the mean and standard deviation (S.D.) of the SADI total score ranged from 4.9 (2.86) to 5.05 (3.03). Therefore, a score of 1 S.D. below the mean, i.e., less than 2, was used as a cut-off score to screen out subjects with significant self-awareness deficits.

5.2.3.2. IVRPM and VRPM training programmes

In the present study, two training programmes had been developed; the IVRPM training programme and the VRPM training programme. The training environment and controls were actually the same for both. The major difference between two training programmes was that former has an AI component built in which is responsible for analyzing the captured users' performance and provide suitable training content and level of difficulty for each user. In the VRPM training programme, all training contents and levels of difficulty were structured for each training session. No variation could be made. This means each participant who received VRPM training would receive the same training content regardless of their abilities and progress in performance. Detailed illustration of each training programme will be shown in the following sub-sections.

5.2.3.3. Development of VR training environment

Both training programmes utilized the same VR environment. Firstly, a suitable training scenario had to be chosen. In order to increase the motivation and the sense of participation of the users, the training scenario must be one that is very familiar to target users and relevant to their daily living. With the experience obtained from the pilot study, shopping in a convenience store was chosen as the training scenario. Convenience stores are located nearly everywhere in Hong Kong, including residential areas, train stations and shopping centers. Although a supermarket environment may be more relevant to most people's daily lives, a convenience store could be regarded as a miniature or simplified supermarket and more manageable for training purposes. All the PM training tasks were thus arranged to occur in the virtual convenience store.

After the decision on the training environment, the 3D layout in the program was designed and built by Maya 8.0. Virtools software was used to develop the program behavior, integrate with the 3D layout and finally form the training programme. Virtools was chosen as it can develop a virtual environment faster than traditional game programming methods. After that a judgment had to be made on the mode of

VR to be adopted in the programme. This had a huge influence on the mode of content delivery.

As mentioned in chapter 2, VR can be divided into immersive and non-immersive type desktop-based and non-immersive type video capture VR. In terms of development cost, although an immersive-type VR system, which uses a head-mounted display and other equipment, could provide a more realistic environment and increase the level of presence, the cost of the necessary equipment was far greater than for non-immersive types VR. Non-immersive type desktop-based VR was the most cost effective as it only required a desktop computer. Secondly, the side effects of immersive VR have been reported to be significant. Regan and Price (1994) reported that as many as 61% of participants suffered from simulator sickness, such as nausea, headache and disorientation. This imposed safety implications on the study. In the pilot study, simulator sickness was observed even under a 32”- inch LCD monitor. The symptom subsided after changing to a smaller monitor. Therefore, a smaller display was recommended to people with ABI. Furthermore, the training facilities typically were community-based self-help groups and outpatient units of general hospitals, and they could not accommodate a large training system. Therefore, a non-immersive type desktop-based VR was chosen in this study. Next, in order to compensate for the weakness in the sense of “presence” of a non-immersive type of VR, the resolution of the graphics used was rendered as high as possible without sacrificing the smoothness of navigation inside the virtual environment.

The two training programmes were designed to be executed by using a desktop computer. A desktop computer with a minimum configuration of a Pentium 4 3.0 GHz CPU, 1 GB physical memory (RAM) and NVIDIA GeForce 6800 display card was recommended for smooth running of the programme. A laptop computer could be an alternative for providing treatment with similar effects. Users interacted with a virtual environment displayed by a 17” LCD monitor, together with other multimedia peripherals, such as stereo speakers and a programmable joystick, a keyboard and a pointing device.

5.2.3.4. Development of training components

The two training programmes utilized the same training components; prospective memory (PM) training component, retrospective memory (RM) training component and inhibition training component. The content in each of the training components is as follows.

Prospective memory (PM) training component

PM training was the core training component of the present training programme. It was conducted inside a virtual convenience store. The PM training consisted of event-based tasks (such as shopping for drinks with discounted prices or calling back home when a gift redemption counter was seen), time-based tasks (such as taking food out of the microwave oven after five minutes) and also ongoing tasks (shopping for items from a shopping list). At the beginning of training, the task requirements were shown in both visual and auditory formats. The subjects had to read or listen to the instructions, and they could replay the auditory instruction if needed. Before entering the virtual environment for execution of those tasks, an immediate recall test was given. The subjects were asked to choose the tasks just mentioned from a task list. They had to correctly pick out all the required tasks before they could proceed to the next step. The subjects then moved on to the virtual convenience store (Figure 3). They were required to perform the previously mentioned PM tasks and also to shop for items on the shopping list provided. They could click on the “watch” icon to show the time. By pressing the “shopping list” icon and “shopping trolley” icon, the shopping list (Figure 4) and items picked would show up on the screen. They could pay at the check-out to indicate they had finished doing the required tasks. Finally, the subjects were asked to recall what they were told to do at the beginning of training.

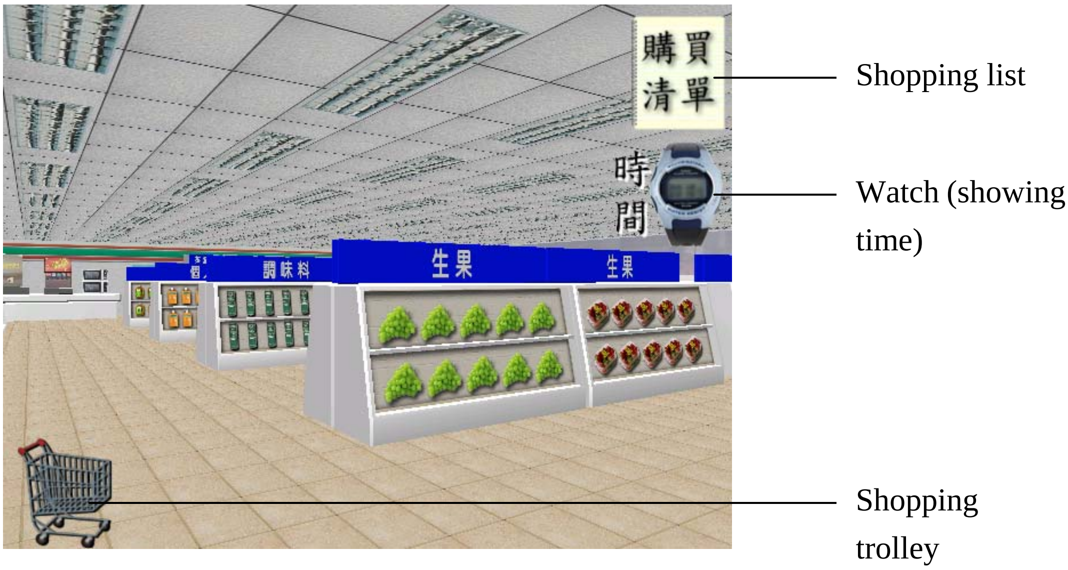

Figure 3. Layout of the virtual convenience store

Users can shop for the items needed when they approach the items shown on the racks. They can click the icons with a mouse pointer for specific information. Items they have to buy and items they have chosen will be shown by clicking the shopping list and shopping trolley icons respectively. Users can also check the time by clicking the watch icon.

Figure 4. Shopping list for ongoing tasks

A shopping list showing the items that the user has to buy in the training session.

Retrospective memory (RM) training component

In the RM training component, subjects were required to remember a list of four shopping items. They had 15 seconds to memorize the items, followed by a short break of 30 seconds. The subjects were then asked to pick the correct items out of eight items. The subjects were required to finish three different sets of memory tasks in the RM training component.

Inhibition training component

The content of inhibition training was also related to the convenience store shopping scenario. Throughout the training period, three types of item would be randomly shown on the screen, one at a time. They were an item with a special price tag, an item with a “new arrival” tag and an item without a tag. The subjects were required to press the spacebar only when they saw an item with a special price tag shown on the screen. There were thirty trials altogether, divided into three sub-sessions. Participants could take a break between each sub-session.

More figures illustrating the three training components can be found in Appendix 4.

5.2.3.5. Development of IVRPM and VRPM programmes

In the IVRPM training programme, as described in Figure 2, users interacted with the training environment through the interface. The training environment was developed to be a virtual convenience store. All the training components were based around this scenario. The development of the virtual environment has already been described in the section 5.2.3.3. The main concern in this section is the description of the programme structure and the development of the AI system in the IVRPM programme. Figure 5 shows the programme structure of the IVRPM programme.

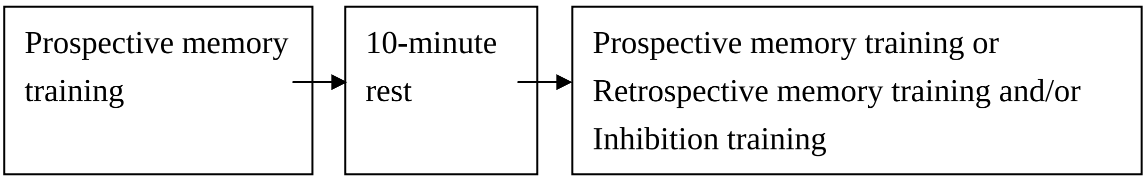

Figure 5. Program structure of IVRCR training

In the IVRPM training programme, each training session would be divided into two parts. At the beginning of each training session, the AI system would use the information on each user’s performance collected in the previous sessions to identify the difficulties that the user may face. The AI system would then adjust the level of difficulty in the PM training component for the first part of the training session and decide on the need for RM and inhibition training in the second part of the training session. If the user was identified as not having difficulty with RM or inhibition which hindered the performance of PM tasks at the present level of difficulty, one more PM training would be given in the second part with the same level of difficulty as the first part. There was a 10-minute rest between two parts of the training session.

AI component in IVRPM programme

As the AI system was responsible for diagnosing users' difficulties and deciding the corresponding training content in each session, errors in diagnosing users' difficulties would lead to the wrong prescription of training content to the users. The development of the AI system was a critical factor in the success of the IVRPM programme. The AI component adopted a rule-based expert system approach. The expert system can be built to give a diagnosis, which can find out the causes of problems in a complex situation based on observed symptoms (Luger, 2005b). When applied in the present programme, the expert system was used to identify whether the user had difficulties in PM, RM or inhibition when performing PM tasks at particular level of difficulty.

As mentioned in Chapter 3, the expert system in the present programme contained four components; programme generator, patient model, expert model and pedagogue. The patient model contains users' information on their session-based performance, including accuracy of the shopping task (ongoing task), accuracy of immediate recall and delayed recall of PM tasks, accuracy of PM task execution and number of time monitoring. By using these collected data, the expert model would utilize the rules in its knowledge base to identify whether each user had difficulties in PM, RM and inhibition. After that, the pedagogue would prescribe appropriate training components. The level of difficulty in the PM training component would be adjusted, too. There were three parameters to adjust the level of difficulty in the PM training component; number of items in shopping list, number of PM tasks and assistance level. Appendix 5 shows the detailed grading of the three parameters. Finally, the programme generator would generate the training session with the decided training component and level of difficulty.

The knowledge in determining appropriate training contents and level of difficulty was the result of an expert panel review. The expert panel had seven members including academics, clinicians and programmers. They had all worked in their fields for more than six years. After being briefed with the project's objectives, they were required to fill in a questionnaire which aimed at collecting their opinions on diagnostic criteria for PM, RM and inhibition and also the ways to adjust the level of difficulty in PM training. The expert opinion questionnaire is shown in Appendix 6.

VRPM training programme

The VRPM training programme was actually a simplified version of the IVRPM training programme. The only difference was the AI component was removed and replaced with structured training content. Figure 6 shows the process model of the VRPM training programme. Users interacted with the training contents through computer input and output devices. Instead of the presence of AI component to plan the training content in each training session for each subject, the training contents in each session of the VRPM training programme were already structured in the development stage. All three training components, the PM training component, RM training component and inhibition training component, were applied in each training session. The programme structure of VRPM training was shown in Figure 7. The level of difficulty in the PM training component was also structured to be increased session by session (Table 1) no matter how the participants performed. Although in clinical situation, therapists will dynamically change the training and level of difficulty according to patients' performance. But to minimize the factor of human intelligence in VRPM training programme, the training content and level of difficulty were fixed regardless the performance of subjects' performance. Therefore, the comparison between IVRPM group and VRPM group was the training effect of two types of computer-assisted training programme, AI as compared with fixed programme structure.

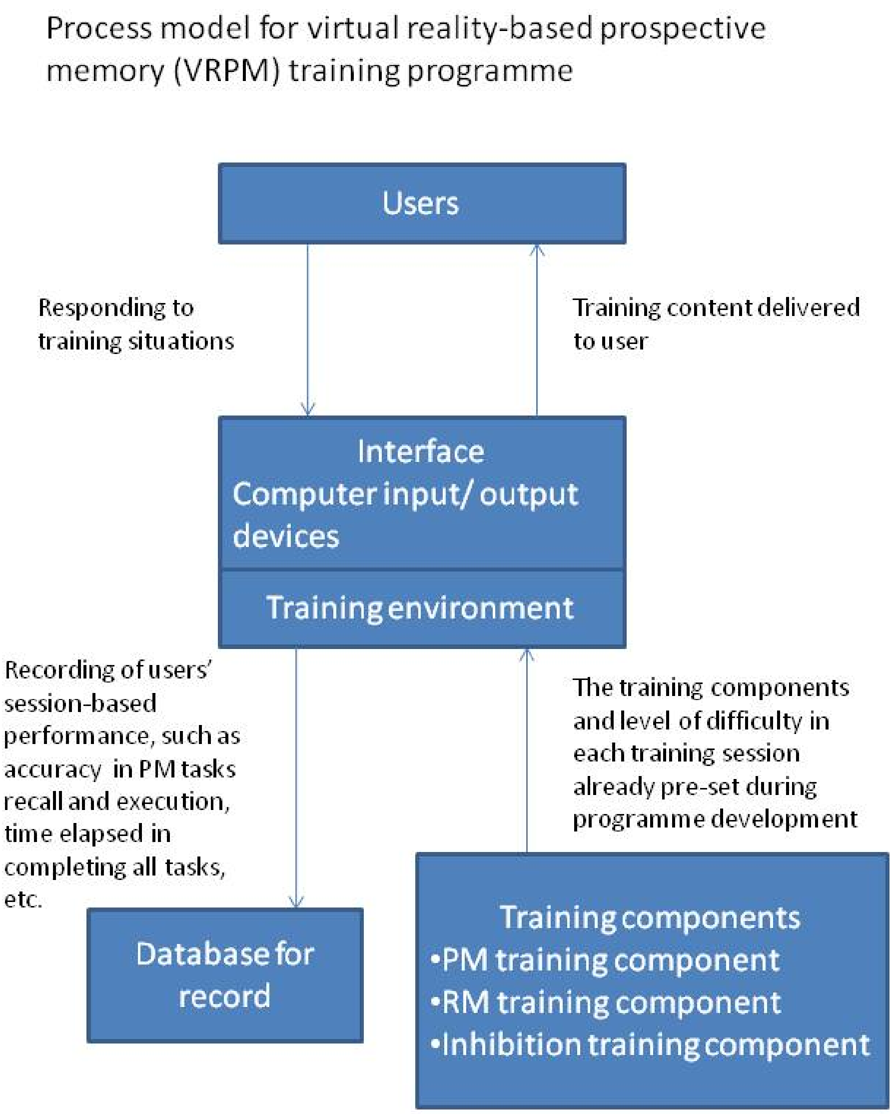

Figure 6. Process model of virtual reality-based prospective memory (VRPM) training programme

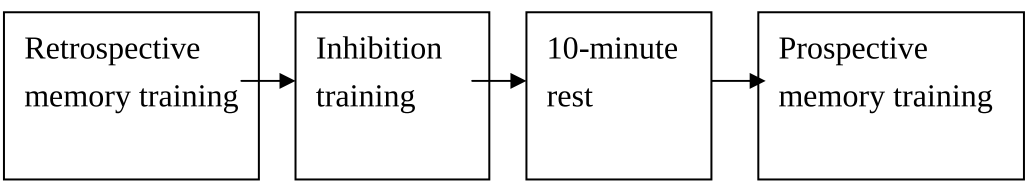

Figure 7. Programme structure of VRPM training programme

Sessions	Number of items in the shopping list (Ongoing task)	Number of event-based PM tasks	Number of time-based PM tasks
1	4	2	0
2	4	2	0
3	5	2	1
4	5	2	1
5	6	3	1
6	6	3	1
7	6	3	2
8	7	3	2
9	7	3	3
10	7	3	3

Table 1. Structure of a 10-session VRPM training programme

5.2.4. Outcome measures

The outcome measures of this study were chosen to document the change in subjects' performance in PM skill acquisition, skill generalization, and self-perceived efficacy in performing PM tasks, as well as possible changes in their cognitive profiles and functional independence. In the present study, an assessor was trained to conduct all the assessments listed below who was blinded to the grouping of subjects.

5.2.4.1. Virtual reality-based test on everyday prospective memory (PM) tasks

A virtual reality-based assessment was developed to document the change in PM performance in a VR environment. As the training content varied from session to session, session-based outcome parameters, like time and accuracy in accomplishing the required PM tasks, could not be compared directly. Therefore, a specific assessment scenario was developed as a standard. It consisted of three event-based PM tasks and three time-based PM tasks. The assessment was conducted in the same way as described for the PM training content. In this assessment, seven domains would be recorded. They included immediate recall of PM tasks, delayed recall of PM tasks, accuracy of event-based and time-based tasks, accuracy of ongoing tasks, total time lapsed and total number of time checks. In order to prevent the exposure of the VR content to the control group subjects, the VR-based assessment was only received by IVRPM group and VRPM group participants.

5.2.4.2. Real life behavioral prospective memory (PM) test (Appendix 7)

A real life behavioral test was developed as a content-specific assessment of prospective memory in a convenience store shopping scenario, such as calling back home when participants saw particular products or writing down the price of particular drinks. Participants were required to perform three event-based PM tasks and two time-based PM tasks. At the same time they had to shop for eight items in a supermarket according to the shopping list provided. The behavioral checklist was used to assess the subjects' performance on PM tasks in a real environment. The results served the purpose of reflecting the outcomes in terms of generalizing the learnt skills to a real environment. A six-point scale (0–5) with a specific scoring guideline was used to mark the participants' performance. The time taken to perform the whole test was not taken into account as it was affected by subjects' mobility and other environmental factors, such as the number of customers in the shop during the assessment.

The reliability of the real life behavioral PM test was established through a small scale test-retest and inter-rater reliability study. Eight subjects were recruited with the same inclusion and exclusion criteria as the present main study. Each subject undertook the two real life behavioral PM tests which were arranged a month apart. In the first test, one trained rater would rate each subject during the test. After a month, the subjects would receive the same test for the second time. One more trained rater was arranged to rate the performance of the subjects at the same time. Due to the small sample size, the correlation of results between two trials (test-retest) and the results between two raters (inter-rater) were analyzed through Spearman's rho. Table 2a and 2b show the results of the test-retest reliability coefficient (Spearman’s rho) and inter-rater reliability coefficient (Spearman’s rho).

	First trial	Second trial	Correlation coefficient (spearman’s rho)
Real life behavioral PM test items			
Event-based PM tasks			
Mean (SD)	9.88 (4.32)	9.75 (3.81)	0.96 ($p<0.05$)
Time-based PM tasks			
Mean (SD)	6.00 (2.39)	6.50 (2.33)	0.86 ($p<0.05$)
Ongoing task			
Mean (SD)	0.91 (0.13)	0.97 (0.09)	-0.30

Table 2a. Test-retest reliability coefficient (Spearman’s rho) of real life behavioral prospective memory test

	Rater 1	Rater 2	Correlation coefficient (spearman’s rho)
Real life behavioral PM test items			
Event-based PM tasks			
Mean (SD)	9.75 (3.81)	10.14 (3.89)	0.96 ($p<0.05$)
Time-based PM tasks			
Mean (SD)	6.50 (2.33)	6.14 (2.55)	0.94 ($p<0.05$)
Ongoing task			
Mean (SD)	0.97 (0.09)	0.96 (0.09)	1.00 ($p<0.05$)

Table 2b. Inter-rater reliability coefficient (Spearman’s rho) of real life behavioral prospective memory test

5.2.4.3. The Cambridge Prospective Memory Test – Chinese Version (CAMPROMT–CV) (Appendix 8)

CAMPROMPT (Wilson et al., 2005) is one of the standardized tests available to test PM performance. In the test, subjects were asked to accomplish six PM testing items, three event-based and three time-based. The whole test lasted 25 minutes. In between the PM test items, there were some paper and pencil tasks, such as a general knowledge quiz or word-finder puzzle, acting as ongoing tasks. The examiner gives instructions on different PM tasks at a particular moment of time as instructed by the manual. The examiner also needs to mark the performance of subjects according to whether they remembered to carry out the task in the right way and at appropriate times. Subjects' performance falls into one of six categories (from A to H) and is later transferred to scores of 6, 4, 2, 1 or 0. CAMPROMPT demonstrates high inter-rater reliability and test-retest reliability. The correlation between the test results scored by two raters and test-retest results scored seven to ten days apart were 0.998 and 0.64 respectively. Besides, CAMPROMPT also has significant correlation with other related cognitive measures, such Rivermead Behavioral Memory Test, Modified Six Elements Test and Map Search test (Wilson, et al., 2005). These show that CAMPROMPT is a reliable and valid measurement for PM. In the present study, the Chinese version of CAMPROMPT was used (Lou, Dou, Zheng, Chen & Man, 2009).

5.2.4.4. Hong Kong List Learning Test (HKLLT) (Appendix 9)

HKLLT is a Chinese list learning test developed by Chan and Kwok (1999). Participants are required to remember a list of 16 two-character nouns belonging to four categories. The test was developed in two versions; random condition and block condition. In random condition, the 16 nouns belong to one of the following categories; family member, country, furniture and vegetable, but they are shuffled in the list. However, in block condition, the 16 nouns are already listed according to the following; clothes, flower, music and occupation. A random version of HKLLT was used in this study with the aim of documenting changes in the effectiveness in learning and memory. Chan and Kwok (1999) stated that people with brain injury would face more difficulty under random conditions and were expected to be more sensitive to changes. During the test, participants had to undergo three learning trials, followed by a 10-minute delayed recall trial and a 30-minute delayed recall trial. The examiner only read out a list of 16 words in the three learning trials and participants needed to recall the words immediately afterwards. By using the results obtained in five trials, the participants' learning slope and forgetting rate after short and long delays were calculated. The measurement of learning slope would tell how many additional words each subject could recall with more learning trials. The higher the score would mean the subject was learning and was able to recall more words trial by trial. The forgetting rate was the difference between trial 3 and trial 4 (10-minute delayed recall) and between trial 3 and trial 5 (30-minutes delayed recall). These two scores would give results for the rates of short delay forgetting and long delay forgetting.

5.2.4.5. Frontal Assessment Battery (FAB) (Appendix 10)

Many studies support the idea that PM performance is related to frontal lobe functions or EF (Kliege, Eschen, Thone-Otto, 2004; Marsh & Hicks, 1998; Martin, Kliegel & McDaniel, 2003). FAB was developed to be an easily administered bed-side assessment to evaluate the presence and severity of dysexecutive syndrome in about 10 minutes (Dubois, Slachevsky, Litvan & Pillon, 2000). FAB demonstrates good internal consistency (Cronbach's alpha = 0.78), and inter-rater reliability (k = 0.87) (Dubois, Slachevsky, Litvan & Pillon, 2000). Authors also present FAB as good at differentiating subjects with frontal cognitive impairment from control subjects. The test consists of six sub-tests, including similarities, lexical fluency, motor series programming, conflicting instructions, GO-NO-GO and environment control. Because the educational level in the subjects recruited in this study was limited, the lexical fluency sub-test could not be administered, so the full FAB score in this study was changed to 15. However, as lexical fluency ability is very important in the successful performance of PM, another verbal fluency test was chosen, which is described as follows.

5.2.4.6. Word Fluency Test – Chinese Version (WFT–CV) (Appendix 11)

Word Fluency Test is a kind of verbal fluency test. Verbal fluency tests require participants to generate multiple responses that are based on phonemic or semantic criteria in a time-restricted environment (Henry & Crawford, 2004). Although phonemic fluency tests are more sensitive than semantics one in identifying frontal lobe dysfunction (Jurado, Mataro, Verger, Bartumeus & Junque, 2000), most of our target subjects were not native English speakers and had varied educational background, which may yield unreliable results. Therefore, in the present study, a semantic fluency test was chosen. WFT–CV measures the number of words generated verbally by the subjects according to a given category within one minute. Two categories were used in the test. The first group was “fruit and vegetables” and the second group was “animals”. The generation of words in the given categories is believed to require frontal lobe function. According to Henry and Crawford (2004), a verbal fluency test measures the subject's organization of verbal retrieval and recall, self-initiation and inhibition. Marsh and Hicks (1998) found moderate correlation between verbal fluency test results and event-based PM performance. They believed that both activities require a successful monitoring process and executive control of working memory. In the present study, the number of words generated in the two groups was added up to form a total score.

5.2.4.7. Color Trails Test (CTT) (Appendix 12)

The CTT was designed as an analogue of the trail making test (TMT), but was free from language influence. It substitutes the use of color for English letters. TMT is a widely used test which measures a range of cognitive abilities such as attention, sequencing, vasomotor speed, cognitive flexibility and set shifting ability (Lange, Iverson, Zakrzewski, Ethel-King & Franzen, 2005). TMT is also a commonly used test in prospective memory research which is believed to be correlated to prospective memory performance (Groot et al., 2002; Mantyla, Carelli, & Forman, 2007; Mathias & Mansfield, 2005). CTT not only retains the same psychometric properties as TMT, but also demonstrates a lower variability across cultures (D'Elia, Satz, Uchiyama & White, 1994).

5.2.4.8. Community Integration Questionnaire – Chinese version (CIQ–CV) (Appendix 13)

The Community Integration Questionnaire (CIQ) was developed by Willer, Ottenbacher and Coad (1994). It contains 15 items divided into three main areas; home integration, social integration and productive activities. It is very useful in measuring the level of integration in the three daily life areas in people with brain injury. The content of CIQ–CV had been validated in people with brain injury (Chan, 1999). Chan found that most of the testing items met the needs of people with brain injury in the Chinese community. Although some relocations of test items were suggested, it would not affect the analysis in the present study. This assessment was chosen to measure whether the level of community integration could be improved in the long run. In present study, CIQ–CV total score was used to document the overall picture of the subjects' level community integration upon changes in PM performance.

5.2.4.9. Self efficacy questionnaire in performing everyday prospective memory tasks (Appendix 14)

A 10-question self efficacy questionnaire was developed to document the subjects' own evaluations of their self efficacy in performing PM tasks before and after training. The design of the questionnaire was based on PM processes. Questions 1 to 4 were based on event-based items, while questions 5 to 8 were based on time-based items. Questions 9 to 10 served as an overall conclusion on self-perceived PM ability. The questionnaire was self-explanatory. The subjects rated themselves according to their self-perceived efficacy in performing various tasks described in each question on a 10-point Likert scale.

5.2.5. Implementation

Procedures

Ethical approvals (Appendix 15) were sought from the Ethical Committee of The Hong Kong Polytechnic University and New Territories West Cluster Clinical & Research Ethics Committee. A face-to-face interview was then carried out to explain the purpose of the study and to explore the subjects' suitability for the study. Subjects would sign a consent form (Appendix 16) to acknowledge that they understood and agreed to join the study. Outcome measures would then be conducted before and after the treatment period. Before the training period began, there was a warm-up period immediately before the start of the first training session. Subjects would be given sufficient time to familiarize themselves with the training environment and choose the input device they preferred the most (such as joystick or keyboard control).

An input profile was then created to record the subject’s individual input style, including the sensitivity of the input device. After these adjustments and warm-up procedures, the first session of IVRPM or VRPM training would commence. During the treatment phase, subjects in the IVRPM and VRPM groups were provided with a 10-session of corresponding training programme. The programme would be run twice a week and each session would last for about 30 to 45 minutes (depending on the difficulty of tasks and the ability of individual subjects). Post-tests would then be arranged one week after training. Subjects in the control group would not be provided with any structural cognitive training during the treatment phase, but pre-test and post-test were conducted in a similar way within a period of five to six weeks. A research assistant was there to provide standby assistance only in case technical problems should arise in the training programme. All necessary instructions were provided in the training programme.

Data analysis

Mixed-model repeated measures of ANOVA was adopted to measure the effectiveness in training everyday PM as between the IVRPM and VRPM training. This was achieved by two main steps. Firstly, results of the VR-based test on everyday PM tasks in IVRPM and VRPM group were analyzed. Next, another mixed model of repeated measures of ANOVA would be done, together with the results of the control group in order to study the within-group factor (pre-test/ post-test) and between-group factor (groups). Univariate ANOVA comparison was also conducted to investigate the differences in post-test outcome measures between the three groups. Bonferroni t-test was adopted as the post-hoc test. A paired t-test was also conducted to help determine the within-group difference in the training effect of the individual training programme and changes in the control group. Lastly, correlations between outcome measures with significant differences were also analyzed by the Pearson product-moment coefficient of correlation to provide additional information on the relationship between different parameters. A significance level of $p<0.05$ was used in all data analysis in the present study.

Chapter 6

Results

A total of 56 participants were successfully recruited. One of the male subjects dropped out during the treatment period due to ill health. He suffered from pneumonia and passed away. A total of 18 and 19 subjects were assigned to the IVRPM group and the VRPM group respectively, the remaining 18 subjects were assigned to the control group. All group assignments were done through randomization.

	IVRPM (n=18)	VRPM group (n=19)	Control group (n=18)
Demographic data			
Mean age (SD)	52.33 (11.08)	51.26 (5.79)	53.06 (7.87)
Gender			
Male	8	12	12
Female	10	7	6
Diagnosis			
Stroke	14	15	14
TBI	4	4	4
Time since injury in years (SD)	5.39 (4.33)	6.37 (2.48)	7.00 (4.72)
Education in years (SD)	9.11(2.68)	7.84 (2.71)	8.61 (3.79)

Table 3. Demographic data of subjects.

	IVRPM	VRPM group	Control group
Screening tests (score range)			
MMSE–CV (0–30) (SD)	25.94 (2.82)	26.00 (2.38)	26.44 (2.53)
TONI–3 (60–150) (SD)	88.00 (8.07)	85.21 (9.36)	89.50 (14.30)
SADI–CV (0–9) (SD)#	1.22 (0.65)	1.00 (0.75)	1.11 (0.47)

Table 4. Screening tests results of subjects in three groups

Key:

- the smaller the score the better the performance

MMSE–CV: A score of 24 or below was used to discriminate cognitive impairment from normal, a score of 18 is used as a cut-off score in the present study.

TONI-3: A score of 90 to 110 is regarded as having average intelligence. A score below 70 indicates "very poor" intelligence and was excluded from present study.

SADI–CV: No standard score were identified to discriminate people with significant awareness deficits. A score of 2 is used as a cut-off score in the present study. It was derived from the reliability study of SADI (Simmond and Fleming, 2003).

6.1.Characteristics of subjects

Table 3 shows the demographics of the three groups. ANOVA showed no significant difference among three groups in these demographic data. Most of the subjects (n=43, 78.2%) had suffered a stroke.

Among three groups, there was no significant difference in their screening test results (Table 4). Using the cut-off point of 23/24 in MMSE–CV as a reference to discriminate subjects with cognitive impairments from normal subjects (Folstein et al., 1985), all three groups did not show significant cognitive impairments. However, TONI–3 results indicated the intelligence of the subjects in all three groups was below average. Finally, there was no interpretation guideline to SADI–CV, but the mean score only ranged from 1.00 to 1.22 out of a full score of 9. It might be interpreted that the subjects' self-awareness of their own deficits was quite high.

6.2. Training effect of the IVRPM and VRPM training programmes within a virtual environment

Table 5a shows the pre-test and post-test results of VR-based test on everyday PM tasks for the IVRPM and VRPM groups. Repeated measures of ANOVA showed significant improvements in all test items, including primary outcome measures on PM:

a. immediate recall of PM tasks [$F(1,35) = 24.39$, $p<0.001$, effect size = 0.41, power = 0.998]
b. delayed recall of PM tasks [$F(1,35) = 21.11$, $p<0.001$, effect size = 0.38, power = 0.998]
c. performance of both event-based [$F(1,35) = 107.97$, $p<0.001$, effect size = 0.76, power = 1.00]
d. time-based PM tasks [$F(1,35) = 142.80$, $p<0.001$, effect size = 0.80, power = 1.00]

e. performance of ongoing tasks [$F(1,35) = 17.97$, $p<0.001$, effect size = 0.34, power = 0.99]

f. total time lapsed [$F(1,35) = 5.79$, $p<0.05$, effect size = 0.14, power = 0.65] and

g. number of time checks [$F(1,35) = 36.73$, $p<0.001$, effect size = 0.51, power = 1.00].

Among these testing items, immediate recall of PM tasks [$F(1,35) = 4.66$, $p<0.05$, effect size = 0.12, power = 0.555], performance of both event-based [$F(1,35) = 8.23$, $p<0.01$, effect size = 0.19, power = 0.796] and time-based PM tasks [$F(1,35) = 13.99$, $p<0.001$, effect size = 0.29, power = 0.953], indicated significant group interaction (Figure 8 a-c). Univariate analysis showed no significant difference in pre-test results in VR-based test on everyday PM tasks between the IVRPM and VRPM groups. Post-test results, however, showed significantly better performance in the IVRPM group than the VRPM group in the performance of both event-based [$F(1,35) = 22.21$, $p<0.001$] and time-based PM tasks [$F(1,35) = 27.86$, $p<0.001$] (Figure 9).

	IVRPM		VRPM group	
Outcome measures (score range)	Pre-test	Post-test	Pre-test	Post-test
VR-based test on everyday PM tasks				
Accuracy (0 – 1)				
Immediate recall of PM tasks	0.46 (0.33)*	0.86 (0.22)	0.55 (0.19)*	0.71 (0.27)
Delayed recall of PM tasks	0.50 (0.29)*	0.84 (0.23)	0.56 (0.26)	0.70 (0.23)
Execution of				
Event-based tasks	0.32 (0.30)*	0.91 (0.19)	0.17 (0.20)*	0.51 (0.26)
Time-based tasks	0.17 (0.17)*	0.87 (0.20)	0.07 (0.14)*	0.44 (0.34)
Ongoing tasks	0.75 (0.31)*	0.92 (0.13)	0.59 (0.32)*	0.84 (0.20)
Total time lapsed (seconds)#	964.94 (246.94)*	755.33 (224.78)	903.53 (301.40)	882.32 (295.82)
Number of time checking	6.33 (8.42)*	10.78 (6.52)	4.11 (4.82)*	7.74 (1.46)

Table 5a. Pre-test and post-test result of VR-based test on everyday PM tasks in IVRPM and VRPM groups

Key: In VR-based test on everyday PM tasks, full mark for accuracy item is 1.

* - within group difference by paired-t-test with significant level p<0.05

- the smaller the score the better the performance

Accuracy score was calculated by the following formula: (No. of correct items minus no. of wrong items)/ No. of total items.

Total time lapse is the total time spent to accomplish all PM tasks and ongoing tasks.

Number of time checking is the total number of times the user clicks on the “watch” icon to find the time at that moment.

	IVRPM group		VRPM group		Control group	
Outcome measures (score range)	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Real life behavioral PM test						
Event-based tasks (0 – 15)	8.39 (3.09)*	13.00 (2.30)	8.74 (3.38)*	12.26 (3.03)	10.83 (3.51)	9.61 (3.65)
Time-based tasks (0 – 10)	5.33 (2.93)*	8.67 (2.06)	3.37 (2.20)*	6.26 (3.26)	4.89 (2.63)	5.00 (2.38)
Ongoing tasks (0 – 1)	0.90 (0.18)	0.98 (0.06)	0.96 (0.08)	0.91 (0.16)	0.90 (0.17)	0.90 (0.17)
HKLLT						
Learning slope	1.80 (1.22)	1.75 (1.03)	1.50 (1.25)	1.84 (1.33)	1.89 (1.12)	1.33 (0.70)
Forgetting rate (short delay)#	1.22 (2.56)	0.83 (1.69)	1.53 (3.26)	2.42 (2.50)	1.94 (1.86)	1.28 (1.53)
Forgetting rate (long delay)#	2.61 (2.57)*	1.17 (1.54)	2.00 (2.43)*	3.32 (3.79)	2.61 (1.79)	1.61 (1.75)
CAMPROMPT–CV (total score) (0 – 36)	24.06 (4.40)*	28.89 (4.13)	20.53 (4.10)*	24.53 (4.34)	20.78 (7.27)	21.94 (6.45)
FAB (0 – 15)	12.89 (1.88)	13.78 (1.44)	13.37 (1.17)*	14.05 (0.97)	12.50 (1.95)	12.83 (1.38)

WFT–CV	25.83 (7.19)*	29.78 (7.37)	25.95 (8.05)*	30.11 (7.48)	23.39 (6.67)	23.78 (7.33)
CTT						
Trail 1 (seconds)#	91.11 (44.83)*	78.94 (41.03)	88.89 (50.30)	75.95 (26.52)	107.61 (47.06)	105.39 (49.76)
Trail 2 (seconds)#	180.61 (117.12)	171.50 (80.77)	210.68 (143.51)	170.47 (101.91)	227.72 (108.26)	213.83 (116.95)
CIQ–CV (0 – 29)	14.37 (4.24)*	17.04 (4.24)	13.93 (1.17)	13.95 (3.60)	11.72 (3.92)	12.12 (3.81)
Self efficacy questionnaire (0 – 100)	65.44 (20.52)*	87.28 (13.39)	62.47 (18.08)*	76.84 (10.69)	67.83 (15.62)	68.83 (14.36)

Table 5b. Pre-test and post-test result of real life behavioral test, PM related cognitive performance and self efficacy outcome measures in three groups

Key: * - within group difference by paired t-test with significant level $p<0.05$

- the smaller the score the better the performance

Real life behavioral PM test assesses the performance of PM in a real life situation. It contains three event-based PM tasks and two time-based PM tasks. Each task carries five marks. Full mark for event-based tasks scores is 15, full mark for time-based tasks score is 10. Full mark for ongoing tasks is 1. It is calculated by the following formula: (No. of correct items minus No. of wrong items)/ No. of total items.

In HKLLT, the high the score in learning slope means the more words subjects recalled across learning trials. The smaller the score in forgetting rate means the fewer words subjects forgot in delay trials compared with the last learning trial.

In CAMPROMPT–CV, the full mark is 36.

In FAB, the full mark is 15.

In WFT–CV, the higher the score means the more words a subject can produce in one minute.

In CTT trials, the higher the score means the slower the subject finished the tasks.

In CIQ–CV, the full mark is 29; In self efficacy questionnaire, the full mark for ongoing tasks is 100. The higher the score means the better the self efficacy in performing PM tasks.

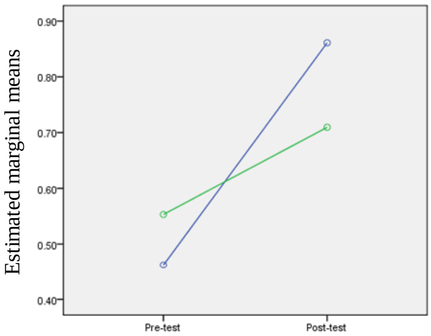

Figure 8a. Group interaction effect for immediate recall of PM tasks

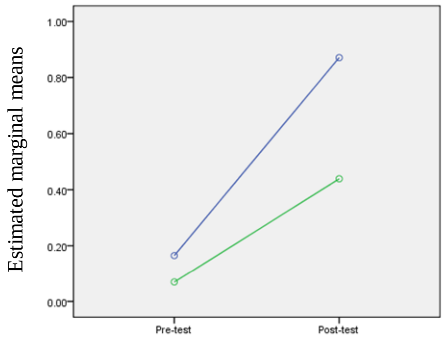

Figure 8b. Group interaction effect for accuracy of time-based PM tasks

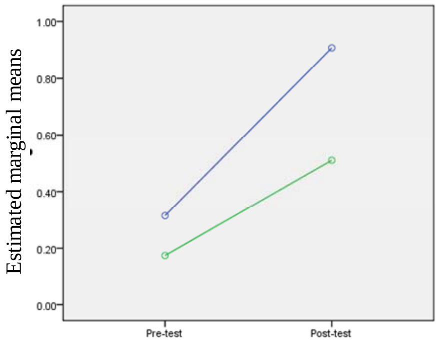

Figure 8c. Group interaction effect for accuracy of event-based tasks

Treatment group

IVRPM group
VRPM group

Figure 8a–c. VR-based assessment items with significant group interaction effect in IVRPM and VRPM group.

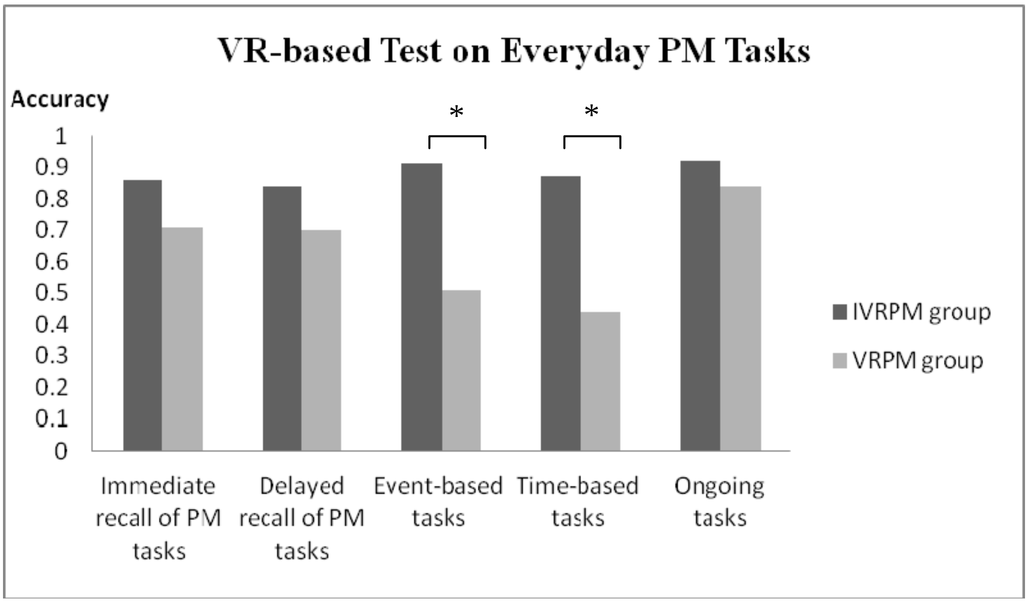

Figure 9. Post-hoc Bonferroni t-test in post-test score of VR-based test on everyday PM tasks

* - significant between group difference

6.3. Training effect of the IVRPM and VRPM training programmes in a real environment

In the real life behavioral PM test, all three groups (IVRPM, VRPM and the control group) had to perform the same PM tasks in a real environment. Their performances in executing time-based tasks, event-based PM tasks and ongoing tasks were recorded. Table 5b shows the results of the three groups in the test. Repeated measures of ANOVA indicated significant within-subject improvement in both time-based [$F(2,53) = 23.64$, $p<0.001$, effect size = 0.31, power = 1.00] and event-based tasks performance [$F(2,53) = 17.75$, $p<0.001$, effect size = 0.27, power = 0.99]. Both time-based [$F(2,53) = 5.25$, $p<0.01$, effect size = 0.17, power = 0.81] and event-based task results [$F(2,53) = 12.11$, $p<0.001$, effect size = 0.31, power = 0.99] showed significant group interaction effect (Figure 10a , b). This means that the three groups performed in different patterns.

Univariate analysis showed no significant difference in pre-test results in all real life behavioral PM test items. Based on the analysis of post-hoc Bonferroni t-test, on time-based tasks performace, the IVRPM group performed significantly better than the VRPM group ($p<0.05$) and the control group ($p<0.001$), but no difference was found between VRPM and control group. For event-based tasks, both the IVRPM group and the VRPM group performed significantly better than the control group ($p<0.05$). No significant difference was found between the IVRPM and VRPM groups (Figure 11). No significant change was observed in ongoing task performance.

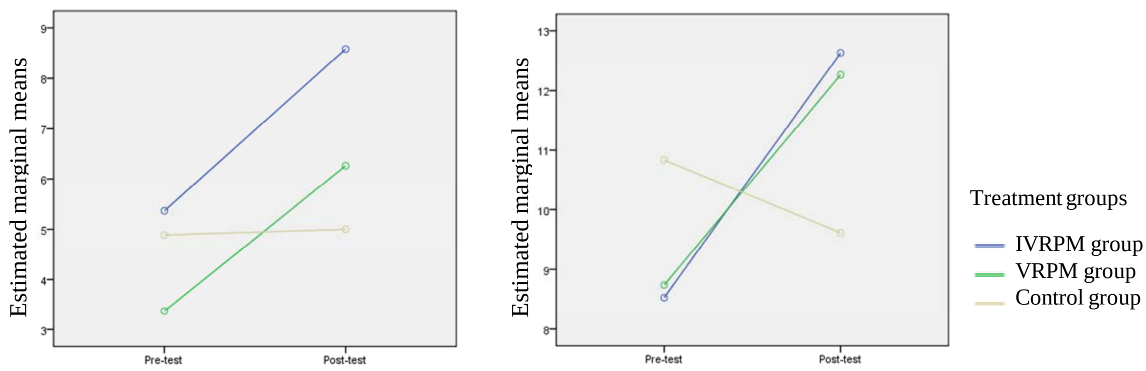

Figure 10a. Group interaction effect for accuracy of time-based PM tasks

Figure 10b. Group interaction effect for accuracy of event-based tasks

Figure 10a, b. Real life behavioral PM test items with significant group interaction effect among the IVRPM group, the VRPM group and the control group

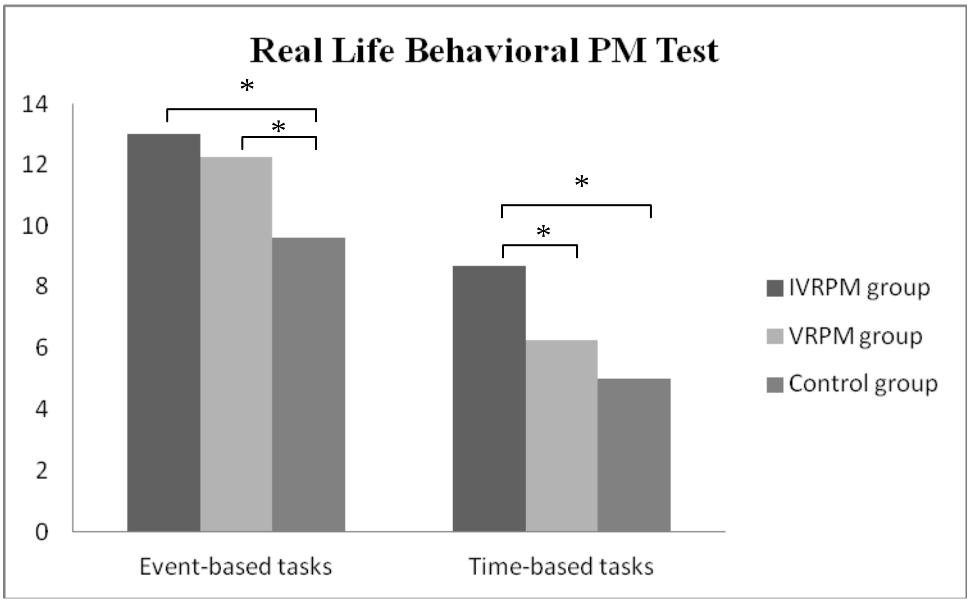

Figure 11. Post-hoc Bonferroni t-test in post-test score of real life behavioral PM test

* - significant between group difference ($p<0.05$)

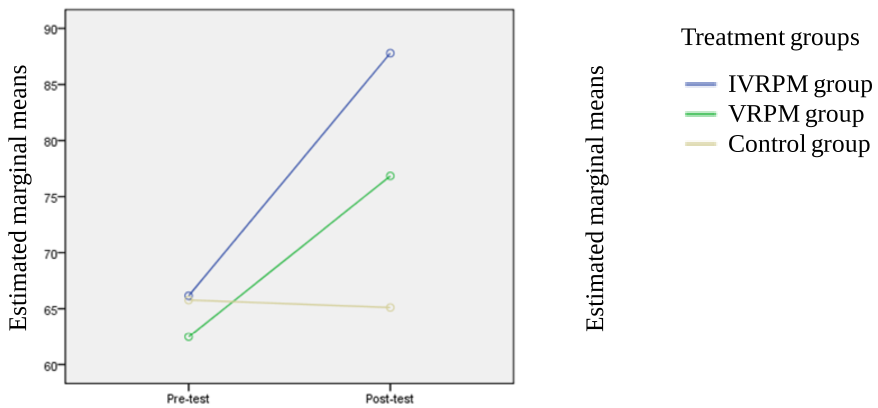

Figure 12. Group interaction effect for self efficacy questionnaire

Figure 12. PM related outcome measures with significant group interaction effect among IVRPM group, VRPM group and control group (only self efficacy questionnaire showed significant group interaction)

6.4. Training effect of the IVRPM and VRPM training programmes in other PM related outcome measures

For other standardized assessments which documented the cognitive profile of subjects, only the CAMPROMPT total score [$F(2,53) = 21.73$, $p<0.001$, effect size = 0.29, power = 1.00], FAB [$F(2,53) = 6.43$, $p=0.014$, effect size = 0.11, power = 0.70] and WFT–CV [$F(2,53) = 11.16$, $p<0.01$, effect size = 0.17, power = 0.91], showed significant within-group improvement.

Finally, the self efficacy questionnaire also showed significant improvement [$F(2,53) = 48.37$, $p<0.001$, effect size = 0.48, power = 1.00]. No significant difference was found in HKLLT, CTT or CIQ–CV. Within these outcome measures with significant difference, only self efficacy showed significant group interaction [$F(2,53) = 3.97$, $p<0.001$, effect size = 0.36, power = 1.00] (Figure 12). Based on the analysis of post-hoc Bonferroni t-test, first of all, no significant result was found in all pre-test outcome measures. Analysis of post-test results indicated that the IVRPM group performed significantly better in CAMPROMPT than the VRPM group ($p<0.05$) and the control group ($p<0.001$) (Figure 13).

Both the IVRPM group and the VRPM group performed significantly better than the control group in WFT–CV ($p<0.05$), but only the VRPM group performed significantly better than the control group in FAB ($p<0.05$) (Figure 14), and the performance of the IVRPM group was significantly better than the control group in CIQ–CV ($p<0.01$) (Figure 15). Finally, both the IVRPM group and the VRPM group scored significantly better than the control group in the self efficacy questionnaire ($p<0.001$ and $p<0.05$ respectively) and the IVRPM group scored marginally, but still significantly, better than the VRPM group ($p=0.054$) (Figure 16).

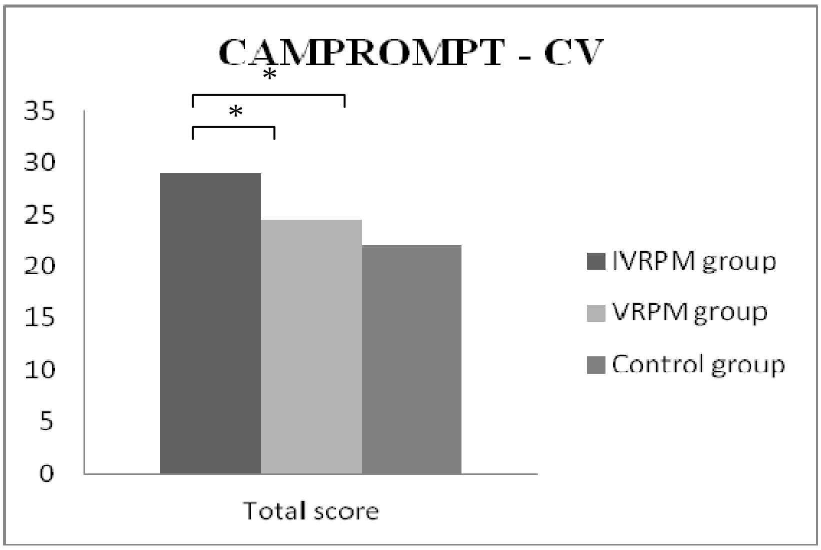

Figure 13. Post-hoc Bonferroni t-test in post-test score of CAMPROMPT–CV (Total score)

* - significant between group difference ($p<0.05$)

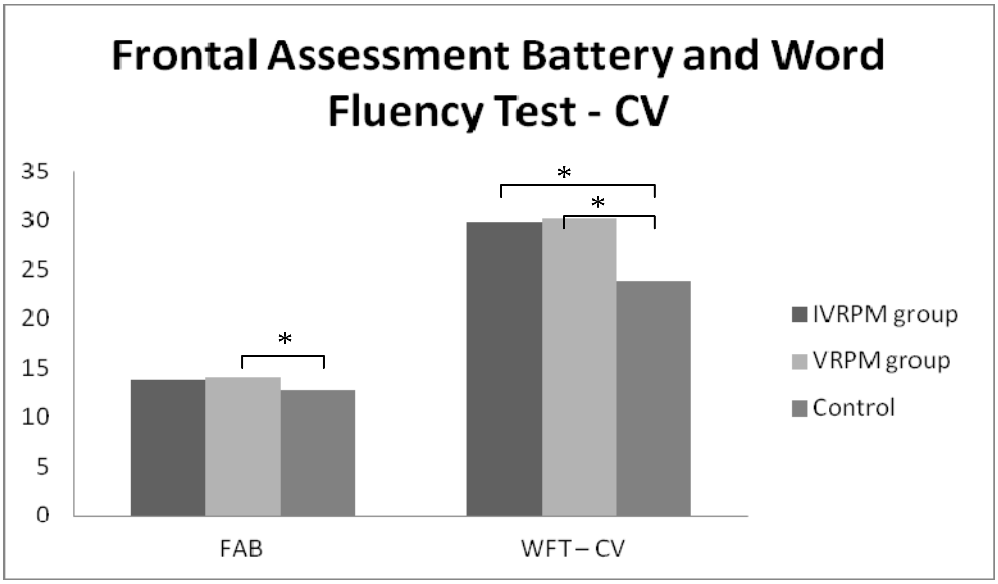

Figure 14. Post-hoc Bonferroni t-test in post-test score of FAB and WFT–CV

* - significant between-group difference ($p < 0.05$)

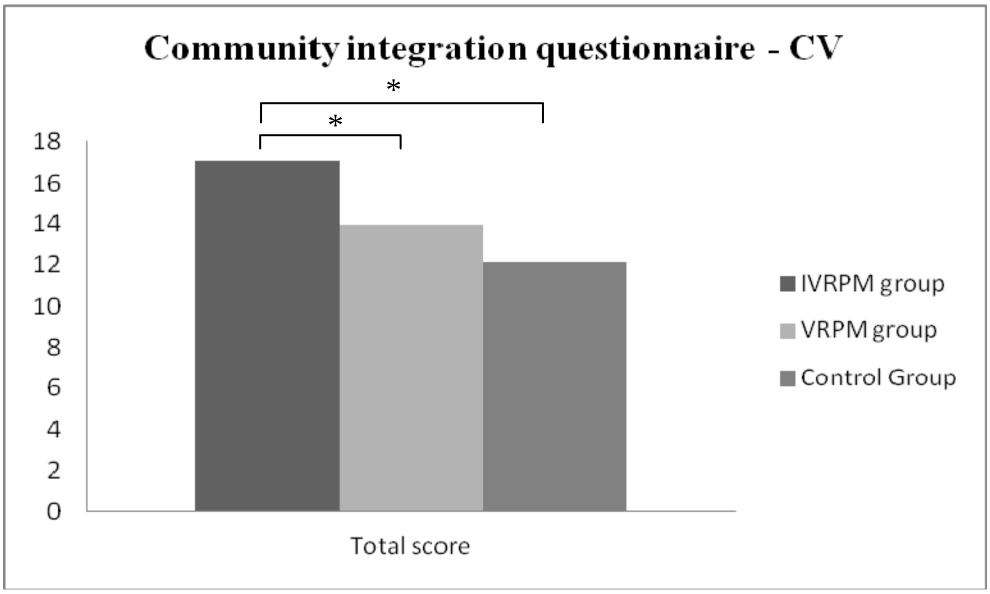

Figure 15. Post-hoc Bonferroni t-test in post-test score of CIQ–CV

* - significant between-group difference ($p< 0.05$)

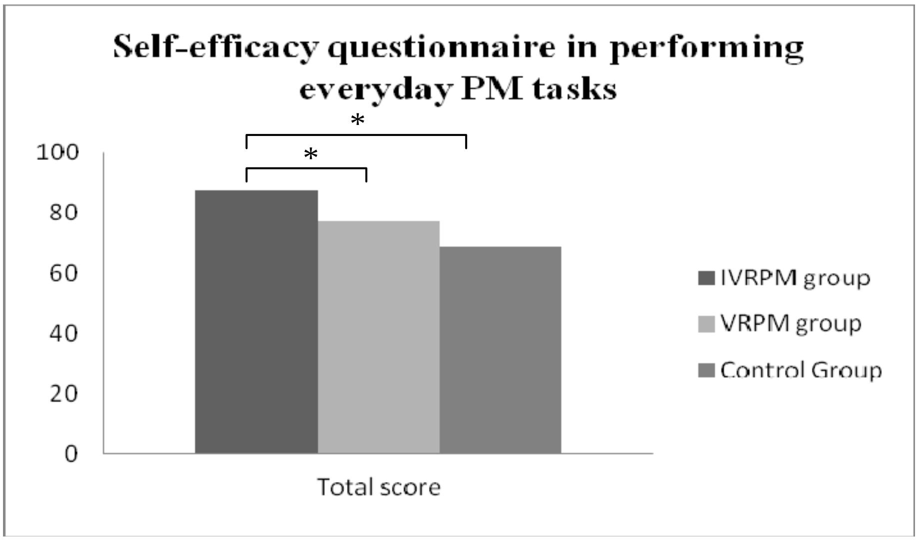

Figure 16. Post-hoc Bonferroni t-test in post-test score of self efficacy questionnaire in performing everyday PM tasks

* - significant between-group difference ($p < 0.05$)

6.5. Correlation of outcome measures

In order to collect additional information about the relationship between different outcomes, correlation analysis was conducted on the test items with significant improvements (Tables 5a & 5b). Items in the IVRPM group and the VRPM group were analyzed separately.

Firstly, the correlation between the VR-based test on everyday PM tasks and the real life behavioral PM test was conducted. In the IVRPM group (Tables 6a & 6b), the accuracy of time-based PM tasks in the real life behavioral test correlated with time-based PM tasks accuracy ($r=0.64$, $p<0.01$), event-based PM tasks accuracy

($r=0.56$, $p<0.05$) and total time lapsed ($r=-0.67$, $p<0.01$) in the VR-based test. No significant correlation was found between event-based PM tasks in the real life test and test items in the VR-based test. Within the VR-based test, delayed recall of PM tasks was significantly correlated with immediate recall of PM tasks ($r=0.64$, $p<0.01$), accuracy of time-based PM tasks ($r=0.64$ $p<0.01$) and total time lapse ($r=-0.75$, $p<0.01$). Accuracy of time-based PM tasks was significantly correlated with event-based tasks accuracy ($r=0.52$, $p<0.05$) and total time lapsed ($r=-0.76$, $p<0.01$). Finally, accuracy of event-based tasks was significantly correlated with total time lapsed ($r=-0.67$, $p<0.01$).

For the VRPM group (Table 7), the accuracy of event-based PM tasks in the real life behavioral test correlated with three test items in the VR-based test, including the accuracy of event-based ($r=0.58$, $p<0.01$), time-based ($r=0.48$, $p<0.05$) and ongoing tasks ($r=0.52$, $p<0.05$), while the accuracy of time-based PM tasks of the two tests were moderately correlated with each other ($r=0.55$, $p<0.05$). Significant correlation was found within VR-based tests. The correlated pairs were; accuracy of event-based tasks and time-based tasks ($r=0.63$, $p<0.01$), accuracy of event-based PM tasks and ongoing tasks ($r=0.49$, $p<0.05$), and finally, accuracy of time-based tasks and number of time checking behavior ($r=0.61$, $p<0.01$). They were all found to be moderately correlated with each other. No significant correlation was found within real life behavioral assessment on PM tasks test items.

The correlations between some significant outcome measures and the VR-based test and also the real life behavioral assessment were analyzed, too. In the IVRPM group (Table 8), WFT–CV was significantly correlated with total time checking in the VR-based test ($r = 0.50$, $p<0.05$). CIQ–CV was significantly correlated with the accuracy of time-based PM tasks in the real life behavioral test ($r = 0.73$, $p<0.01$), delayed recall of PM tasks ($r = 0.54$, $p<0.05$) and total time lapsed ($r = -0.57$, $p<0.05$) in the VR-based test. No other significant correlation was found between cognitive outcome measures and PM performance tests in the VRPM group.

		Real life behavioral PM test	
		Accuracy of event-based tasks	Accuracy of time-based tasks
Real life behavioral PM test	Accuracy of event-based tasks		0.16
	Accuracy of time-based tasks	0.16	
VR-based test on everyday PM tasks	Immediate recall of PM tasks	-0.19	0.18
	Delay recall of PM tasks	-0.04	0.45
	Accuracy of time-based tasks	0.17	0.64**
	Accuracy of event-based tasks	0.00	0.56*
	Accuracy of ongoing tasks	-0.08	0.14
	Total time lapsed	-0.16	-0.67**
	No. of time checking	0.04	0.17

* - Pearson correlation with significant level at p<0.05 ** - Pearson correlation with significant level at p<0.01

Table 6a. Pearson correlation between VR-based test on everyday PM tasks and real life behavioral PM test of the IVRPM group

		VR-based test on everyday PM tasks						
		Immediate recall of PM tasks	Delay recall of PM tasks	Accuracy of time-based tasks	Accuracy of event-based tasks	Accuracy of ongoing tasks	Total time lapsed	No. of time checking
Real life behavioral PM test	Accuracy of event-based tasks	-0.19	-0.04	0.17	0.00	-0.78	-0.16	0.04
	Accuracy of time-based tasks	0.18	0.45	0.64**	0.56*	0.14	-0.67**	0.17
VR-based test on everyday PM tasks	Immediate recall of PM tasks		0.64**	0.45	0.30	0.30	-0.42	-0.28
	Delay recall of PM tasks			0.64**	0.38	0.42	-0.75**	-0.31
	Accuracy of time-based tasks				0.52*	0.04	-0.76**	0.07
	Accuracy of event-based tasks					0.42	-0.67**	0.03
	Accuracy of ongoing tasks						-0.27	-0.45
	Total time lapsed							0.02
	No. of time checking							

* - Pearson correlation with significant level at p<0.05 ** - Pearson correlation with significant level at p<0.01

Table 6b. Pearson correlation between VR-based test on everyday PM tasks and real life behavioral PM test of the IVRPM group

		Real life behavioral PM test		VR-based test on everyday PM tasks				
		Accuracy of event-based tasks	Accuracy of time-based tasks	Immediate recall of PM tasks	Accuracy of time-based tasks	Accuracy of event-based tasks	Accuracy of ongoing tasks	No. of time checking
Real life behavioral PM test	Accuracy of event-based tasks		0.43	-0.14	0.48*	0.58**	0.52*	0.06
	Accuracy of time-based tasks			0.13	0.55*	0.42	0.21	0.23
VR-based test on everyday PM tasks	Immediate recall of PM tasks				0.09	-0.12	-0.06	-0.36
	Accuracy of time-based tasks					0.63**	0.36	0.61**
	Accuracy of event-based tasks						0.49*	0.44
	Accuracy of ongoing tasks							0.16
	No. of time checking							

* - Pearson correlation with significant level at p<0.05   ** - Pearson correlation with significant level at p<0.01

Table 7. Pearson correlation between VR-based test on everyday PM tasks and real life behavioral PM test of the VRPM group

	Real life behavioral PM test		VR-based test on everyday PM tasks						
	Accuracy of event-based tasks	Accuracy of time-based tasks	Immediate recall of PM tasks	Delay recall of PM tasks	Accuracy of time-based tasks	Accuracy of event-based tasks	Accuracy of ongoing tasks	Total time lapsed	No. of time checking
HKLLT – Forgetting (long delay)	-0.29	-0.13	-0.24	0.05	-0.18	0.12	0.226	-0.04	0.26
WFT–CV	-0.02	0.25	0.26	0.41	0.28	0.08	0.20	-0.35	-0.50*
CTT – trail 1	0.20	-0.28	-0.41	-0.42	-0.38	0.07	0.05	0.39	0.14
CIQ–CV	-0.05	0.73**	0.43	0.54*	0.42	0.39	0.15	-0.57*	-0.13
Self efficacy questionnaire	0.30	0.24	0.16	0.09	0.07	-0.26	-0.29	0.00	0.40

* - Pearson correlation with significant level at p<0.05 ** - Pearson correlation with significant level at p<0.01

Table 8. Pearson correlation between PM performance tests and other PM related outcome measures of the IVRPM group

Chapter 7

Discussion

As reported in chapter 6, 55 subjects were randomly assigned to one of three groups: the IVRPM group, the VRPM group and the control group. Subjects were provided with 10 sessions of corresponding training programme. For control group, no structured cognitive training was given. Provided that all subjects were living in the community, it was assumed that they have similar exposure to environmental stimulation. No significant baseline differences were found in the subjects' demographic data (age, time since injury and education level), cognitive profile as reflected in MMSE–CV and TONI 3, and level of self-awareness towards their deficits. From the results of the three screening tests (Table 4), the subjects had "average" to "below average" level of intelligence, full self-awareness of their own deficits and did not show significant cognitive impairments. The pretest results of CAMPROMPT–CV (Table 5b) showed that subjects in all three groups showed mild impairment in their PM functioning (also see Section 5.2.3.1 for a detailed description of the screening tests) and were suitable to receive PM training. They realized that they had memory difficulties, but they were able to learn from the novel PM training strategy. But out of expectation, the number of subjects who suffered from stroke was much more than subjects suffered from TBI. As there were only three recruitment sites and due to the time constrain in the study period, it was difficult to recruit similar number of subjects with TBI.

The subsequent discussion is organized and presented by following the flow of the structural model and the process model developed in the present study.

7.1. Training effectiveness of IVRPM and VRPM training programme in PM functioning

The aim of the present study was to investigate the training effectiveness of the innovative IVRPM and VRPM training programmes. One of the key outcome measures in the present study was the PM performance in a virtual environment. As shown in the IVRPM rehabilitation model (structural model) (Section 3.2.1) the training contents were manipulated and delivered within the virtual training environment. The training effects should be directly reflected in the virtual environment. Therefore, it was assumed that if the subjects were able to learn from the IVRPM or VRPM training programme, their performance should be reflected in the VR-based test. The improvement in real environment and self efficacy originated from the effect of the virtual training environment. If the training effect in the virtual environment cannot be proven, the training effects of related outcome measures cannot be established. The results in the VR-based test were found to be satisfactory. Test items showed similar significant improvements in the IVRPM group and the VRPM group (except the delay recall of PM tasks and total time lapsed; see Table 5a).

The IVRPM and VRPM training programmes were designed to tackle difficulties in the PM processes. Acquisition and retention of intention, initiation and execution of intended action were the focus of the training programmes, as these processes were found to be most difficult for people with ABI (Kliege, Eschen & Thone-Otto, 2004; Roche, et al, 2007). The improvement in PM performance may indicate that changes would have happened in these underlying processes.

7.1.1. Acquisition and retention of PM intentions

The probability of successfully recalling a PM intention depends greatly on the association between cues and intended actions (Knight, Harnett & Titov, 2005). If ABI subjects could not remember what they were required to do in the very beginning, it would not be surprising that they could not remember when to execute it (Brook et al., 2004). Therefore remembering PM intention was very important for their successful PM performance. In the present study, the ability of a subject to remember

PM intention was documented in two dimensions; immediate recall and delayed recall.

For immediate recall, subjects were asked about the PM tasks right after briefing on the tasks required. This reflected the subjects’ ability to encode cue and target actions during the briefing session. For delayed recall, the requirement of these PM tasks was asked again after the training was completed. According to the theory proposed by Ellis (1996), the delayed recall was beyond the five phases of PM. But this was still worth noting as it reflected how long and how completely the subject could retain the PM intentions.

Table 5a shows that the IVRPM group showed significant improvement in both immediate and delayed recall of PM tasks, while the VRPM group only improved in immediate recall. These findings suggest that subjects in the IVRPM group not only hold the PM intention better in capacity, but also longer in duration.

Another interesting observation was that during the assessment session, it was found that many subjects in the VRPM group had forgotten the PM tasks in the delayed PM tasks assessment even though they could perform the tasks successfully in the training session. Many of them had chosen an answer with a correct PM cue, but the intention was wrong. This may suggest that the cue–intention connection decays with time. The strength of the cue–intention connection was stronger in the IVRPM group, and therefore more resistant to decay. The significant correlation between accuracy in immediate recall and delayed recall of PM tasks in the IVRPM group but not in the VRPM group may also be in line with this assumption. Further study would be worthwhile.

7.1.2. Execution of PM intentions

Remembering the PM intention is important for performance, and it was expected that the accuracy of time-based and event-based PM performance would improve together with immediate recall of PM tasks. The results confirmed this. Both treatment groups demonstrated a significant within-group improvement in the accuracy of performance of event-based and time-based PM tasks (Table 5a). With the better performance in immediate recall performance in the IVRPM group, they performed significantly better in both accuracy of event-based and time-based PM tasks execution than the VRPM group (Figure 9).

Besides accuracy of execution, the performance of PM could also be reflected by the effectiveness of execution, the time that elapsed in performing all the required PM tasks. Although time-based tasks had a fixed performing period, it was observed that subjects with poor performance always spent more time in figuring out what needed to be done even though the time to perform the task had already passed. Only the IVRPM group showed a significant improvement in total time lapsed in the VR-based PM test (Table 5a). Furthermore, the total time lapsed in the IVRPM group showed significant negative correlation with both time-based and event-based performance. This means that subjects in the IVRPM group should have improved both in accuracy and efficiency.

Improvement in PM performance was also reflected in the standardized PM assessment, CAMPROMPT–CV. Participants in both the IVRPM and VRPM groups performed significantly better after training. The IVRPM group showed significantly better results than the VRPM group and the control group.

7.1.3. Time monitoring behavior during PM performance

Some studies had pointed out the relationship between time-based PM performance and frequency of time checking. Although there were some variations across studies, the conclusion was quite similar. Mantyla, Carelli and Forman (2007) stated that in normal adults, performance of time-based PM was significantly related to updating and inhibition performance but not monitoring frequency, as monitoring frequency may be affected by developmental effects, bias and the acceptance of using an external time-keeping device. In the study of Shum, Valentine and Cutmore (1999), both people with TBI and normal control showed a significant relationship between performance of a time-based PM task and time monitoring frequency but only in the interval closest to the target time. Despite the significant relationship, the difference in the frequency and pattern of time monitoring between people with TBI and control subjects was not significant. Shum and colleagues (1999) concluded that the worse performance in people with TBI in time-based PM tasks could not be explained by time monitoring behavior. It may be due to the poor estimation of the passage of time instead.

In the present study, the relationship between time monitoring behavior and time-based PM performance could not be established, too. Firstly, in spite of the fact that both the IVRPM and VRPM groups showed significant improvement in frequency of time checking and performance in time-based PM tasks, a significant correlation between the frequency of time checking behavior and the accuracy of time-based PM tasks (in VR-based tests) was only established in the VRPM group, and not in the IVRPM group. Secondly, the IVRPM group showed significantly better results in time-based PM performance, and the frequency of time checking did not show significant difference with VRPM group. Thirdly, during the training and assessment period, it was observed that different subjects had different time checking behaviors. For those who could correctly execute the time-based tasks, some checked the time frequently when approaching the target time, while some only checked a few times. The results and observations support that the performance in time-based performance cannot simply be explained by time checking behavior.

7.1.4. Training effect on PM related cognitive functions

The process approach (Bracy, 1983) was adopted in the development of the IVRPM rehabilitation model. RM and inhibition support PM functioning (Burgess, Quayle & Frith, 2001; Kinch & McDonald, 2001). Therefore, the training of these two cognitive functions was integrated in the training programmes. Moreover, many studies have shown that VR-based rehabilitation can activate related neural structures. Astur and colleagues (2005) demonstrated the activation of the hippocampus under functional imaging during virtual navigation. Cortical reorganization in stroke patients was found in the primary sensorimotor cortex under fMRI examination in Jang and colleagues' (2005) VR-based motor training study. Therefore, RM and inhibition abilities may benefit from the two PM training programmes. Results from the present study support this. Although no fRMI measuring was done, performance gained in frontal lobe functioning (as reflected by WFT–CV and FAB) in the IVRPM and VRPM groups might indicate the activation of related neural functioning after VR-based PM training as frontal lobe functioning (Burgess, Quayle & Frith, 2001) and semantic fluency (Groot et al., 2002; Knight, Harnett & Titov, 2005) were found to support PM performance.

Although frontal lobe functioning (as reflected in WFT–CV and FAB) improved, it was quite surprising that the subjects' RM functioning did not show significant improvement as expected. As indicated before, RM is an important component in successful PM. Only forgetting rate (long delay) in HKLLT in the IVRPM group was in coherence with the significant improvement in delayed recall of PM tasks in the VR-based PM test. Other testing components in the verbal learning test HKLLT–CV did not show any sign of improvement, no matter on the rate of learning or the rate of forgetting. Differences in the nature of the recall tests in the VR-based test and the verbal learning test may account for the phenomenon. The recall test in the VR-based test contained a visual component, which may aid ABI subjects in the encoding and recalling processes. Moreover, they could repeat the verbal instruction or read the written instruction as many times as they wished. They proceeded to the immediate recall test once they felt confident, but the word list in HKLLT–CV could only be read once.

7.2. Training effectiveness of IVRPM and VRPM training programme in other outcome measures

7.2.1. Generalization of training effects to real environment

The generalization effect in VR-based training and rehabilitation is widely documented (Brook & Rose, 2003; Lam, Tam, Man & Hui-Chan, 2003; Yip & Man, 2009). Some studies have pointed out that the best method for documenting the generalization power was the calculation of the transfer efficiency ratio (TER) (Chou & Handa, 2006). TER means *"the ratio of how much time spent learning on the simulator was equivalent to time spent learning on the real task"* (Torkington, Smith, Rees & Darzi, 2001). But the use of TER may encounter several methodological difficulties. First, the development of a VR-based training programme as it was not feasible to perform real life training on people with brain injury, especially when they were not yet ready and lacked confidence. Therefore it was difficult to establish a real life training group for comparison purposes. Secondly, there is no standard TER score established so far which was regarded as desirable. Although TER > 0.5 is used as a guideline in the flight industry (Chou & Handa, 2006; Munz, Kumar, Moorthy, Bann & Darzi, 2004), it may not be appropriate to the medical or rehabilitation field.

In this study, the performance in a real life behavioral assessment of PM could provide some information about the transfer of learnt skills to a real setting. In the real life behavioral assessment, subjects were brought to a real life situation and performed tasks which were very similar to those they had performed in the training and VR-based tests. As all the subjects were living in the community and there was no significant difference in their pre-test CIQ–CV score, it was assumed that they had similar exposure to the community. Furthermore, they all had stated they did not receive any structured memory training or any form of VR training. It was thus assumed that the improvement in real life behavioral assessment in PM could be mainly due to the transfer effects of the IVRPM or VRPM training programme.

Both the IVRPM and VRPM groups showed significant improvement in accuracy of event-based and time-based PM tasks in a real life behavioral assessment, but not the control group (Table 5b). The results suggest that both treatment groups showed good generalization effects.

The investigation of the correlation between the VR-based test and real life behavioral assessment would provide further information about the transfer of training effects. Significant correlations were found between corresponding accuracy scores. In the IVRPM group, performance of time-based PM tasks was significantly correlated between the virtual and real life PM test ($r=0.64$, $p=0.004$), while in the VRPM group, both accuracy in performing time-based ($r=0.55$, $p=0.015$) and event-based PM tasks ($r=0.58$, $p=0.01$) correlated significantly. As no significant correlation was found in the event-based PM tasks between two PM tests in the IVRPM group ($r=0.00$, $p=1.00$), thorough investigation of the results of individual subjects was done. It was discovered that most of the subjects in the group gained full marks in event-based tasks in VR-based PM test. The ceiling effect in the VR-based test might explain why the correlation between two tests could not be established. The close relationship between virtual and real life PM tests may again reflect the high transfer of training effect from the virtual to the real environment.

In the IVRPM rehabilitation model, the CL approach (Gordon, Cantor, Ashman & Brown, 2006) was adopted. Therefore, training took place in a situation which was highly related to subjects' daily living, a shopping scenario, instead of focusing on isolated cognitive abilities. By using VR technology, the shopping environment can be simulated. Subjects can have a feeling of “presence” in that shopping environment and perform shopping tasks as they would usually do it in a real life situation. As both the IVRPM group and the VRPM group shared the same virtual environment and training scenarios, it is not surprising that the generalization effect appeared in both treatment groups. However, with the same training duration, the IVRPM group performed better in both the virtual and real life environments than the VRPM group. This may suggest that the IVRPM training programme offered a better generalization effect.

7.2.2. Self efficacy in performing everyday PM tasks and community participation

Both the IVRPM group and the VRPM group showed significant improvement in self efficacy score in the self efficacy questionnaire, while the IVRPM group had significantly better results than the VRPM group and control group. This result supported the characteristics of the IVRPM training programme. In the IVRPM training programme, the major advantage was its AI component. The AI component detected the weakness of each subject and provided only the necessary training. On the other hand, it gave each participant suitable challenges to avoid boredom while not being so difficult as to create sense of failure. The training difficulty was on the appropriate level to bring optimal learning environment. In the VRPM group, all training content was fixed in the training programme. Even when the participants might fail to catch up with the progress, they were forced to proceed to the next level of difficulty. This may affect subjects' self efficacy as they may not gain a sense of achievement or may even have a feeling of being unable to manage the execution of PM tasks during the training. Therefore, the self efficacy score in the VRPM group was significantly lower than the IVRPM group.

Finally, the IVRPM group also performed significantly better in the CIQ–CV total score than the VRPM and control group. Besides the significant improvement in the IVRPM group, the total score also showed a significant relationship with accuracy of time-based PM tasks in the real life behavioral test, delayed recall of PM tasks and total time lapse in the VR-based PM test. In other words, time-based PM task, duration of PM intention and the efficiency in performing the PM tasks may be important factors contributing to successful community participation.

CIQ-CV was documenting the number and types of activities related to family, social and work a subject performed in the past month. The improvement in CIQ-CV score indicated that subjects were participating more in these aspects. It was suggested that the improvement in CIQ-CV score was firstly due to the improvement in PM functioning. Subjects performed more accurate and efficient in PM tasks. With the input of VR, learnt skills were able to generalize to real environment. Furthermore, subjects’ self efficacy was boost up through the strength of AI in providing suitable training content and level of difficulty. Therefore, Subjects were more willing to go out and had more activities in the community.

7.3. Understanding of the difference between IVRPM and VRPM training programmes

7.3.1. The contribution of AI system in effectiveness of IVRPM training programme

It was anticipated that better performance in PM would be achieved by the AI system embedded in the IVRPM training programme. The role of the AI system was to detect if subjects had difficulties in RM or inhibition through analyzing the captured behaviors. Related training would be only offered to subjects in need. Through this "capture-analysis-adjust" process, training content in the programme would match the needs of each individual subject. Without wasting time in practicing what they were already performing well, their efforts could be focused on practicing what showed difficulty. When the AI system detected that a user had attained a certain level in RM and inhibition, the training would focus back on PM training.

Next, for those who did not progress well in the IVRPM training, besides the identification of RM and inhibition problems, the AI system would reduce the level of difficulty in the PM training component. Not only number of PM tasks (both time-based and event-based) would be adjusted, but also the demands of ongoing tasks. It has been documented that both ongoing tasks and PM tasks demand cognitive resources from a limited capacity and so changes of difficulty in either types of tasks would affect the performance of the others (McNerney & West, 2007; Smith, 2003). Therefore, appropriate reduction of the cognitive demand in PM tasks and ongoing tasks can facilitate subjects successfully achieving the training requirement. The AI system can achieve this through adjusting the number of event-based and time-based PM tasks and number of shopping items in each of the training sessions. Furthermore, the AI system can also determine the suitable level of assistance such that when subjects encountered difficulty in the training, appropriate cues could be given. This additional support could possible done through analyzing the subject's behavior in the training.

From the evidence presented so far, subjects in the IVRPM group gained better ability in PM and this was reflected in all PM assessments, whether in a virtual or in a real environment, and by means of a standardized assessment. They also gained higher self efficacy and improved community participation. In related cognitive abilities performance, they improved similarly with VRPM group participants. These results matched the characteristics and the theoretical framework of the IVRPM training programme. In order to provide further evidence for the contribution of the AI system, it is worthwhile to investigate the ability to detect the subjects' difficulties in RM and frontal lobe functioning and provide corresponding training. As the sample size was too small for parametric analysis, a non-parametric Mann Whitney U test was conducted to investigate if the subjects who received RM training and inhibition training in the IVRPM programme were those with significantly poorer RM and frontal lobe functioning than those who did not receive the training. Their pre-test performance in HKLLT (learning slope, forgetting rate (short delay and long delay)) and VR-based test on everyday PM tasks (immediate and delayed recall in PM tasks results) were compared between subjects who received RM training and those who did not. The pre-test performance of WFT–CV and FAB were compared between subjects who received inhibition training and those who did not.

Among 18 subjects who received IVRPM training, 12 subjects were identified to have RM difficulties by the AI system and they received RM training. Three subjects were identified to have inhibition difficulties by the AI system and they received inhibition training. Six subjects received neither RM training nor inhibition training. The Mann Whitney U test showed that subjects who received RM training performed significantly worse in delayed recall in PM tasks than those did not receive RM training ($p<0.05$), while subjects who received inhibition training were those who performed significantly worse in FAB ($p<0.01$). It should be noted that delayed recall of PM tasks was one of the criteria which contributed to the activation of RM training in the AI system. There is no doubt that delayed recall of PM tasks showed significant differences between subjects who received RM training to those who did not. As explained in the previous section, HKLLT is not able to reflect the nature of RM training in the present study. Therefore, it is not surprising that there was no significant difference between results in HKLLT. But FAB is a global frontal lobe functioning test. The significant difference between subjects who had received and not received inhibition training suggested that the AI system was able to pick up those subjects who demonstrated difficulties in frontal lobe functioning and thus were provided with suitable treatment.

7.3.2. Summary of the difference between training effectiveness of IVRPM training programme and VRPM training programme

In contrast with IVRPM training programme, RM and inhibition training was scheduled in every session in the VRPM training programme. This explains why the VRPM group had similar performance in RM and frontal lobe function performance to the IVRPM group. The boost up of PM performance in IVRPM training, might be the result of the optimal adjustments of training content and level of difficulty (which was set by AI). The significantly higher self efficacy demonstrated in the IVRPM group could also reflect that the training content and difficulty were appropriately chosen. In the IVRPM group, subjects' gained higher sense of success, they improved in self efficacy and were more motivated. If subjects can be motivated in a rehabilitation programme, their PM ability can be improved (Brooks et al., 2004). The more subjects were motivated, the more they improved in their ability. That formed a cycle in the improvement of self efficacy and PM performance in the IVRPM group. This also explains why the training effectiveness of the IVRPM group was much higher than the VRPM group.

Finally, another major difference between the two treatment groups was the level of community participation. Participants in IVRPM gained better skills together with higher self efficacy. They showed more confidence in performing community activities. It was discovered that "remember when to do a task" (time-based PM performance), "less forgetful" (delayed recall of PM tasks) and "effectiveness in performing PM tasks" (total time lapsed) were three major aspects correlated with community participation.

In short, the training effects of the both IVRPM and VRPM training programme were initially established. Subjects in both training programmes were able to learn and showed significant performance gain in PM functioning. But it should take note that for subjects who performed poorly in PM functioning and demonstrated significant deficits in RM and inhibition, there was no difference in receiving IVRPM or VRPM training programme at the beginning. This is because no matter which training programme they had received, all the PM, RM and inhibition training components would have been given anyway. Therefore, they were not considered to be the group of people who received most benefit from the AI-based training programme. On the other hand, for subjects located in the “middle of the spectrum”, the AI-based training programme could offer the most benefits. As they possessed a basic level of PM functioning (i.e. able to perform one to two PM tasks), but further increase of the PM functioning demand might expose the limitation in RM and inhibition. In this situation, the AI system could adjust the level of difficulty in PM training so as to provide a suitable amount of challenges. Furthermore, corresponding RM or inhibition training can be offered to further boost up the RM and inhibition abilities. Once the RM and inhibition abilities are no longer a limiting factor, the training can be resumed back to PM focus training. Although subjects who performed poorly in PM functioning and demonstrated significant deficits in RM and inhibition were not receiving the most benefit, the individualized gradation in training difficulty offered by the AI-based training programme still had advantages over a pre-determined programme structure.

7.4. Limitation of the present study

The present study faced several limitations in terms of programme design, rater and the research design.

1. The knowledge base is the most important part of the AI component in the present IVRPM training programme. It was contributed by a panel of experts, clinicians and academics. The significant improvements in subjects' performance may imply that the knowledge base was suitable for the recruited subjects. But in many AI systems, revisions through trials are needed to refine parameters in the knowledge base. The more the testing, the more accurate the AI can perform. Due to the constraints in time and budget, this test and revision process was skipped in the present study. This may limit the training effectiveness to the IVRPM training programme.
2. Other cognitive abilities were identified to be related to PM functioning, such as working memory (Kliegel & Jager, 2006). In the present study, only RM and inhibition were chosen to be the focus of training. The AI system was made to identify these two cognitive abilities and provide corresponding training. This may limit the training effectiveness of the programmes as subjects may have

other PM related cognitive impairments, other than RM and inhibition, and they were not directly tackled in present training.

3. Some of the outcome measures were tailor-made in the present study. The reliability and validity were not studied. Although there was only one rater in the study, bias may have resulted. Some of the outcome measures did not have a parallel version. A learning effect may happen within pre-test and post-test.
4. The subjects recruited in the present study were mainly people with CVA. Although significant training effects were shown, the differences in training effects between the subjects in terms of their types of ABI were not analyzed. In the present situation, it seemed that the results could be more applicable to people with CVA than TBI. Furthermore, subjects were recruited in only three rehabilitation settings. This would also reduce the power of generalization in target population.
5. The training programme structures for IVRPM group and VRPM group were different. In the VRPM group, every subject was receiving the same training content. While in the IVRPM training programme, the training contents were personalized for each subject. That meant each subject was receiving different training. Some had only received the PM training component, while some had received RM or inhibition training components and some had received all

training components in one training session. The results of the IVRPM group shown here was the overall performance of these subjects. As the training effectiveness of individual training component was not studied, it is difficult to say whether the training components provided by the IVRPM training programme provided most benefits to the subject who was receiving it.

6. From the results, reflected in standardized assessments and behavioral assessments, subjects' PM functioning was improved together with RM and frontal functioning. They were more confident with their PM functioning and more integrate into their community. But due to the time constrain in the study period, the how long did the training effect could last was not investigated by a follow up assessment. There was also lack of similar study to document the effect in this area, too. Therefore it is worthwhile to perform a follow up study to see if a booster course is needed to enhance the training effect.

7.5. Clinical implications

In the present study, the theoretical framework, methodology and possible application of AI and VR are presented. The findings support the effectiveness of both VR-based training and intelligent VR-based training in PM. Both had significant effect in elevating the functioning in PM and significant generalization to the real environment was observed. Besides this, the additional advantages brought by the incorporation of AI were also demonstrated. The successful development of the present IVRPM training programme may mark a milestone in the development of computer-assisted rehabilitation. Firstly, traditional session-based training with pre-programmed training content could be improved, in terms of training effectiveness and users' self efficacy, through the incorporation of AI technology. Secondly, as training effectiveness and the generalizing power is raised, that means it would take a shorter time to bring a significant training effect, which training effects is going to apply effectively in real environment. It may be a possible solution to reduce the burden and difficulties faced by patients, carers and the society. Therefore, further study is worthwhile to investigate the usability of the IVR model in other training contexts.

7.5.1. Possible applications of IVRPM programme

Commercialization or product development of the IVRPM training programme developed in present study is possible for the following reasons. From patients' point of view, it is widely agreed that people with ABI required long-term intensive rehabilitation. Many of them cannot afford long-term expenses in rehabilitation services, however. With the high training effectiveness of the IVR-based training programme, the rehabilitation period can be shortened, especially as training contents and grading of difficulties are automatically adjusted according to the patient's latest abilities. This can reduce the number of face-to-face rehabilitation sessions, in other word, reduce medical expenses. This also fits in the public healthcare point of view, the reduction of patients' rehabilitation period and increasing the duration between follow-ups means reduction on the pressure in service provision. To further enhance the usability of the training programme, the development of an online version is suggested. Therapists in healthcare centers can monitor patients' progress through the internet, or the programme can notify the therapist if any patient is not performing as expected. Therefore, follow-up sessions can be scheduled to those needing them most. This also helps to improve service delivery.

7.5.2. Possible applications of IVR model to other training focuses

From the evidence gathered in the pilot study and the main study, the training areas which may benefit most from AI and VR technology are those everyday functional tasks which are supported by multiple basic cognitive functions. The community living tasks involved in the pilot study, such as community orientation, using public transport and shopping, are possible applications. From the results in the pilot study, besides the functional improvements, the VR-based training also resulted in improvement in basic cognitive abilities, such as memory functioning. Through identifying the related cognitive abilities and how these cognitive abilities affect the processes in performing the functional tasks, the AI system can be developed to detect if the user shows difficulty in related cognitive abilities which hinder functional performance. The training programme can come up with suitable training contents and level of difficulty.

7.5.3. Characteristics of PM functioning in people with CVA and the possible application of the IVRPM programme

Nearly 80% of the subjects recruited in the present study had suffered a CVA. But the PM performance in people with CVA is rarely reported or was just based on assumptions (Brooks et al., 2004; Titov & Knight, 2000). Although the present study did not aim at investigating the characteristics of people with stroke in performing PM tasks, the results may still provide some useful information. The mean score of pre-test results in CAMPROMPT–CV of subjects with CVA was 21.88 out of 36 (SD = 5.68). In the real life behavioral PM test, they scored 9.60 out of 15 (SD = 3.63) and 4.49 out of 10 (SD = 2.89) in the accuracy of performing event-based PM tasks and time-based PM tasks respectively. These showed that they have significant deficits in PM functioning especially in performing time-based PM tasks. This result was not totally in line with the study conducted by Brook and colleagues (2004). Although impairment was found in both event-based and time-based PM performance in people with stroke, Brooks found that time-based PM was less impaired. This was not supported in the present study. The difference between the nature of the time-based PM tasks in the two studies may lead to this contradiction. In Brook and colleagues' study, subjects were asked to press a button located next to the clock every five minutes. The duration was so short that it may have helped subjects to build up a habit in performing the task. Eventually, the cognitive demand in performing the tasks may be reduced. Locating the button next to the clock may also act as a cue which reminded subjects to check the clock or that there was a relationship between the clock and the button. In the present study, the time-based PM tasks would not repeat within each session. Subjects were required to click on the “clock icon” in order to tell the time. This would ensure that the time checking behavior was intentional. Lastly, pressing a button every five minutes was not a usual everyday task that people would do. This special task may reinforce the memory of the tasks. Kliegel, Martin, McDaniel and Einstein (2001) pointed out that the importance of tasks had significant effects on the performance of time-based PM tasks. This may also have a positive effect on PM performance in Brook and colleagues’ study. But on the whole, both studies support that PM impairment happens in people with CVA.

PM rehabilitation is always ignored in the conventional rehabilitation of people with CVA. Literature reporting the rehabilitation of PM in people with CVA is rare, although some have documented the treatment effectiveness of a PM rehabilitation programme for people with TBI. In the present study, after receiving IVRPM training, subjects with CVA showed significant improvements in PM performance as reflected in CAMPROMPT–CV ($p<0.05$) and in real life behavioral test (event-based and time-based PM tasks, p<0.01). People with CVA would also benefit from the IVRPM training programme. The cognitive profile of both the TBI and CVA may vary according to the site and severity of the damage where executive functioning and memory deficits are commonly reported (Ashman, Gordon, Cantor & Hibbard, 2006; de Haan, Nys & Van Zandvoort, 2006). It seems that the introduction of IVR-based training may provide an effective way to enhance PM performance especially for this group of people whose clinical presentation varies across individuals. Finally, like their TBI counterparts, people with CVA are reported to have deficits in community integration (Carod-Artal, Gonzalez-Gutierrez, Herrero, Horan & de Seijas, 2002). With the introduction of the IVRPM training programme, they also gained higher level of community integration as reflected in CIQ–CV (p<0.01). The introduction of IVR-based training may provide an effective way to enhance community integration for people with CVA who are already medically stable and ready for community living.

Chapter 8

Conclusion

In this study, an IVR-based PM training programme was successfully developed. The results from an RCT study initially supported the effectiveness of the combination of AI and VR in PM rehabilitation. The understanding of PM is widely reported in recent years, but there is very limited literature on the rehabilitation of PM. The IVRPM rehabilitation model (structural model) proposed in this study and the results may enrich the understanding of PM rehabilitation. PM is highly related to daily community living. It is a cognitive functioning which consists of a series of processes and is supported by other cognitive abilities. That may mean that the traditional cognitive rehabilitation approach, like paper-and-pencil tasks or repeated drills, does not yield satisfactory results. In the IVRPM rehabilitation model, the enriched environment (EE) and contextualized learning (CL) approaches tackled the need for simulated practice. The supporting cognitive abilities also received necessary training through the process approach and top-down activation from the CL approach. This formed a more holistic training strategy and therefore resulted in significant improvement in PM functioning and supporting cognitive abilities. Finally, through AI adjustment to the training contents and level of difficulties, the levels of self efficacy and community integration were improved, too. That may mean subjects in this study not only improved their cognitive functioning, but they actually applied the learned skills to their daily community living. This is the ultimate goal for every rehabilitation programme. The IVRPM rehabilitation model demonstrated the possible essential components in PM rehabilitation.

The development of the IVRPM rehabilitation programme also demonstrated a practical combination of AI and VR technology in cognitive rehabilitation. Although VR is again demonstrated to be a possible tool in cognitive rehabilitation with its strength in ecological validity and generalization of training effect, the weakness of applying VR alone is identified. The fixed programme structure made the training too inflexible to cater the needs of individual subjects. This limited the training effectiveness of the programme, no matter the training target (PM functioning) itself, self efficacy and community integration. This limitation is also applicable to other traditional computer-assisted cognitive rehabilitation programmes with a fixed programme structure. In the present study, the combination of AI with a VR-based PM training programme further enhanced the training effectiveness in terms of PM functioning and the sense of self efficacy. The generalization power was further boosted up.

The ability of AI to analyze individual subjects' weakness, offering flexibility in training content and adjustment of difficulty was demonstrated. Further application of this technology to other training focuses or in enhancement of some existing cognitive rehabilitation is possible. There are several considerations suggested in the development of AI training programmes. Firstly, choosing a suitable type of AI is important. In the IVRPM training programme, a rule-based expert system approach was adopted. This was a possible choice if the programme was made to give a diagnosis under several known criteria. The IVRPM rehabilitation model (process model) was derived to adopt this AI approach. This is a possible guideline in the process of AI system development for a training programme which can offer therapist-like decisions. The criteria or rules for the diagnosis and the response that the programme will offer to subjects require the input from an expert panel. Several trials and revisions are recommended to refine the system. Lastly, how the subjects' characteristics can be stored effectively is also important. As many behaviors will be captured in the training, how this information is stored and represented by variables so that the AI system can "understand" is a technical consideration to be solved by software engineering.

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LIST OF APPENDICES

Appendix 1

Mini-Mental State Examination – Chinese Version (MMSE – CV)

簡短智能測試 – 中文版

ORIENTATION

1. Day of week (1)
   今日係(星期幾)？
2. Date (Correct day of the month +1 or -1) (1)
   今日係(幾號) [接受加減一天]？
3. Month (1)
   依家係什麼(月份)？
4. Season (1)
   依家係什麼(季節)？
5. Year (1)
   依家係什麼(年份)？
6. Recognise nature of place : home / hospital / clinic – Nature of place (1)
   我地依家係邊度？： 家中 / 老人院 / 老人中心 / 醫院 / 診所
7. Name of building ? (1)
   建築名稱，例如：東頭村龍東樓，安寧老人院、伊利沙伯醫院
8. Floor of building ? (1)
   依度係幾樓
9. Name of region ? (1)
   香港 / 九龍 / 新界
10. Name of district ? (1)
    例如：黃大仙、荃灣

REGISTRATION

11. Repeat the following words : apple, newspaper, train (3)
    依家我會講三樣野既名，講完之後，請你重複一次: [蘋果]，[鎖匙]，[單車]
    依家請你講番哩三樣野俾我聽。

ATTENTION & CALCULATION・

12. Perform the serial 7s up to 5 times, Score 1 point for each correct subtraction (5)
    請你用一百減七，然後再減七，一路減落去，直至我叫你為止。｛ 減五次後便停 ｝
    OR Perform "Digits Backwards" : (4, 2, 7, 3, 1)
    或：依家我讀幾個數目俾你聽，請你倒轉頭講番出黎：[4, 2, 7, 3, 1,]

RECALL

13. Tell me the three things I've just tell you (3)

我頭先叫你記住既三樣野係什麼呀？

LANGUAGE

What is this : 哩樣係什麼？

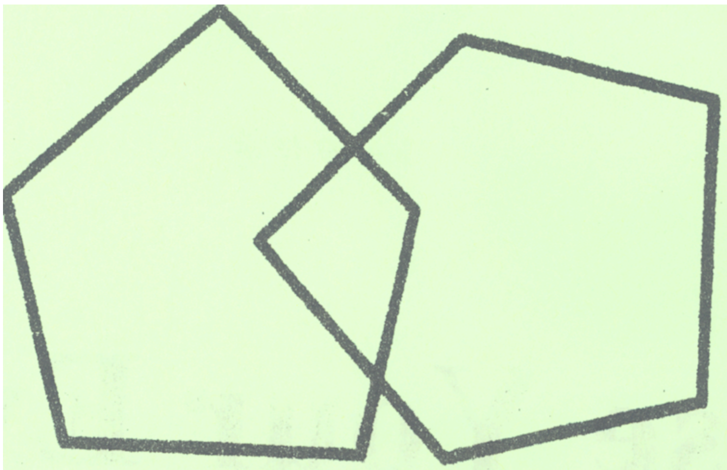
14. Pencil [鉛筆] (1)
15. Watch [手錶] (1)
16. Ask patient to repeat the sentence after saying it once. (1)
    請你跟我講句說話–"姨丈買魚腸"。[中文版]
17. Listen to the 3-stage commands & follow accordingly (3)
    依家檯上面有一張紙，用你既右手拿起張紙，用雙手一齊將紙摺成一半，然後放番張紙係檯上面。
18. Follow the written command (1)
    請讀出紙上面既字，然後照住去做。

[拍手]

19. Speak any complete sentence. Score if the sentence is meaningful. (1)
    請你講任何一句完整的句子俾我聽，例如：我係一個人/今日天氣好好。

PRAXIA

20. Copy interlocking pentagons. Score if 5 sides preserved & intersecting sides form a quadrangle. (1)
    哩處有幅圖，請你照住黎畫啦。



Appendix 2

Test of Nonverbal Intelligence – 3rd Edition (TONI – 3)

TONI–3

FORM A
Answer and Record Form

Test of Nonverbal Intelligence

Third Edition

Section I. Identifying Information

Name ______________________ Parent/Guardian ______________________

	Year	Month
Date Tested	____	____
Date of Birth	____	____
Age	____	____

School ______________________ Grade ______

Examiner's Name ______________________

Examiner's Title ______________________

Section II. Profile of Test Results

TONI–3 Scores

Quotient

SEM

Percentile Rank

Total Raw Score

TONI–3 Quotient

M = 100 SD = 15

Form A ____ date

Form B ____ date

160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40

Results of Other Measures

1. ____ 2. ____ 3. ____ 4. ____ 5. ____

Section III. Other Test Data

Test Name	Date Tested	Equivalent Quotient
1.		
2.		
3.		
4.		
5.		

8 9 10 07 06

Section IV. Administration Conditions

Who referred the subject? ______________________

____

What was the reason for referral? ______________________

____

____

____

Who discussed the referral with the subject (and with the subject's parent/guardian, if appropriate)? ______

____

____

Please describe the administration conditions for the TONI-3 by checking the appropriate categories at the right and noting if the variables were deemed to be interfering (I) or noninterfering (N) in the test situation.

Location Variables

- Noise level ______
- Interruptions, distractions ______
- Light, temperature ______
- Privacy ______
- Other ______________ ______

Respondent Variables

- Understanding of test content ______
- Understanding of test format ______
- Energy level ______
- Attitude toward testing ______
- Health ______
- Rapport with examiner ______
- Other ______________ ______

Section V. Anecdotal Comments

____

____

____

____

____

____

____

____

____

____

____

____

____

____

Section VI. Responses to the TONI-3 Form A

____	1.	1	2	3	4	5	6	____	24.	1	2	3	4	5	6
____	2.	1	2	3	4	5	6	____	25.	1	2	3	4	5	6
____	3.	1	2	3	4	5	6	____	26.	1	2	3	4		
____	4.	1	2	3	4	5	6	____	27.	1	2	3	4	5	6
____	5.	1	2	3	4	5	6	____	28.	1	2	3	4		
____	6.	1	2	3	4	5	6	____	29.	1	2	3	4	5	6
____	7.	1	2	3	4	5	6	____	30.	1	2	3	4	5	6
____	8.	1	2	3	4	5	6	____	31.	1	2	3	4	5	6
____	9.	1	2	3	4	5	6	____	32.	1	2	3	4		
____	10.	1	2	3	4	5	6	____	33.	1	2	3	4	5	6
____	11.	1	2	3	4			____	34.	1	2	3	4	5	6
____	12.	1	2	3	4	5	6	____	35.	1	2	3	4	5	6
____	13.	1	2	3	4	5	6	____	36.	1	2	3	4		
____	14.	1	2	3	4	5	6	____	37.	1	2	3	4		
____	15.	1	2	3	4	5	6	____	38.	1	2	3	4	5	6
____	16.	1	2	3	4	5	6	____	39.	1	2	3	4	5	6
____	17.	1	2	3	4			____	40.	1	2	3	4		
____	18.	1	2	3	4	5	6	____	41.	1	2	3	4	5	6
____	19.	1	2	3	4	5	6	____	42.	1	2	3	4	5	6
____	20.	1	2	3	4	5	6	____	43.	1	2	3	4	5	6
____	21.	1	2	3	4	5	6	____	44.	1	2	3	4	5	6
____	22.	1	2	3	4	5	6	____	45.	1	2	3	4	5	6
____	23.	1	2	3	4	5	6	☐	**Total Raw Score**						

Begin testing at Item A1 and continue testing to Item A45 or until the subject has made three errors in five consecutive items.

Section VII. Interpretation and Recommendations

Were the results of the TONI-3 interpreted to the:

subject? _____ If yes, by whom? ______________________________

subject's parent/guardian (if appropriate)? _____ If yes, by whom? ______________________________

Were the results of the TONI-3 used in a staffing, IEP meeting, or other planning conference? _______ If yes, please attach a copy of the results or recommendations of that meeting to this form.

Section VIII. Administration and Scoring Instructions

The testing location should include a chair for the examiner, a chair for the test subject, and a surface to display the Picture Book. Assemble the appropriate testing materials, including the Picture Book, a copy of the Form A Answer and Record Form, and a pencil. Establish rapport with the individual taking the test and complete the identifying information on the front of the Answer and Record Form. Place the Picture Book in front of the subject with the stimulus items at the top of the page and the response choices at the bottom. Both the subject and the examiner should be able to see the items and the response choices. (See Chapter 3 for specific accommodations that can be made for subjects who are unable to sit in a chair or who must use assistive devices to indicate their response choices.)

Administer the training items. Allow subjects to complete the training items without prompting if they clearly understand the process. Readminister the training items if the subject does not understand what is expected. If the subject still does not seem to understand after the training items have been administered twice, discontinue testing. If you believe the subject understands the task, proceed to the actual test items.

Turn to the Form A portion of the Picture Book. Begin testing with Item A1. Use the pantomime administration procedure described in detail in Chapter 3. Record the subject's responses in Section VI by placing an "X" over the number of the response selected by the subject. Correct response numbers are printed in boldface type inside a circle. Continue testing to Item A45 or until the subject has made three incorrect responses in five consecutive items. (See Chapter 3 for specific scoring instructions.)

Determine the total raw score by counting the number of correct responses between Item 1 and the ceiling item, and record this score in the space provided at the end of Section VI and in the appropriate place in Section II.

Appendix 3

Self-Awareness of Deficit Interview – Chinese version (SADI – CV)

對缺陷的自覺性面試

1. 對缺陷的自覺性

你現在與你未病發之前比較，有沒有甚麼不同的地方？在那一方面呢？
你覺得你或你的能力有沒有轉變呢？
那些對你熟識的人，有沒有發覺你自病發之後有一些轉變呢？
你的發病或意外為你帶來了（如果有的話）甚麼問題呢？你最想處理或改善的是甚麼？

提示
身體活動能力？（例如手腳的活動、平衡、視力、耐力）
記憶力／清醒程度？
精神集中力？
解決問題、做決定、組織和計劃事情？
行為的自制的能力？
溝通？
跟別人相處？
個性的轉變？
有沒有其他的困難是我沒有提及的呢？

2. 在缺陷對日常生活能力的影響上的自覺性

你今次發病有沒有為你帶來日常生活上的影響？在那一方面呢？

提示
獨立生活能力？
財務的管理？
照顧家人或打理家務？
駕駛車輛？
工作或學業？
娛閒或社交活動？
有沒有其他生活上的事情或將會有轉變的呢？

3. 定立實際（現實）目標的能力

在未來六個月你有甚麼事情希望達到的呢？你有沒有定立一些目標？是甚麼？
在六個月之後你認為你將會做些甚麼？你將會在那裡？
你認為六個月之後你的病仍然對你有一些影響嗎？如果有的話，會怎樣影響你呢？如果沒有的話，你又是否肯定呢？

Appendix 4

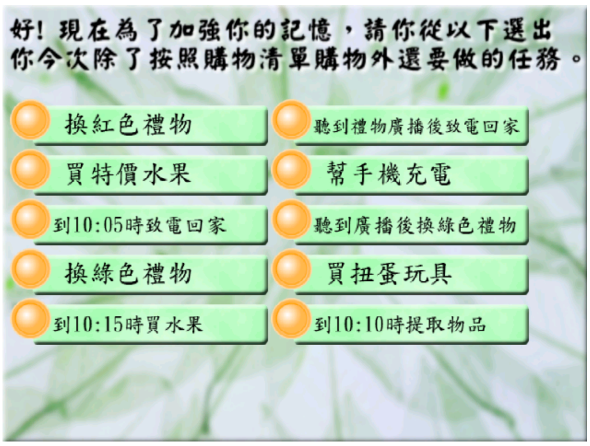
Screenshot of the training components

RM training component (encoding)

RM training component (Recall)

Item with a special price tag in inhibition training

Watching time



Recall of PM tasks

Check out in the cashier

Appendix 5

Detailed grading of difficulties in PM training component

1. No. of items in shopping list

Grade 1 (lease difficult)	Shop for 3 items
Grade 2	Shop for 4 items
Grade 3 (default)	Shop for 5 items
Grade 4	Shop for 6 items
Grade 5	Shop for 7 items

2. no. of PM tasks

Grade 1 (lease difficult)	1 event-based task
Grade 2	2 event-based tasks
Grade 3 (default)	2 event-based tasks + 1 time-based task
Grade 4	2 event-based tasks + 2 time-based tasks
Grade 5	3 event-based tasks + 2 time-based tasks
Grade 6	3 event-based tasks + 3 time-based tasks

3. Assistance level (subject to confirm)

Grade 1 (lease difficult)	● Inhibit ongoing activities and ask about PM goals every 2 minutes
Grade 2	● Inhibit ongoing activities and give verbal prompting every 2 minutes without action
Grade 3 (default)	● Give verbal prompting every 2 minutes without action
Grade 4	● Show visual prompting every 2 minutes without action
Grade 5	● Show auditory prompting (beep sound) every 2 minutes without action

Appendix 6

Expert opinion questionnaire on intelligent virtual reality prospective memory (IVRPM) training

Background of IVRPM program:

The IVRPM training program is developed to offers prospective memory training to people with acquired brain injury. The program development followed the four phases in the framework of prospective memory, i.e. intention formation, intention retention, reinstaniation of intention and execution of reintantiated intention (Martin, Kliegel, & McDaniel, 2003). For the first two phases, intention formation and intention retention, involve information encoding and recalling. These belong to the retrospective component of prospective memory. Kopp & Thone-Otto (2003) stated that intention must held in memory over a period of time. Literatures also showed that retrospective memory (RM) is the pre-requisite for successful prospective memory. Besides retrospective component, PM performance also relies on executive functions. Martin and colleague (2003) continued to show the executive functions (shifting, inhibition and planning) explained significant amount of variance in event-based and time-based prospective memory performance. Furthermore, Mantyla, Carelli & Forman (2007) showed that adults with good performance in inhibition task showed better time-based PM performance. Inhibition can be defined as the ability to suppress irrelevant information (Mantyla, Carelli & Forman, 2007) and responds (Thoma, Wiebel & Daum, 2007). This is very important as ongoing task is needed to stop before the execution of PM tasks.

Due the above findings, RM training and inhibition training are, therefore, incorporated in the IVRCR training program. Figure 1 and 2 showed the description of RM training and inhibition training.

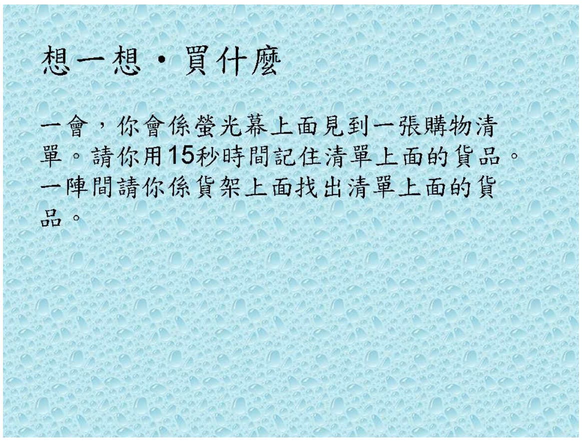


Figure 1. Task description of RM training

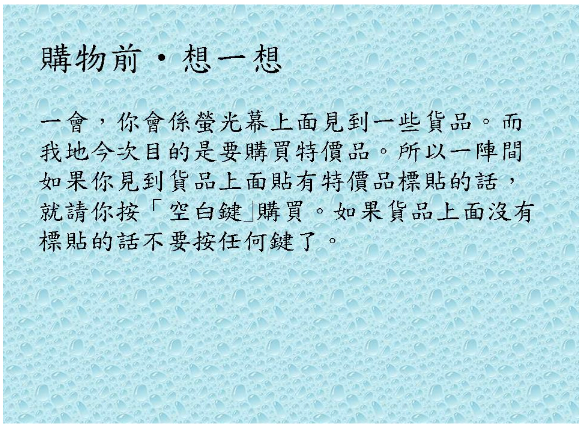


Figure 2. Task Description of inhibition training

In this program, convenience store shopping tasks is chosen as a training scenario. In this training, clients need to remember a series of prospective memory tasks, including event-based and time-based tasks. For example, to buy fruit with special price or to call back home at a specific moment, say 10:10. At the same time, a shopping list is given to them. They need to search for the correct items in the shop, pick up the correct items and pay in the cashier. In order to see if the participants are able to remember the PM tasks before and after the training session, so after the tasks description and after accomplishment of the PM training, participants will be asked about the PM tasks which they need to perform in that training session. Below is an example of one of the training content (Figure 3).

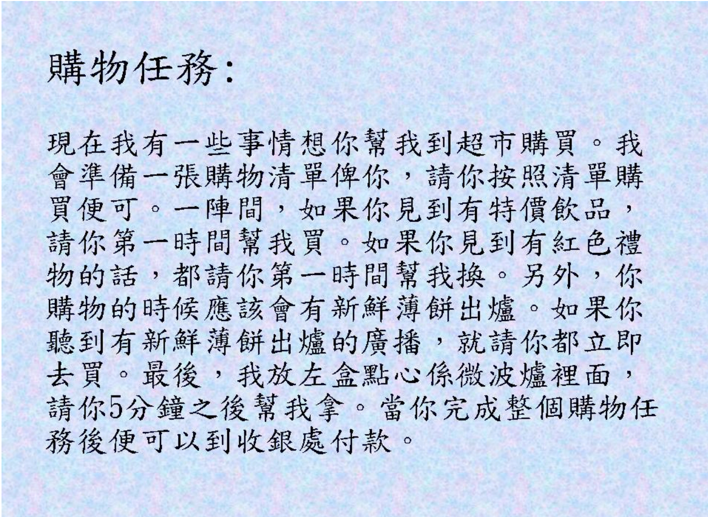


Figure 3. example of one of the training content

Structure of IVRPM program:

As mentioned before, RM and inhibition are two important components in successful PM performance. Together with the core PM training component, the program structure is shown below (Figure 4).

Prospective memory training	10 minutes rest	Prospective memory training or Retrospective memory training and/ or Inhibition training

Figure 4. Program structure of IVRPM training

As shown in the figure 4, each training session consists of the core PM training component, followed by 10 minutes rest. After that, participant will either receive RM training, inhibition training or one more PM training. The difficulty in PM training component and the training content of the last part will then depend on the analysis of participants' performance by AI system. Therefore, the AI system plays an important role in this IVRCR program, which is to analyze the weakness of the participants from their performance and to give suitable training component, as well as in suitable difficulty to each of them.

Aims:

In order to develop an optimal AI system for the IVR training program, experts' opinion in related fields, including academia, clinicians and researches etc, have to be consulted. The information like, the main predicting parameters, training technique, methods in offering assistance, as well as the rules in upgrading and downgrading training difficulties are very important components in the AI system. The more comprehensive the data gathered, the better the AI system performed. That means the closer the AI performs like real therapists do. Your participations are highly appreciated. Thank you!

Instruction to fill in questionnaire:

There are totally 5 questions in the questionnaire. Question 1 is about evaluation of participants' performance during PM training. Question 2 concerns the judgment in grading of difficulty, and judgment of the necessarily in adding RM or inhibition training component. Question 3 asks about different ways in offering suitable assistance during PM training. Finally, Question 4 and 5 collect demographic data and general comments respectively.

Please fill-in all 5 questions. Questions 1 and 3 require you to add and prioritize different options. In question 2, expect adding and prioritizing different options, you are required to give a condition for each item chosen. Please write down the number in the box provided to indicate the priority. The smaller the number, the higher the priority that item is placed. Please **DO NOT** duplicates the number. Detailed explanation will be given in each question. Please return the completed questionnaire to rs.ben@___________. Thank you!

Question 1

Just think if you are conducting PM training by using convenience store shopping scenario. How would you evaluate your clients' performance which could help you in planning next treatment session? Please prioritize* your opinion below according to its importance in reflecting PM performance:

* Please choose number 1 to 7 and fill-in the box provided, the smaller the number indicate the higher the importance. **DO NOT** duplicates the number

Item	Priority 1—2—3—4—5—6—7 Highest priority Lowest priority
1. Accuracy of shopping task (ongoing task)	☐ (choose 1 to 7)
2. Accuracy of PM tasks recall before training	☐ (choose 1 to 7)
3. Accuracy of PM task (event-based & time-based)	☐ (choose 1 to 7)
4. No. of time checking	☐ (choose 1 to 7)
5. Accuracy of PM tasks recall after training	☐ (choose 1 to 7)
6. Others:	☐ (choose 1 to 7)
7. Others:	☐ (choose 1 to 7)

Question 2

Below are some decisions which you would make during PM training. Please prioritize* and suggest a threshold** for each parameter which will make you do the following action.

* Please choose number 1 to 7 and fill-in the box provided, the smaller the number indicate the higher the importance. **DO NOT** duplicates the number. Choose N/A if the item is not related to the action stated.

** Please indicate to what extent you will do the action stated. For example, you can write down "If accuracy >50% or If accuracy between 25% to 50%"

2.1. Upgrade perspective memory training difficulty:

Item		Priority 1—2—3—4—5—6—7 Highest priority Lowest priority		Threshold
1.	Accuracy of shopping task (ongoing task)	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
2.	Accuracy of PM tasks recall before training	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
3.	Accuracy of PM task (event-based & time-based)	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
4.	No. of time checking	☐ (choose 1 to 7)	☐ N/A	If time checking < _____
5.	Accuracy of PM tasks recall after training	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
6.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________
7.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________

2.2. Downgrade perspective memory training difficulty

Item		Priority 1—2—3—4—5—6—7 Highest priority Lowest priority		Threshold
1.	Accuracy of shopping task (ongoing task)	☐ (choose 1 to 7)	☐ N/A	If accuracy <___%
2.	Accuracy of PM tasks recall before training	☐ (choose 1 to 7)	☐ N/A	If accuracy <___%
3.	Accuracy of PM task (event-based & time-based)	☐ (choose 1 to 7)	☐ N/A	If accuracy <___%
4.	No. of time checking	☐ (choose 1 to 7)	☐ N/A	If time checking > _____
5.	Accuracy of PM tasks recall after training	☐ (choose 1 to 7)	☐ N/A	If accuracy <___%
6.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________
7.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________

2.3. Introduce one more perspective memory training session:

Item		Priority 1—2—3—4—5—6—7 Highest priority Lowest priority		Threshold
1.	Accuracy of shopping task (ongoing task)	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
2.	Accuracy of PM tasks recall before training	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
3.	Accuracy of PM task (event-based & time-based)	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
4.	No. of time checking	☐ (choose 1 to 7)	☐ N/A	If time checking < _____
5.	Accuracy of PM tasks recall after training	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
6.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________
7.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________

2.4. Introduce retrospective memory training:

Item		Priority 1—2—3—4—5—6—7 Highest priority Lowest priority		Threshold
1.	Accuracy of shopping task (ongoing task)	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
2.	Accuracy of PM tasks recall before training	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
3.	Accuracy of PM task (event-based & time-based)	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
4.	No. of time checking	☐ (choose 1 to 7)	☐ N/A	If time checking < _____
5.	Accuracy of PM tasks recall after training	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
6.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________
7.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________

2.5. Introduce inhibition training:

Item		Priority 1—2—3—4—5—6—7 Highest priority Lowest priority		Threshold
1.	Accuracy of shopping task (ongoing task)	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
2.	Accuracy of PM tasks recall before training	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
3.	Accuracy of PM task (event-based & time-based)	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
4.	No. of time checking	☐ (choose 1 to 7)	☐ N/A	If time checking < _____
5.	Accuracy of PM tasks recall after training	☐ (choose 1 to 7)	☐ N/A	If accuracy >___%
6.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________
7.	Others:	☐ (choose 1 to 7)	☐ N/A	If____________

Question 3

Please suggest and prioritize* what types of assistance you will offer when you clients face difficulties in prospective memory training.

* Please choose number 1 to 7 and fill-in the box provided, the smaller the number indicate the higher the importance. **DO NOT** duplicates the number

Item	Priority 1—2—3—4—5—6—7 Highest priority Lowest priority
1. Inhibit ongoing activities and ask about PM goals every 2 minutes	☐ (choose 1 to 7)
2. Inhibit ongoing activities and give verbal prompting every 2 minutes without action	☐ (choose 1 to 7)
3. Give verbal prompting every 2 minutes without action	☐ (choose 1 to 7)
4. Show visual prompting every 2 minutes without action	☐ (choose 1 to 7)
5. Show auditory prompting (beep sound) every 2 minutes without action	☐ (choose 1 to 7)
6. Others	☐ (choose 1 to 7)
7. Others	☐ (choose 1 to 7)

Question 4

Please state if you have any other comment to this project.

____

____

____

____

____

____

Question 5

Please state your profession:

How long have you been working in cognitive rehabilitation or related training:

How long have you been working with people with acquired brain injury:

-----------End of the questionnaire----------

Thank you

Appendix 7
Real life behavioral prospective memory (PM) test
現實生活前瞻記憶行為評估表

1. 進行中任務 – 依購物清單購買八種特定貨品
(ongoing task – buy six item according to the shopping list)

甲、 準確度 (accuracy):

對 (Correct)	錯 (Error)
買對數目 (correct items):	多買數目 (intrusion errors):
	少買數目 (omission errors):
答對比例 (Correct ratio): * (correct item – intrusion errors – omission errors)/6	

乙、 完成時間 (time required): ________________________

2. 事件性前瞻記憶任務 (Event-based PM task):

項目	分數
甲、 見到有特價洗頭水打電話回中心 Call back center when you see shampoo with special price	
乙、 見到汽水，寫下三種不同種類的價格 Write down the price of 3 difference kinds of soft drink	
丙、 經過屋村辨事署時，向評分員說今日記得交租 When you pass estate management office, remind the examiner to pay fees	

3. 時間性前瞻記憶任務 (Time-based PM task):

項目	分數
甲、 進入超市購物 5 分鐘後，提醒評分員要記得訂枱食飯 Ask examiner to reserve a table for lunch 5 minutes (± 10s) after entering the shop	
乙、 進入超市購物 10 分鐘後，提醒評分員要記得到入口見朋友 Remind examiner to meet a friend at the entrance 10 minutes after entering the shop	

4. 記憶任務內容 (memorize task content)

甲、 開始前 (before start)

i. 事件性後置記憶任務(event based PM task) 1☐ 2☐ 3☐

ii. 時間性後置記憶任務(time-based PM task) 1☐ 2☐

乙、 完成後 (after finish)

i. 事件性後置記憶任務(event based PM task) 1☐ 2☐ 3☐

ii. 時間性後置記憶任務(time-based PM task) 1☐ 2☐

5. 購物清單 (shopping list)

i. 1 打裝紙巾 (tissue paper – a pack of 1 dozen)
ii. 電芯 4 粒裝 1 件 (battery – a pack of 4)
iii. 可口可樂 8 罐裝 (coca cola – a pack of 8)
iv. 即食麵 4 包 (instant noodle – 4 packs)
v. 雪糕 1 盒(ice cream)
vi. 朱古力 1 包(chocolate)
vii. 橙 4 個(orange)
viii. 洗潔精 1 支 (detergent)

Marking criteria of real life behavioral prospective memory (PM) test

5. 即時正確執行
Spontaneously carries out correct task
4. 即時執行但做錯，提示，正確執行
Spontaneously, but carries out a wrong task, carries out correct task after prompt
3. 即時執行但做錯，提示，仍然做錯
Spontaneously, but carries out a wrong task, still carries out wrong task after prompt
2. 沒執行，提示，正確執行
No response, carries out correct task after prompt
1. 沒執行，提示，仍然做錯
No response, still carries out wrong task after prompt
0. 沒執行，提示，忘記
No response, still forget after prompt

Appendix 8
The Cambridge Prospective Memory Test – Chinese Version (CAMPROMT – CV)

CAMPROMPT Record Form

Name ______________________ Hospital number ______________

Date of birth ______________________

Date of test ______________________

Assessment ☐ First ☐ Second

Version ☐ A ☐ B

Ability Band ☐ Below average (< 90) ☐ Average (90-110) ☐ Above Average (111+)

SUMMARY OF SCORES

		Time	Event
(12)	Book/map		______
(13)	Change task/pen	______	
(14)	Take keys/mug	______	
(15)	Give message		______
(16)	Objects and locations		______
(17)	Ring garage/reception	______	
	Total time-based	______	
	Total event-based		______
	Overall total score	☐	
	Classification	☐	

Score conversion

Score A = 6
Score B = 4
Score C = 2
Score D = 4
Score E = 2
Score F = 1
Score G = 1
Score H = 0

Tester's own record of five small objects and where hidden:

☐

Harcourt Assessment
The Psychological Corporation

TVTC Thames Valley Test Company

(The following summary is provided to help the tester keep track of the correct procedure. It is not a substitute for the detailed instructions provided in the manual, pages 11-21, which must be followed at all times.)

Put a mark against each of the items from 1-11 as a sign the correct procedure has been followed. Circle examinee's responses for items 12-17.

1. Read the introductory information from the manual, pages 1-8.
2. Show, name and hide the five objects, as described in the manual, page 12.
3. Demonstrate beeper, set timer and press START, as in manual, page 13.
4. Reminder not to forget keys (mug), as in manual, page 13.
5. Instructions about EastEnders (Coronation Street) quiz question and giving book (map), as in manual, page 13.
6. Tell examinee to begin the puzzles.
7. At **18 minutes** give message card and envelope, as in manual, page 13.
8. At **16 minutes** give instructions about changing task (pen) in seven minutes, as in manual, page 13.
9. Adjust clock hands under table and note time.
10. At **15 minutes** put clock on table and give instructions re time and ringing garage (reception), as in manual, page 14.
11. At **13 minutes** give Quiz Question sheet A or B and instruction, as in manual, page 14.

[1] 12. Watch until examinee has done **quiz question 14**, the one about EastEnders (Coronation Street). Examinee should then give the book/map, as in manual, page 14.

a) <u>examinee spontaneously carries out some task</u>

gives book/map	<u>Score A</u>
wrong task, prompt, gives book/map	<u>Score B</u>
wrong task, prompt, still wrong task	<u>Score C</u>

b) <u>no response</u>

prompt, gives book/map	<u>Score D</u>
prompt, wrong task, prompt, gives book/map	<u>Score E</u>
prompt, wrong task, prompt, wrong task	<u>Score F</u>

c) <u>no response</u>

prompt, 'no', prompt, gives book/map	<u>Score G</u>
prompt, 'no', prompt, 'no'/wrong task	<u>Score H</u>

13. At **nine minutes** examinee should change task (pen), as in manual, page 15.

a) examinee spontaneously carries out some task
- changes task/pen — Score A
- wrong task, prompt, changes task/pen — Score B
- wrong task, prompt, still wrong task — Score C

b) no response
- prompt, changes task/pen — Score D
- prompt, wrong task, prompt, changes task/pen — Score E
- prompt, wrong task, prompt, still wrong task — Score F

c) no response
- prompt, 'no', prompt, changes task/pen — Score G
- prompt, 'no', prompt, 'no'/wrong task — Score H

[3] 14. At **seven minutes** examinee should remind you to take your keys (mug), as in manual, page 16.

a) examinee spontaneously carries out some task
- 'take keys/mug' — Score A
- wrong task, prompt, 'take keys/mug' — Score B
- wrong task, prompt, still wrong task — Score C

b) no response
- prompt, 'take keys/mug' — Score D
- prompt, wrong task, prompt, 'take keys/mug' — Score E
- prompt, wrong task, prompt, still wrong task — Score F

c) no response
- prompt, 'no', prompt, 'take keys/mug' — Score G
- prompt, 'no', prompt, 'no'/wrong task — Score H

[4] 15. At **five minutes** ***'There are five minutes left.'*** Examinee should give message, as in manual, page 17.

a) examinee spontaneously carries out some task
- gives message — Score A
- wrong task, prompt, gives message — Score B
- wrong task, prompt, still wrong task — Score C

b) no response
- prompt, gives message — Score D
- prompt, wrong task, prompt, gives message — Score E
- prompt, wrong task, prompt, wrong task — Score F

c) no response
- prompt, 'no', prompt, gives message — Score G
- prompt, 'no', prompt, 'no'/wrong task — Score H

16. At 0 alarm goes off, ***'We have finished this test.'*** Examinee should now tell you about the five objects and their locations, as in manual, page 18.

a) <u>examinee spontaneously carries out some task</u>
objects and locations — <u>Score A</u>
wrong task, prompt, objects and locations — <u>Score B</u>
wrong task, prompt, wrong task — <u>Score C</u>

b) <u>no response</u>
prompt, objects and locations — <u>Score D</u>
prompt, wrong task, prompt, objects and locations — <u>Score E</u>
prompt, wrong task, prompt, wrong task — <u>Score F</u>

c) <u>no response</u>
prompt, 'no', prompt, objects and locations — <u>Score G</u>
prompt, 'no', prompt, 'no'/wrong task — <u>Score H</u>

[5b] Examinee should tell you about the five objects and their locations. If not ***'Can you remember what they were and where they were hidden?'***, as in manual, page 20.

Record examinee's responses and whether or not prompts were needed either for object or for location.

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

[6] 17. At * (the time you specified – ***five minutes after end time***) examinee should remind you to ring the garage/reception, as in manual, page 20.

a) <u>examinee spontaneously carries out some task</u>
ring garage/reception — <u>Score A</u>
wrong task, prompt, ring garage/reception — <u>Score B</u>
wrong task, prompt, wrong task — <u>Score C</u>

b) <u>no response</u>
prompt, ring garage/reception — <u>Score D</u>
prompt, wrong task, prompt, ring garage/reception — <u>Score E</u>
prompt, wrong task, prompt, wrong task — <u>Score F</u>

c) <u>no response</u>
prompt, 'no', prompt, ring garage/reception — <u>Score G</u>
prompt, 'no', prompt, 'no'/wrong task — <u>Score H</u>

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Appendix 9

Hong Kong List Learning Test (HKLLT)

香港文字記憶學習測試

Agnes S. Chan, Ph.D., & Isaac C. Kwok, B.S.Sc
陳瑞燕博士及郭澤恩先生

Record Form 記錄表

Form 1 (Random Condition) 表一（隨意詞句）

(Trial 1)(第一回)

「我會讀一些詞語給你聽，請你儘量記住它們。當我讀完之後，請你告訴我你記得的詞語，次序不要緊，你記得多少便多少。你有沒有問題呢？沒有便開始。」

(Trial 2 & 3)(第二及第三回)

「我會將那些詞語再讀多一次給你聽，請你儘量記住它們。我讀完之後，請你告訴我所有你記得的詞語，連同你剛說給我聽的那些都請再說一次，次序不要緊，預備好便開始。」

	Trial 1 第一回	**Trial 2** 第二回	**Trial 3** 第三回
祖母 △			
書檯 O			
印度 ♦			
鏡子 O			
瑞士 ♦			
嬸母 △			
茄子 ▼			
姪女 △			
寮國 ♦			
黃瓜 ▼			
智利 ♦			
表弟 △			
電燈 O			
芥菜 ▼			
衣櫃 O			
洋葱 ▼			

你用什麼方法幫助你記憶以上的詞語？

____

____

(Trial 4, 10-minute delay recall) (第四回，十分鐘後口述)

「我剛才讀過一些詞語給你記，讀過三次，請你現在告訴我那些詞語是什麼，次序不要緊，預備好便開始。」

	Trial 4 第四回
祖母 △	
書檯 O	
印度 ♦	
鏡子 O	
瑞士 ♦	
嬸母 △	
茄子 ▼	
姪女 △	
寮國 ♦	
黃瓜 ▼	
智利 ♦	
表弟 △	
電燈 O	
芥菜 ▼	
衣櫃 O	
洋葱 ▼	

(Trial 5, 30-minute delay recall) (第五回，三十分鐘後口述)

「我剛才讀過一些詞語給你記，讀過三次，請你現在告訴我那些詞語是什麼，次序不要緊，預備好便開始。」

(Recognition)(別認)

「現在我讀一些詞語給你聽，當中有部份你剛才已聽過，有部份則是未聽過的。如果你曾聽過，你就說舊的。如果是新詞語，你就說新的。」

	Trial 5 第五回	**Recognition** 別認					
祖母 △		電燈	O		油菜	NSR	
書檯 O		茄子	O		印度	O	
印度 ♦		地氈	NR		表哥	NSR	
鏡子 O		衣架	NSR		游水	N	
瑞士 ♦		姪女	O		鏡子	O	
嬸母 △		狐狸	N		跑步	N	
茄子 ▼		姑丈	NR		嬸母	O	
姪女 △		書檯	O		瑞士	O	
寮國 ♦		寮國	O		火車	N	
黃瓜 ▼		秋天	N		豌豆	NR	
智利 ♦		荷蘭	NR		衣櫃	O	
表弟 △		祖母	O		芥菜	O	
電燈 O		印尼	NSR		暴風	N	
芥菜 ▼		表弟	O		洋葱	O	
衣櫃 O		輪船	N		黃瓜	O	

Appendix 10

Frontal Assessment Battery (FAB)

Seniors' Mental Health Programs Standardized Assessment Scales

FAB:
A Frontal Assessment Battery at the Bedside

Age: ____________

Date: ____________________________________

Assessed By: ______________________________

Patient/Client Label

Test & Scoring	Instructions:		Score
SIMILARITIES 3 correct ---------------------------------- 3 2 correct ---------------------------------- 2 1 correct ---------------------------------- 1 0 correct ---------------------------------- 0	**In what way are they alike?** (can prompt for #1 only) – but score 0 for that item	**1. A banana and orange?** **2. A table and a chair?** **3. A tulip, a rose and a daisy?**	
LEXICAL FLUENCY > 9 words --------------------------------- 3 6 - 9 words ------------------------------- 2 3 - 5 words ------------------------------- 1 < 3 words --------------------------------- 0 (don't score repetitions or word variations)	**Say as many words as you can beginning with the letter "S", except surnames or proper names.**	Time 60 seconds. Can give example if no response in 5 seconds or prompt if quiet for 10 seconds.	
MOTOR SERIES PROGRAMMING 6 series alone --------------------------- 3 3 series alone --------------------------- 2 fails alone, but 3 with ------------------ 1 can't do ----------------------------------- 0	**Look carefully at what I'm doing:** Luria: fist-palm-edge (3 times)	**Now with your right hand, do the same series with me, then alone.** (with X3, alone X6)	
CONFLICTING INSTRUCTIONS No error ----------------------------------- 3 1 or 2 errors ------------------------------ 2 > 2 errors --------------------------------- 1 taps like examiner 4 consecutive times - 0	**Tap twice when I tap once:** series 1-1-1 **Tap once when I tap twice:** series 2-2-2	Series: **1-1-2-1-2-2-2-1-1-2**	
GO-NO-GO (INHIBITORY CONTROL) No error ---------------------------------- 3 1 or 2 errors ----------------------------- 2 > 2 errors -------------------------------- 1 taps like examiner 4 consecutive times - 0	**Tap once when I tap once** 1-1-1 **Do not tap when I tap twice** 2-2-2	Series: **1-1-2-1-2-2-2-1-1-2**	
ENVIRONMENTAL CONTROL Patient doesn't take hands ------------- 3 Hesitates and asks what to do --------- 2 Takes hands without hesitation -------- 1 Takes hands even after told not to ---- 0	Place the patient's hands palm up on his/her knees	Move your hands close to patient's hands and touch the palms of both hands with your fingers. If patient takes hands, say **"Now, do not take my hands"** and try again.	
Scoring: 16 – 18 = normal; below 13 = severe frontal dysfunction		**Score:**	/18

Comments:____

____

Dubois, B., Slachevsky, A., Litvan, I., & Pillon, B. (2000) . The FAB: A frontal assessment battery at bedside. Neurology, 55, 1621-1626.

Revised: Jan. 17/05

Enquires: SAS Committee Chair/ Alberta Hospital Edmonton Community Geriatric Psychiatry, (780) 424-4660.

Appendix 11

Word Fluency Test – Chinese Version (WFT – CV)

請在一分鐘時間內盡量說出屬於以下類別的詞語。

生果/ 蔬菜
動物

生果/ 蔬菜: ____________

動物: ____________

總數: ____________

Appendix 12

Color Trail Test (CTT)

Color Trails Test™

Record Form

Louis F. D'Elia, PhD, and Paul Satz, PhD

Name ______________________ Test Date ____/____/____

ID# ______________________ Date of Birth ____/____/____

Gender ________ Race ____________ Handedness ________ Age ______

Education ______________ Examiner ______________

	Raw score	Percentile range	Standard score	*T* score	Percentile score
Color Trails 1 (time in seconds)					
Color Trails 1 Errors					
Color Trails 1 Near-Misses					
Color Trails 1 Prompts					
Color Trails 2 (time in seconds)					
Color Trails 2 Color Errors					
Color Trails 2 Number Errors					
Color Trails 2 Near-Misses					
Color Trails 2 Prompts					
Interference Index (Color Trails 2 time raw score minus Color Trails 1 time raw score) ÷ Color Trails 1 time raw score					

Normative table ______________

Notes: ______________

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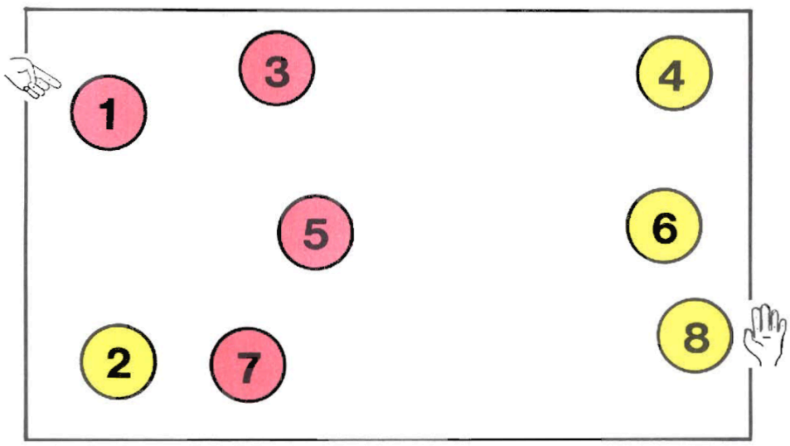
Color Trails 1

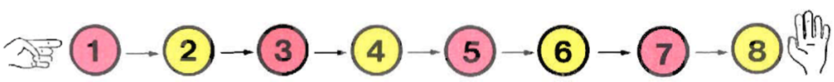
Louis F. D'Elia, PhD, and Paul Satz, PhD

Form A

Name: ______________________________

ID#: ____________________ Date: ____________





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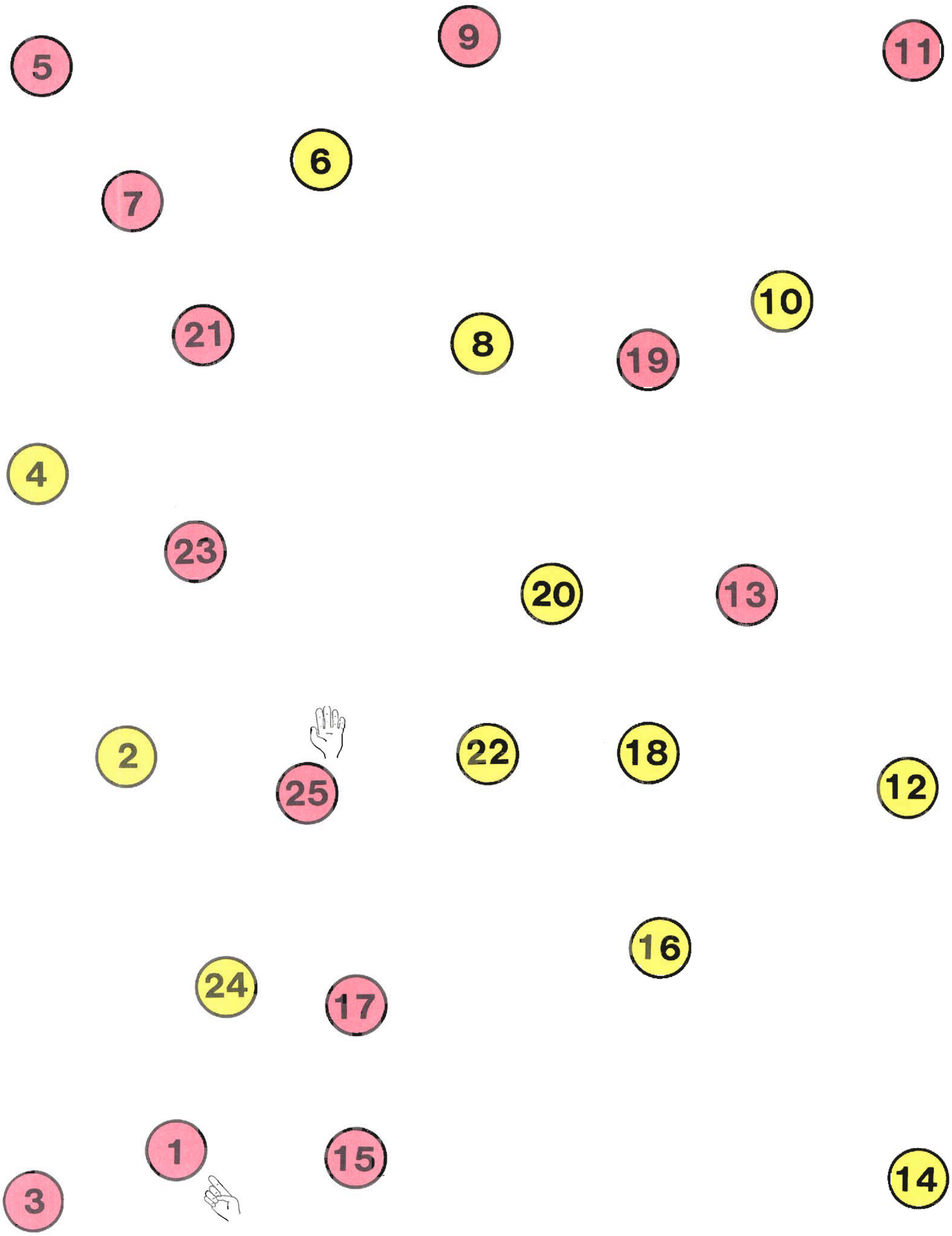


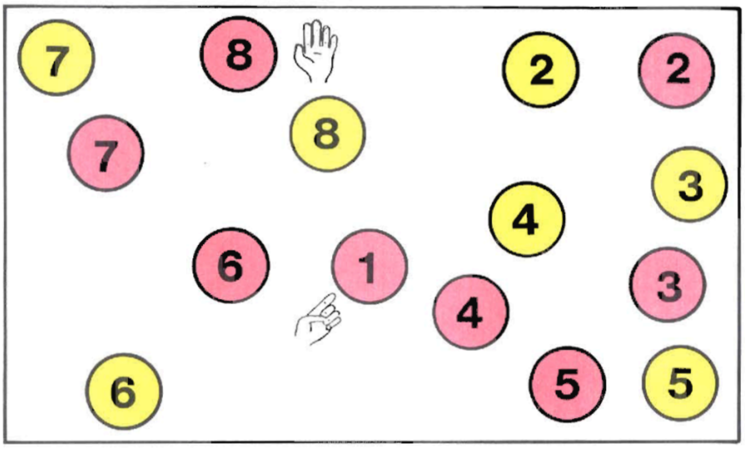
Color Trails 2

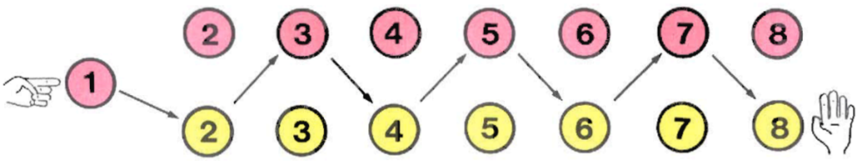
Louis F. D'Elia, PhD, and Paul Satz, PhD

Form A

Name: ______________________________

ID#: ________________ Date: __________





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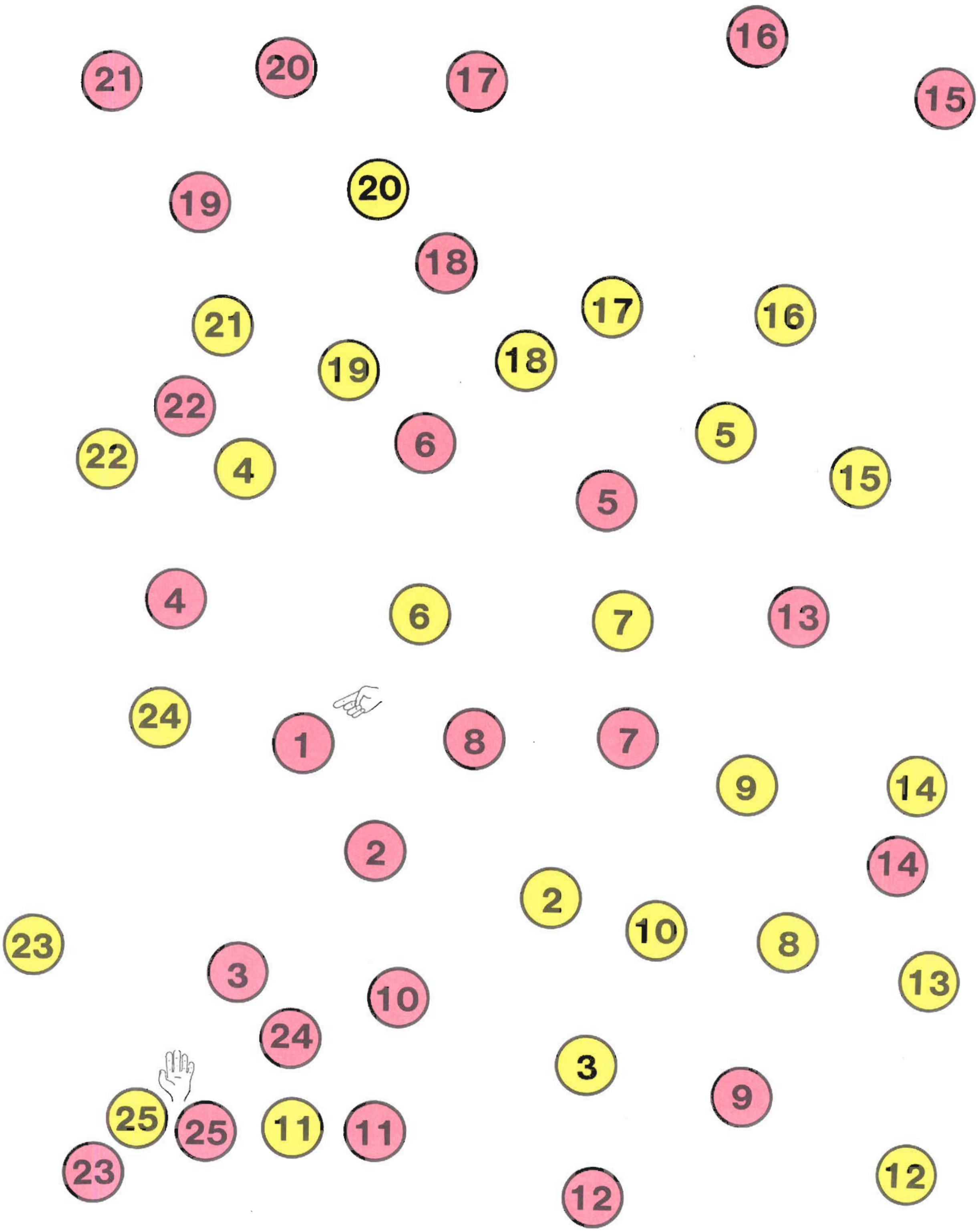

Appendix 13

Community Integration Questionnaire – Chinese Version (CIQ – CV)

APPENDIX VI

Finalized CIQ (Chinese Version)

融入社區問卷

日期 (/ /) (/ /) (/ /)

融入家庭	病發前	現在	覆檢
1. 誰負責購買你家裏的雜貨及其他日用品？	( )	( )	( )
2. 誰負責準備你家裏的飯餐？	( )	( )	( )
3. 在你家裏誰通常負責日常家務？	( )	( )	( )
4. 誰通常負責照顧你家中的孩子?	( )	( )	( )
5. 誰通常負責安排一些與親友聚會之類的活動？	( )	( )	( )
6. 誰通常負責管理你的個人財務？ 例如銀行事務或繳交雜費,包括水電及供樓費用。	( )	( )	( )
融入家庭分組得分	[ ]	[ ]	[ ]

融入社交

你可否約略告訴我，你最近一個月內參加多少次下列家庭以外的活動？

7. 購物。 例如逛街、購買衣服鞋襪或其他消費品。	( )	( )	( )
8. 閒暇活動。 例如出外用膳、看電影、做運動、打麻雀、看影碟等。	( )	( )	( )
9. 探望朋友或親戚。	( )	( )	( )
10. 你通常是一個人或者與人一起參與閒暇活動？	( )	( )	( )
11 你有沒有一個可以信賴的好朋友？	( )	( )	( )
融入社交分組得分	[ ]	[ ]	[ ]

融入工作、訓練或義務工作等活動

12. 你有多經常外出呢？ 例如步行或乘車到任何地方。	( )	( )	( )
13. 請選擇一個最合適的答案來形容你最近一個月的工作情況:			
☑全職（每星期工作多於二十小時）	☐	☐	☐
☑兼職（每星期工作少於或等於二十小時）	☐	☐	☐
☑失業，但正積極找工作	☐	☐	☐
☑失業，沒有找工作	☐	☐	☐
☑不適合,因年紀大已退休	☐	☐	☐
☑在社區內當義工	☐	☐	☐
14. 請選擇一個最合適的答案來形容你最近一個月的上學或訓練的情況:			
☑全日上學或訓練	☐	☐	☐
☑兼讀或非全日訓練	☐	☐	☐
☑沒有上學或參加訓練課程	☐	☐	☐
15 上個月內，你參加了多少次義務工作？☐	—	—	—
第十三至第十五項綜合得分	( )	( )	( )
融入工作、訓練或義務工作等活動分組得分	[ ]	[ ]	[ ]
融入社區問卷總分	☐	☐	☐

評分標準：

第一至第六項：

得分：

2 = 完全自己做

1 = 有人幫忙一起做

0 = 完全依靠別人做

備註：第四項，如果家中沒有17歲或以下的孩子，將由第一至三項及第五第六項平均(中位數)得分代替。

第七至第九項：

得分：

2 = 最近一個月參與5次或以上這類活動

1 = 最近一個月參與1至4次這類活動

0 = 最近一個月未曾參與過這類活動

第十項：

得分：

2 = 多數與沒有腦部受損傷的朋友或者家人一起參與

1 = 多數與腦部受損傷的朋友或者家人一起參與

0 = 多數獨個兒

第十一項：

得分：

2 = 有

0 = 無

第十二項：

得分：

2 = 差不多每日

1 = 差不多每個星期

0 = 很少/沒有(每星期少於一次)

第十三至第十五項：

備註：這些項目資料雖然是個別地搜集回來，卻綜合形成單一個項目『工作、訓練或義務工作』。而評分標準如下：

得分：

0 = 沒工作、沒找工作、沒上學、無做義工

1 = 一個月做1至4次義工『和』沒工作、沒找工作

2 = 積極找工作『和/或』每個月做5次或以上義工

3 = 兼讀『或』兼職(每星期少於20小時)

4 = 全日上學『或』全日工作

5 = 全職和兼讀『或』全日上學和兼讀(每星期少於20小時)

Appendix 14

Self efficacy questionnaire on every day prospective memory tasks

日常前瞻記憶任務自我勝任能力評估表

事件性前瞻記憶任務

	0	1	2	3	4	5	6	7	8	9	10
1. 我能夠**記得**日常生活中的一些將要做的事情，如回家途中買麵包											
2. **經過一段時間**，我仍能夠**記得**日常生活中的一些將要做的事情，如回家途中買麵包											
3. 我能夠在見到預定的地方時，如麵包店，執行先前計畫的事情，即買麵包											
4. 我能夠正確執行己計畫的事情，如購買所需的麵包，不會買錯											

時間性前瞻記憶任務

	0	1	2	3	4	5	6	7	8	9	10
5. 我能夠**記得**日常生活中的一些將要發生的事情，如: 約會、覆診、食藥等											
6. **經過一段時間**，我仍能夠**記得**日常生活中的一些將要發生的事情，如約會、覆診、食藥等											
7. 我能夠在預定的時間，如約會當日，執行日常先前計畫的事情，如: 應約、覆診、食藥等											
8. 我能夠不延誤或做錯一些預定事情，如約會、覆診、食藥等											

總結

	0	1	2	3	4	5	6	7	8	9	10
9. 我能夠在記憶和執行一些將要發生的事情時**不會影響日常生活**											
10. 整體而言，我能夠妥善記憶並執行一些將來要發生的事情											

Appendix 15

Ethical approval from the Ethical Committee of The Hong Kong Polytechnic University

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

MEMO

To : MAN Wai Kwong, Department of Rehabilitation Sciences
From : NG Yin Fat, Chairman, Departmental Research Committee, Department of Rehabilitation Sciences

Ethical Review of Research Project Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following research project for a period from 12/04/2005 to 31/03/2007:

Project Title : An intelligent rehabilitation system for cognitive rehabilitation

Department : Department of Rehabilitation Sciences

Principal Investigator : MAN Wai Kwong

Please note that you are responsible for informing the Departmental Research Committee Department of Rehabilitation Sciences in advance of any changes in the research proposal or procedures which may affect the validity of this ethical approval.

You will receive separate notification should you be required to obtain fresh approval.

NG Yin Fat
Chairman
Departmental Research Committee
Department of Rehabilitation Sciences

Ethical approval from New Territories West Cluster Clinical & Research Ethics Committee

新界西·醫院聯網
New Territories West Cluster

聯網辦事處 Cluster Office
屯門醫院 Tuen Mun Hospital
Tsing Chung Koon Road, Tuen Mun, New Territories, Hong Kong. Tel: (852) 2468 5111 Fax: (852) 2455 1911
新界屯門青松觀路 電話：(852) 2468 5111 傳真：(852) 2455 1911

NTW Cluster Clinical & Research Ethics Committee
新界西醫院聯網臨床及研究倫理委員會

Confidential

Our Ref.: (3) in NTWC/CREC/695/09

24 February 2009

Dr MAN Wai-kwong David
Associate Professor
Department of Rehabilitation Sciences
The Hong Kong Polytechnic University

Dear Dr MAN

Application for Ethics Approval
Clinical Research Study

Study Title: An intelligent virtual reality cognitive rehabilitation (IVRCR) system for people with acquired brain injury (ABI)

Principal Investigator: Dr MAN Wai-kwong David, Ass. Prof., HK PolyU

Study Site(s) Approved: Tuen Mun Hospital

I am pleased to inform you that the NTW Cluster Clinical & Research Ethics Committee has reviewed your application and approval was given to you on 20 February 2009 for conducting the above Study in accordance with the following documents submitted:

1.	Clinical Research Ethics Review Application Form;
2.	Letter from Research Office, The Hong Kong Polytechnic University dated 2 May 2007 – Confirmation of Registration & Transfer from MPhil to PhD;
3.	Study Protocol;
4.	參與研究邀請書 dated 20 January 2009, Chinese Version;
5.	Patient Consent Form: 5.1 English Version; 5.2 Chinese Version;
6.	Investigator's Conflict of Interest Declaration Form: 6.1 Dr MAN Wai-kwong David, Principal Investigator; 6.2 Dr LAU Fat-chuen Andy, Co-investigator;

新界西・醫院聯網
New Territories West Cluster
聯網辦事處 Cluster Office
屯門醫院 Tuen Mun Hospital
Tsing Chung Koon Road, Tuen Mun, New Territories, Hong Kong. Tel: (852) 2468 5111 Fax: (852) 2455 1911
新界屯門青松觀路 電話：(852) 2468 5111 傳真：(852) 2455 1911

7.	CV of Principal Investigator.

Please note that you are required to adhere to the following conditions:

1. Do not deviate from, or make changes to the study protocol without prior written approval of the NTWC-C&REC, except when it is necessary to eliminate immediate hazards to research subjects or when the change involves only logistical or administrative issues.
2. Report the followings to NTWC-C&REC: (i) study protocol or consent document change (use 'NTWC CREC001F7'), (ii) serious adverse event (use 'NTWC CREC001F8'), (iii) new information that may be relevant to a subject's willingness to continue participation in the research.
3. Report research progress [use "NTWC CREC001F9a"] to NTWC C&REC at 12-monthly intervals until study closure. Submit a final report [use "NTWC CREC001F9b"] to the NTWC C&REC upon research completion.

(Forms down-loadable from http://ntwc.home/ccrec/*)*

The NTW Cluster Clinical & Research Ethics Committee serves to ensure that research complies with the Declaration of Helsinki, ICH GCP Guidelines, local regulations and HA policies.

Yours sincerely

(Alfred CHAK)
Secretary
NTW Cluster
Clinical & Research Ethics Committee

cc Dr POON Hak-kin, CC (OccTh), NTWC

Secretary of NTW Cluster Clinical & Research Ethics Committee
Room 5.130, Rehabilitation Block, Tuen Mun Hospital, Tuen Mun, N.T. Tel. No.: 3767 7553 Fax No.: 2464 4643
醫院管理局
HOSPITAL AUTHORITY

HA 1110/NTWC

Appendix 16

同意書

研究項目名稱 ： 人工智能虛擬實景認知訓練治療效果研究

研究員姓名 ： 文偉光副教授、邵志強助理教授、葉智斌先生

		請在方框中加√
1.	我已閱讀及明白這份參與研究資料書 (___/___/____)，並且已經獲得提問的權利。	☐
2.	我明白我的參與完全出於自願並且可以在任何時候退出，而無需任何理由。我的決定不會影響我所受到的醫療待遇和法律權利。	☐
3.	我明白此研究的有關人員會查閱我的醫療記錄，我同意授權有關人員查閱我的記錄。	☐
4.	我同意參與這項研究。	☐

參與研究病人／監護人姓名	日期	簽名
*見證人姓名 (如適用)	與病人關係	簽名
*獲取同意者姓名 (如不是研究人員)	日期	簽名
研究人員姓名	日期	簽名

如有任何有關這項研究的問題或緊急情況，請電 27664845 與研究員葉智斌聯絡。

Patient Consent Form

Title: An intelligent virtual reality cognitive rehabilitation (IVRCR) system for people with acquired brain injury (ABI)

Name of Researcher: Dr Man Wai Kwok, Dr. Shiu chi Keung & Mr Yip Chi Bun

Please initial box

1. I confirm that I have read and understood the information sheet dated ___/___/___ for the above study and have had the opportunity to ask question.	☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.	☐
3. I understand that my medical notes may be read by responsible individuals concerned in this research. I give permission for these individuals to have access to my records.	☐
4. I agree to take part in the above study and to cooperate fully with the researcher.	☐

Name of Patient/Guardian	Date	Signature
Name of Witness (if applicable)	Date	Signature
Name of person taking consent (if different from researcher)	Date	Signature
Researcher	Date	Signature

In case of any emergency/any questions related to this study, please contact Mr. Yip Chi Bun at 27664845