Assessment of Prospective Memory using Immersive Virtual Reality Technology

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Doctoral Dissertation

Assessment of Prospective Memory using Immersive Virtual Reality Technology

没入型仮想現実を用いた展望記憶の評価に関する研究

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Abstract

Prospective memory, as a form of memory, is the ability that refers to remembering to take actions in the future. Prospective memory is frequently used in our daily live and is important in maintaining everyday social communications. For example, taking medicine after breakfast or meeting with someone at a certain time.

As a standard psychological paradigm, slide-based task has been developed for measuring prospective memory performance in laboratory settings. At present, the slide-based task is used in evaluating prospective memory performance and prospective memory related neuroimaging studies. Because the widespread use of slide-based task, some researchers realize that basic laboratory level of psychological paradigm cannot reflect all prospective memory processes in real-world condition. In recently, some studies, used 3D modeling to measure the prospective memory performance under real-life conditions by designing a virtual experiment environment, and these studies show the significant potential in using Virtual Reality (VR) technology to assess real-life related prospective memory function. With the increasing use of VR, VR based approach has become the “hotspot” and is widely used in psychology, engineering and entertainment. VR refers to the environment we build by software which can simulate the user's physical presence. Unlike 3D modeling technology, VR generally uses a

head-mounted display to build immersive VR platform that can create a more life-like experience.

On the other hand, with the advancement of neuroimaging technology, positron emission tomography (PET), electroencephalography (EEG), functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS) have been developed and widely be used in memory researches. It was found by using slide-based task, that the performance of prospective memory will be accompanied by the activation in rostral prefrontal cortex (BA10).

However, when we are using VR system with immersive VR device to study neural correlation of VR prospective memory task, there are several limitations for most of neuroimaging technologies such as PET, EEG and fMRI. Therefore, using fNIRS can avoid the problems. As the noninvasive neuroimaging technique, fNIRS is used to localize, monitor the brain activation, and measure the change in the hemoglobin oxygenation state. The fNIRS is a non-invasive, portable and generally worn on the forehead, where the BA10 of brain can be measured related to prospective memory activation. fNIRS makes it possible to be used together with the immersive VR equipment, simultaneously.

The objective of this research is to develop a VR technology so as to realize assessment of Prospective Memory performance during everyday life. The research aims to clarify the following three issues:

1) Whether the VR task we developed can be used to test prospective memory performance in real-life conditions comparing with the task performance with a

standard slide-based task.

2) With the use of fNIRS, whether can we investigate BA10 function during performing the VR based prospective memory related task.

3) Whether the comparison of the BA10 activities during the slide-based task and the VR task can lead to discovery of deeper potential relevance between the classical laboratory setup prospective memory and the prospective memory that closer to reality.

In detail, firstly, we developed a real-life test environment using the immersive VR technology and asked the 10 young subjects to perform shopping task in it. By comparing with the results from slide- based task, we found that, the performance of slide- based task is much better than that of the VR based task, however, the reaction times of the two tasks have high relationship.

Therefore, it is clear that, immersive VR task has the potential to evaluate perspective memory more accurately in daily life condition.

Secondly, we used the fNIRS to record subjects' brain activities when they are performing prospective memory tasks in immersive VR environment. 10 subjects were asked to perform prospective memory tasks in a virtual environment while wearing a VR headset and an fNIRS device. By comparing the hemodynamic changes in BA10 of the prospective memory component and the ongoing component, the result shows that VR prospective memory task can also induce more activation at BA10. Making use of the fNIRS technique provides a feasible way to measure BA10 activity in simulated real life environment using immersive VR device.

Finally, we used the immersive VR technology to simulate prospective memory performance in real life environment and used the fNIRS to record rostral prefrontal cortex activities in it. By comparing the results with the fNIRS data from slide- based task, this study provides that the activation of BA10 in VR task is greater than slide-based task, and VR task have the potential to find the particular area of BA10 that connecting with the prospective memory performance of our daily live.

Contents

Chapter 1
Introduction

Prospective memory is important in our everyday life, and it is a central that connect to normal functioning. Evaluation of prospective memory also can reflect the severity of cognitive ability regression. For this reason, the study of prospective memory has not yet been neglected until recently. Previous studies have developed slide based task and real-life based task to evaluate prospective memory capability in different conditions. To measure brain activities in laboratory setting prospective memory task, with the use of slide-based task, previous studies also found that the activation of rostral prefrontal cortex was related to the Prospective memory performance. However, as a new technology that can create a realistic test environment, immersive virtual reality (VR) has not yet been widely used in evaluate prospective memory or measure brain activities of prospective memory. In this study, we developed a VR system with immersive VR device to evaluate prospective memory function under simulated daily life condition. This system is designed for daily life routine, such that the task tries to mimic a typical shopping experience in a shopping area. In addition, not only used a slide-based task to compare with the task performance of VR task. But also, used the functional near-infrared spectroscopy (fNIRS) to record rostral prefrontal cortex activities, and measuring the activation of rostral prefrontal cortex in slide-based prospective memory task and VR prospective memory task.

1.1 The Importance of Prospective Memory

Remembering to buy a bottle of Coke on the way back to home, remembering to take medicine after breakfast, and remembering to return a book to library at Monday morning are the examples of prospective memory. Our day lives are permeated by huge numbers of prospective memory, and prospective memory performance determined the major part of our life quality. However, most memory function failures in day lives are the failures of prospective memory recall. In 1984 (Crovitz & Daniel, 1984), Crovitz and Daniel asked participants to record their instances of forgetting in the diary that over a week longer. In the study, the result shown that half of the memory forgetting can be interrelated to the performance of prospective memory. Recently, with the improved quality of life, the number of studies on prospective memory risen dramatically (figure 1.1), a lot of researchers has been pay attention to find the method that can be evaluate prospective memory function and understanding the neural basis of prospective memory.

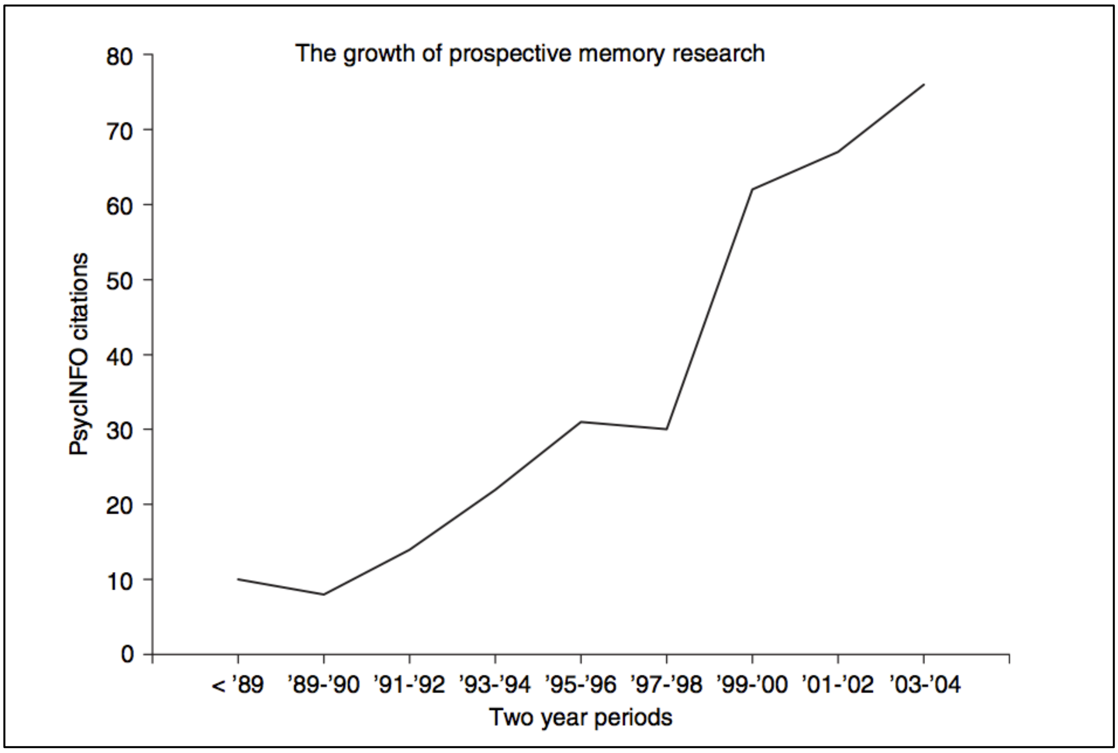


Figure 1.1 The growth of prospective memory research in the PsychINFO database (Marsh, 2006).

1.2 Prospective Memory Research Paradigms

The methods for investigating prospective memory can be divide into the out-laboratory paradigm and the laboratory paradigm.

1.2.1 The out-laboratory paradigm

For study the behavior of prospective memory at outside of laboratory, Maylor (1990) asked participants to take telephone for him at the particular time. The result shown that conducted participants to do daily routines can be used for investigating prospective memory. In another study (Marsh et al. 1998), Marsh asked participants to list the plan of activities for the next week. After one week later, Marsh asked participants to indicate which activities had been performed and which had not been. Then, participants were required to explain the reason of the activities that they were not performed. This study shown that, examine the success of participants remember to carry out their own activities, can been used for examine prospective memory under daily life conditions.

On the other hand, study prospective memory in outside laboratory environment have an apparent limitation. That is the difficulty to control variables and strategies when participants performing the "real-life task". For example, after participants go out of laboratory, they could use memo to note the task.

1.2.2 The laboratory paradigm

Maylor (1993) developed the first standard psychological paradigm named slide-based task to evaluating prospective memory performance in the laboratory setting. Basic slide-based task is conducted by giving participants instructions to perform a specific action when a target condition is met. As the ongoing component of the task, participants are also required to perform another action, the ongoing action, such that they are receiving constant background stimulus. The ongoing action should be trivial, such as comparing the length, size, or colors of an item (figure 1.2), and must be different from the action required by the prospective memory component, which is the target condition. A typical laboratory setup for slide-based task should follow five points (Einstein & McDaniel, 2005): 1) a slide-based task must have instructions and practice trials for the participants; 2) the prospective memory instructions should be presented to the participants; 3) a delay is introduced during which participants perform other activities; 4) reintroduce the slide-based task without reminding participants of the prospective memory component; 5) the prospective memory target condition occurs several times in the slide-based task, and prospective memory performance is measured by the participants' response time (RT) when the target condition occurs.

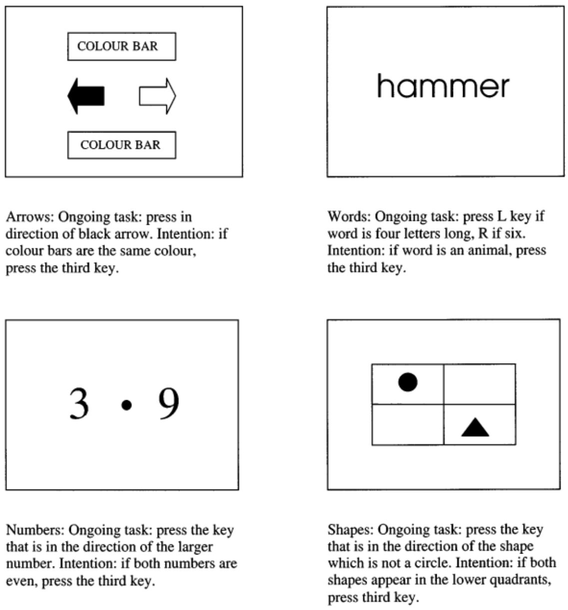


Figure 1.2 The type of slide-based task in common prospective memory studies (Burgess, 2001).

However, With the widespread use of slide-based task, many researchers came to realize that this basic laboratory setup cannot reflect all the prospective memory processes under real-world conditions. There are two main reasons why laboratory setup (such as slide-based task) pro- vides limited predictive information. Firstly, everyday real-life prospective memory demands are well learned and determined by individual's life experience, so they are different from the prospective memory demands in laboratory tasks (Dismukes et al. 2008). Secondly, laboratory experiments have traditionally focused on quantifying brain damage, rather than appraising prospective memory functional performance in real-life condition (Titov & Knight, 2001). While laboratory experiments have been useful in understanding, basic processes related to encoding, storage, and retrieval of prospective memory (Kliegel et al., 2008), prospective memory tasks derived from laboratory settings, however, may not simulate the prospective memory demands placed on the memory in the real world (Titov & Knight, 2001).

1.2.3 The VR task

In order to measure the prospective memory performance of real world conditions in laboratory settings, the task requires real world-based design and real world- like environment that can be controlled. To overcome this obstacle, (Titov & Knight, 2001) designed and constructed a standardized prospective memory testing task with video-based technology, called the Prospective Remembering Video Procedure (PRVP) to assess prospective memory performance by stimulating everyday memory-based activities with video recordings. The procedure required participants to complete everyday memory-based actions in response to the observed cues while watching a video recording. The video presents a First-person perspective of walking through a shopping district to create the feeling of a shopping trip. Based on the result of the study, Knight considered the video recordings of everyday activities can be used as experimental measures of prospective memory with high ecological validity. Moreover, the study showed that participants' task performance of PRVP sensitively varies with environment in the task. In his later work, Knight also at- tempted to assess the impact of old age and noisy environment (Knight et al., 2008) using a similar setup. He designed a computer-based platform to simulate a shopping street, and linked a set of 1200 photographs of street scenes that allowed participants to walk along "the virtual street". As for the prospective memory task in this study, participants were required to respond to different cues, such as "if you hear a dog barking, tell me the name of the shop in front of you". The result showed a significant contrast between young and elderly people. Elderly people had difficulty remembering future intentions, even with naturalistic stimuli. In addition, the noisy environments have a particular impact to older adults' prospective memory performance. This study suggested that the use of computer-based environments to measure functional cognition deficits should be encouraged.

With the advancement of 3D graphics technology, some studies used 3D modeling to design virtual experiment environment. For testing cognitive function performance of brain-damaged subjects, Okahashi et al. (2013) developed a virtual shopping test (VST) with 3D modeling technology. This VST task has Japanese style shopping street environment with shops on both sides of road. All the shops have a signboard written in Japanese. Participants are required to buy items and perform some actions in the VST. As a result, it is able to evaluate attention ability and everyday memory performance in patients with brain damage, and it has shown that the completion time of the VST increased by age.

While VR technology has been used in assessing prospective memory performance, it has also been applied on the training front. Mitrovic et al. (2014) developed a 3D virtual model-based task to try to improve patient's prospective memory performance. In this study, the task environment is a house with common household objects and garden. Participants execute tasks and interact with objects by performing various actions, such as turning on a TV set or using the cooking stove. As a training study, Debarnot et al. (2015) used the theta burst stimulation (TBS) technique to stimulate the left frontopolar cortex, which has been shown to enhance prospective memory performance in aged subjects. The behavioral effects were evaluated by a 3D model-based task. In this task, Debarnot designed a virtual city environment which has one road and 12 connecting scenes. It also included common city objects such as buildings and stores. After the TBS, participants entered the learning stage to learn how to detect prospective memory cues. After the training, participants were asked to navigate in the virtual city. They were asked to stop at the appropriate time or place and tell researchers what action they were supposed to do. Debarnot successfully found the evidence that intermittent TBS might counteract the normal aging of prospective memory performance, which was confirmed by the VR prospective memory task.

Recently, with the increasing use of immersive VR, immersive VR has become the "hotspot", and this technology is widely used in psychology, engineering and entertainment. Immersive VR refers to the environment we build by software, which can simulate the user's physical presence. Unlike 3D modeling technology, immersive VR generally uses a head-mounted display to build immersive VR platform that can create a more life-like experience.

1.3 Neuroscience of Prospective Memory

with the use of slide-based task, Okuda (Okuda, 1998) published a prospective memory neuroimaging study that shown rostral prefrontal cortex was connected to the performance of prospective memory. In 2003, for investigate the role of rostral prefrontal cortex in prospective memory, Burgess (Burgess, 2003) designed three different tasks, and made use of positron emission tomography (PET) to investigate the role of rostral prefrontal cortex in prospective memory. The result showed that by monitor the regional cerebral blood flow changes of rostral prefrontal cortex during tasks were performing. Burgess found the activation of BA 10 was related to the prospective memory performance. This finding was later repeatedly reproduced in other studies (Gilbert, 2006; Gilbert, 2010). Also, several functional Magnetic Resonance Imaging (fMRI) studies are shown that the performance of prospective memory will be accompanied by the activation in rostral prefrontal cortex. (McDaniel et al., 2013; Beck et al., 2014; Cona et al., 2015;). With the advancement of neuroimaging technology, new technique, such as functional near-infrared spectroscopy (fNIRS) have been widely used in research of memory studies, which is used to localize, monitor the brain activation, and measure the change in the hemoglobin oxygenation state. (Jobsis, 1977) In 2015, Oboshi (Oboshi Y, et al. 2015) used fNIRS to monitor rostral prefrontal cortex activity when participants were performing a basic slide-based task. By compare the Δoxyhemoglobin (ΔoxyHb) of the ongoing component and the prospective memory component, Oboshi found a definite relationship between left rostral prefrontal cortex activity and prospective memory performance.

1.3.1 The functional neuroimaging study

The functional neuroimaging study of prospective memory is composition of PET and fMRI studies. For PET study, with the use of PET, Burgess (2003) tried to investigate whether the delayed individual or maintenance of prospective memory was involved with rostral prefrontal cortex. This study used activities of ongoing component as the baseline condition, and compared the activities of prospective memory component to the baseline. As result, he found that the when the prospective memory cue was executing, lateral rostral frontal cortex, right parietal cortex and the precuneus region were not reveal activation. This finding suggest that the function of rostral frontal cortex was more support the maintenance of prospective memory processes during the delay, than the processes that related to the detection of prospective memory cue. For fNIRS study, McDaniel et al (2013) asked participants to performed the ongoing classification task in focal and nonfocal conditions. In addition, participants were under fMRI in the whole experimental session. The result was revealed a clear dissociation of brain, and proved that prospective memory recruited the activity in attentional control areas- rostral frontal cortex.

1.3.2 The event-related potential (ERP) study

Studies of this methodology, can be address to three fundamental issues that related to the neural base of event-based prospective memory. First, the ERP study can be used to identify the temporal dynamics of the neural correlates of prospective memory. Second, investigations with ERP have sought to determine whether the neural correlates of prospective memory can be related to target processing function. Third, the finding of ERP is link the theories of cognitive processes to neural correlates of prospective memory with the described in of prospective memory. The results of ERP study reveal two important findings. “First, with the multiprocess view of prospective memory, these data reveal that both relatively automatic and more resource demands processes contribute to the detection of prospective cues. Second, these data reveal that the N300 and prospective positivity may be coupled to one another, a finding that is consistent with the general architecture of the discrepancy plus search theory” (Einstein et al, 2008).

1.3.3 The fNIRS study

Pinti (2015) used a fiberless fNIRS device to monitor brain activity in a real-word based prospective memory task. In this study, participants are asked to remember to respond to the prospective memory cue, such as a parking meter or a familiar face, while they are performing the ongoing component of task. The fNIRS device settled with the baseline condition before the task was start to perform. As the results, this study suggests that the fNIRS can be used for measure rostral prefrontal cortex activities when participants performing the prospective memory in the real word condition.

In 2015 (Oboshi et al 2015), with the use fNIRS, Oboshi required participants to perform the basic slide-based prospective memory task, and monitor rostral prefrontal cortex activity. The task in this study include a behavior task, and the slide-based task with ongoing and prospective memory components. Compaction between the ΔoxyHb of ongoing component and prospective memory components, Oboshi found that, in rostral prefrontal cortex, the activity of prospective memory component is generally greater than the activity in ongoing component.

1.4 Summary and the Dissertation Focus

Previous studies shown the significant potential in using VR technology to assess real-life prospective memory function. Although some studies (Okahashi et al., 2013; Mitrovic et al., 2014; Debarnot et al., 2015) claimed that they used VR technology to build the task environment, such experiments were only using computer monitor to present the task, which may not be technically regarded as true "VR" experiment environment. Our study using head-mounted display (immersive VR) to create a life-like experience is necessary. We consider the use of immersive VR device will enable us to create an environment that can test prospective memory performance in real-life conditions more naturally and accurately.

Because, study the neural correlation of VR prospective memory task, there are several limitations and problems of most neuroimaging technology (EEG, fMRI). Firstly, the immersive VR device is normally worn on the participants' head. The band for fixing the VR device will be on top and sides of head. Therefore, participants can hardly wear the EEG caps that covered with scalp electrodes precisely. In addition, with the EEG caps, participants cannot take any head movements, and head or body movements will also interfere with the EEG signal. Secondly, utilizing fMRI technique to study the neural correlation of immersive VR prospective memory task will also cause some problems: 1) The fMRI machine is huge and expensive, the cost of experiment will greatly increase. 2) The noise of machine will probably disturb the performance of prospective memory task, which has been proven by Knight's study (Knight, 2008). 3) The electro-magnetic field interference with almost all the electronic equipment, which makes it impossible to do experiments with immersive VR devices. To avoid the third issue, past studies used a mirror to reflect a monitor placed outside of fMRI machine. However, for using monitor to do neuroimaging study of VR prospective memory experiments, the remaining problems still exist, and the experiment environment without the use of immersive VR device may not be regarded as a true VR experiment environment technically. Compare to most neuroimaging technology, using fNIRS to study the neural correlation of immersive VR prospective memory task is a best choice at present. The fNIRS allows the participants to be almost free in movements, and it ears on the forehead, and that is just the prefrontal cortex of brain. In this study, we were used the fNIRS to investigate prefrontal cortex function, during the prospective memory task in the immersive VR environment. In addition, according to the increasingly recognized potential of VR task to test the prospective memory in a real-life test environment, we consider that explore the neural correlation of slide-based prospective memory task and VR prospective memory task is necessary, and should discover deeper potential relevance about classical laboratory setup.

1.5 Dissertation Overview

This paper is organized by these chapters:

Chapter 2: Background and knowledge of the rostral prefrontal cortex function, and the theory of fNIRS. This chapter presented brain area of rostral prefrontal cortex and the detail about fNIRS techniques.

Chapter 3: As a new technology that can create a realistic test environment, immersive VR has not yet been widely used in evaluate prospective memory. We developed a real-life test environment using the immersive VR technology and asked the subjects to perform common shopping task in it. In addition, we performed the task of 10 healthy young participants, and the result suggest that both VR task score and RT are related to the PM "target" search ability, and this has not been discussed in previous VR studies. In slide-based task, more than half participants are receive a perfect score of 30, and can be add to the "ceiling effect". However, the VR task score is not shown this phenomenon, which means the VR task is able to more reliably assess real-life PM ability in controlled laboratory setting.

Chapter 4: To measure the real-life like prospective memory ability in laboratory settings, present studies used photograph-base, video-base and VR-base to simulate real-like environment. However, the more realistic real-like environment we can simulate, the harder we can monitor the brain activation. As a solution, we used fNIRS technique to record the brain activity when participants performing the prospective memory task in VR environment.

Chapter 5: We consider that explore the neural correlation of slide-based prospective memory task and VR prospective memory task is necessary, and should discover deeper potential relevance about classical laboratory setup. In order to testify this idea, we used a VR system with an immersive VR device to simulate prospective memory function in daily life condition, and a standard slide-based task to compare with the VR task.

Chapter 6: General discussions on the assessment of prospective memory using immersive virtual reality technology, and the final conclude.

Chapter 2

Background and Knowledge

2.1 The Rostral Prefrontal Cortex

2.1.1 Function of neuron

Neuron (figure 2.1), as the role in transmitting neural signal and charge the electrochemical signal, have almost 100 billion numbers in human brain. For the structure of neuron, as the biggest cells, cell body (soma) consist of nucleus and organelles. Genetic code, that constitute by protein synthesis is filled the nucleus. All neuron includes a lot of dendrites and merely one axon. Various processes, dendrites and axon extending out from cell body. For the bridge to communication with other neurons, dendrites transmit the information of electrochemical signals from neuron to neuron. Axon only send the information to the cell body of another neuron. The terminal arborization of cell body is synapse enable the electrochemical signal to communication between neurons. Presynaptic and postsynaptic is the two form of the synapse, they are reflecting the information flow that direction from axon to dendrite.

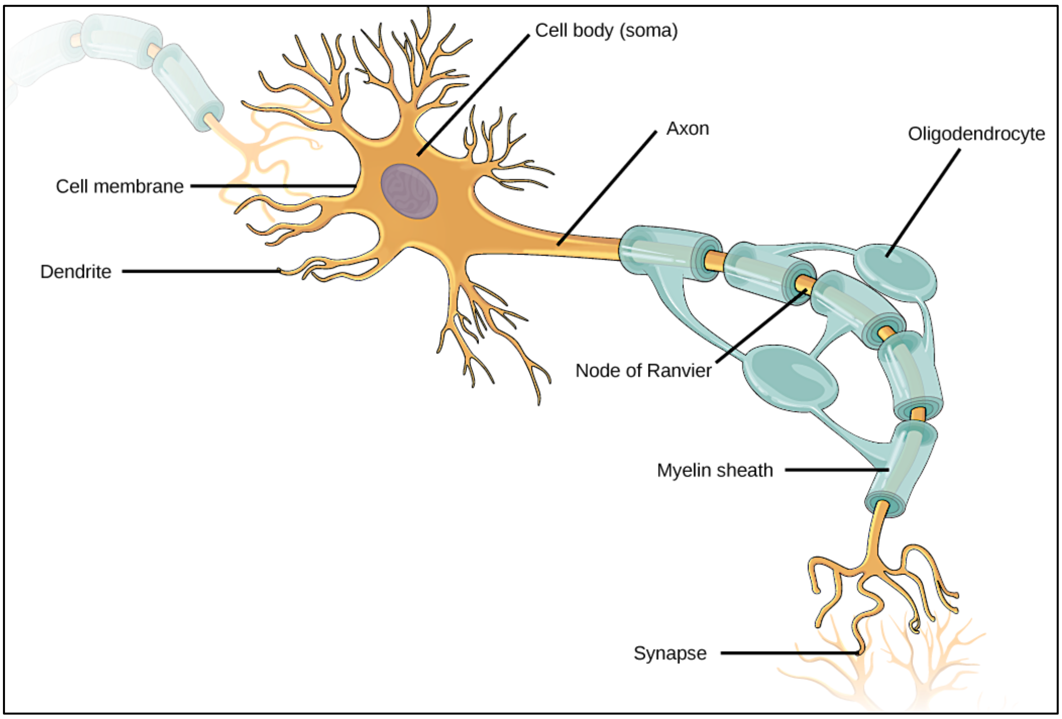


Figure 2.1 The neuron (OpenStax CNX, 2013).

2.1.2 The role of rostral prefrontal cortex

The brain is control our body to preform actions and do response to outer-stimulation from the environment. For the area of human brain, rostral prefrontal cortex (figure 2.2) is involved in the memory capability, attention, executive functions, and above all, the prospective memory performance. As the area that we least understood, rostral prefrontal cortex is the "largest cytoarchitectonic area" in the brain. rostral prefrontal cortex can be divided into three part of areas, the 10p, the 10m and the 10r. The frontal pole is possessed by the 10p, and ventromedial part is covered by 10m and 10r. Although the rostral prefrontal cortex has three parts, boundaries of these three parts are vague to demarcation, and hard to draw the shape of them.

Figure 2.2 The rostral prefrontal cortex area in brain (the red area).

2.2 Functional Near-infrared Spectroscopy Technique

2.2.1 The principle of fNIRS

As a non-invasive technique to monitoring the oxygenation that can be measure the cerebral blood flow, the fNIRS is used for monitor the hemodynamic change of brain and corroboration the activation of the brain area. The fNIRS optical data is basically follow the Beer-Lambert law (Spectratech Inc., 2009), and calculate the changes. As a certain density, the incident light can be assumed to the I_0. The I is the solution of pass thorough light, and the absorbance is expressing as the A (equation 2.1).

$$A = -\text{In}\left(\frac{I}{I_0}\right) = \varepsilon c d \qquad \text{(Eq. 2.1)}$$

As the modified Beer-Lambert Law that for adapted to fNIRS, the equation 2.2 shown the expression for describes the optical attenuation in the highly scattering medium environment. The ΔA express the change of absorbance and the ΔI express the amount change of transmissive light. The Δc is the change of concentration, and the *d* is the average length of light path, then the Δs is the effect change of scattering. In equation 2.3, the computing method of oxyhemoglobin and deoxyhemoglobin has been shown. The I0 (λ) is the specific wavelength of the incident light to subjects. The scattering of incident change light amount that absorption by subjects and return to external subjects' body, is expressed as ΔI (λ). After that, the total hemoglobin change is calculated by the sum of oxyhemoglobin and deoxyhemoglobin concentration change.

$$\Delta \mathrm{A} = -\mathrm{In}(\Delta I / I_0) = \varepsilon \Delta \mathrm{c} \langle d \rangle + \Delta \mathrm{s} \qquad \text{(Eq. 2.2)}$$

$$\Delta \mathrm{A}(\lambda) = (\ \varepsilon\ \mathrm{oxy}\ (\lambda) \Delta \mathrm{Coxy} + \varepsilon\ \mathrm{deoxy}\ (\lambda)\ \Delta \mathrm{Cdeoxy})\ \langle d \rangle\ + \Delta \mathrm{s} \qquad \text{(Eq. 2.3)}$$

2.2.2 Data obtainable from fNIRS

The fNIRS system we used in this study is OEG-16(Spectratech Inc. Tokyo, Japan). For this system, the measurement of channel is used as the standard, and described as the 16CH. Signals in the combinations are obtained at the same time, when the actual light demodulating circuit to taking the advantage of the characteristic that the multi-channelization can be done in the smooth operator environment.

In the fNIRS device (figure2.3), the light-emitting parts of LD1~LD6 is emitting near-infrared lights. Then the regardless of each signal strength is measured by the light-receiving parts of PD1~PD6 in simultaneously. That means, as a whole part, light wavelength signals of 36 channels is able to measure. In addition, because there a two wavelength light sources represent as λ1 and λ2, the whole system is measure 72 channels of the light signals in total. With the function of spread spectrum modulation/demodulation circuit, the alignment of LD1~LD6 and PD1~PD6 signals can be arrange naturally, and the measurement channel becomes 16CH in this arrangement.

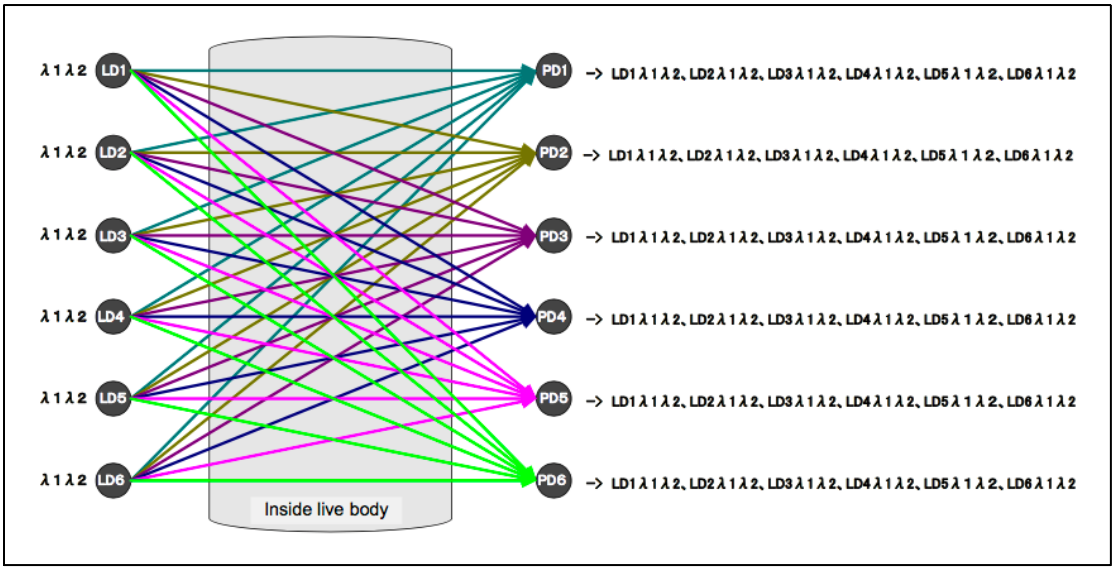


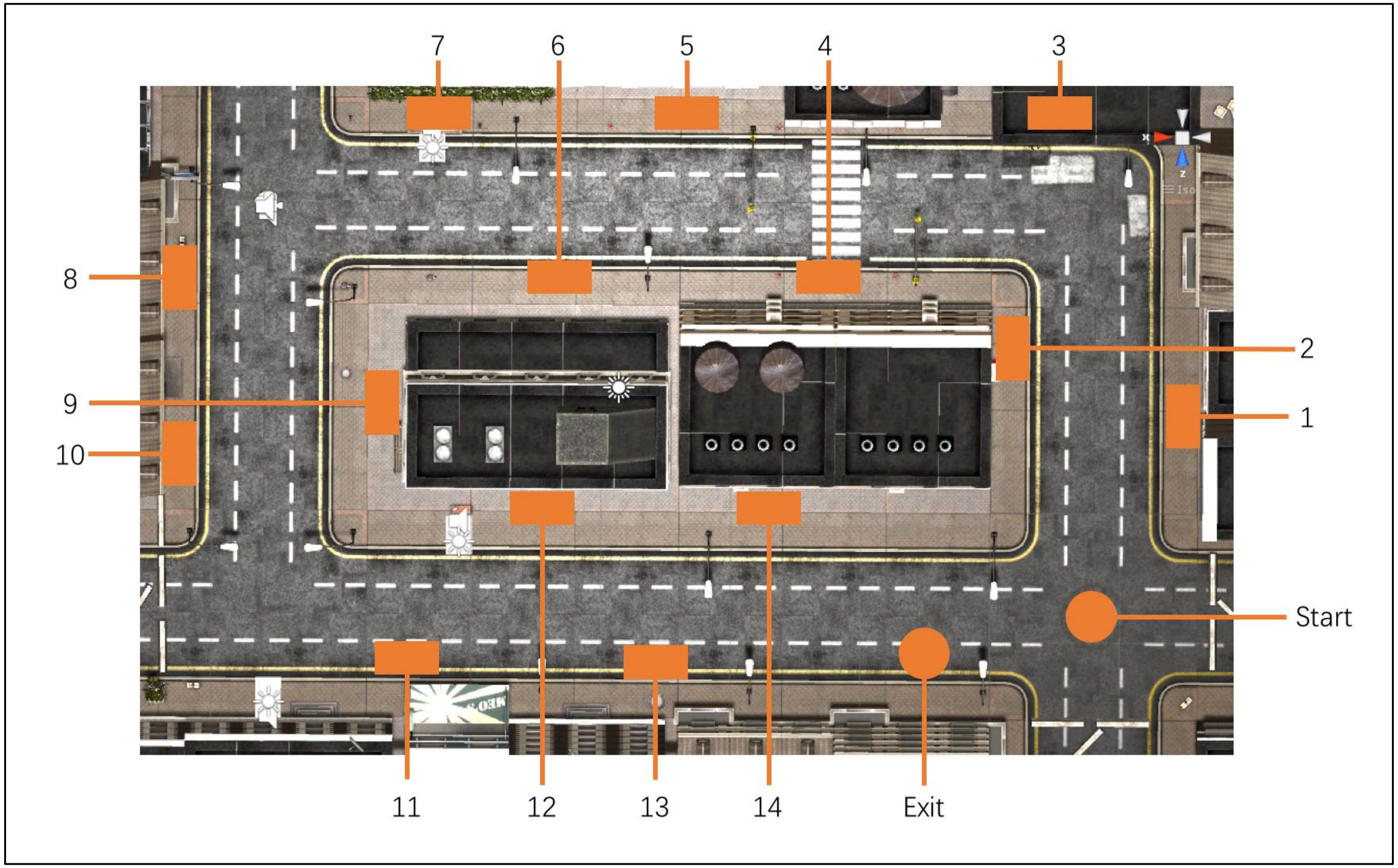
Figure2.3 Data obtainable of the fNIRS device (Spectratech et al., 2009).

2.3 The Basic Settings of VR Environment

The VR display system includes a computer with desktop monitor and immersive VR device (Oculus Rift Development Kit 2, with 960×1080 per eye resolution). The desktop monitor is used for observe participants' movement in the VR environment.

The VR environment consists of a street with 12 shops (fish shop, fruit shop, coffee shop, greengrocer, flower shop, hardware shop, book shop, glasses shop, vending machine, clothes shop, drugstore, meat shop) and two special action points (dustbin, mailbox). Participants can be start the task in a start point, and exit the task in an exit point (figure2.4).

There are 3 different types of external appearance in the VR environment: the exit, shops and action points (figure2.5, 2.6, 2.7). In particular, shops and action points have both different types of shape and menu. In shopping tasks, participants require to buy the correct item in the shopping menu (figure 2.6). In action task, participants require to take the action by select the icon in the action menu (figure 2.7).



1. Fish shop
2. Fruit shop
3. Coffee shop
4. Greengrocer
5. Flower shop
6. Hardware shop
7. Book shop
8. Glasses shop
9. Vending machine
10. Clothes shop
11. Dustbin
12. Drugstore
13. Mailbox
14. Meat shop

Figure2.4 The constitution of VR environment.

Figure2.5 The exit of VR environment.

Figure2.6 The shop and the shopping menu.

Figure2.7 The action point and action menu.

Chapter 3

A Novel Approach for Assessing Prospective Memory Using Immersive Virtual Reality Task

Prospective memory can maintain our ability to living independently, which is important for our daily lives. Evaluation of prospective memory can be reflecting the severity of cognitive ability regression. Previous studies developed slide-based task and living-based task to evaluate prospective memory performance in different conditions. However, as a new technology that can provide a more realistic environment, immersive virtual reality is not yet used in this area. Our study first uses immersive virtual reality technology to develop a more real-life like test environment. As a result, by comparing with slide-based task, our VR task can show some potential to evaluate the perspective memory in daily life condition more accurately.

3.1 Background

For testing prospective memory performance in laboratory settings, slide-based prospective memory task – as a standard psychological paradigm had been developed (Maylor, 1993). Basic slide-based task is by giving participants intention to perform when the target item appear at the later time. More specifically, participants are required to keep response stimulus by performing an intended action (such as, comparing the length, size, or colors of the item) in an ongoing setting. In prospective memory component, participants are required to perform the specific action that is different from ongoing component action at the appropriate moment when specific stimulus was shown.

Because the widespread use of slide-based task, some studies realize that this basic laboratory psychological paradigm cannot reflect all prospective memory processes in real-world condition. For constructing a standardized prospective memory testing procedure with video-based technology, Knight (2001) designed the Prospective Remembering Video Procedure (PRVP) to assess prospective memory performance by stimulating everyday memory-based activities with video recordings. The study showed that participants' task performance of PRVP sensitively varies with environment in the task. In order to lead to more information about this phenomenon, Knight attempted to assess the impact of old age and noisy environment (knight, 2008). He designed a computer-based platform to simulate a shopping street, and linked a set of 1200 photographs of street scenes that allow participants to walk along "the virtual street". As for the prospective memory task in this study, participants were required to respond to different cues, such as "If you hear a dog barking, tell me the name of the shop in front of you". The result showed that a significant contrast between young and elderly people. Elderly people had difficulty remembering future intentions, even with naturalistic stimuli. In addition, the noisy environments have a particular impact to older adults' prospective memory performance. This study suggested that the use of computer-based environments to measure functional cognition deficits should be encouraged.

With the progress of 3D graphics technology, some study used 3D modeling to design virtual experiment environment. For testing cognitive function performance of brain-damaged subjects, Okahashi et al. (2013) developed a virtual shopping test (VST) with 3D modeling technology. This VST task has Japanese style shopping street environment with shops on both sides of road. All the shops have a signboard written in Japanese. Participants are required to buy items and perform some actions in the VST. As a result, it is able to evaluate attention ability and everyday memory performance in patients with brain damage, and it was clarified that the testing time of VST is increased by age.

On the other hand, Mitrovic (2014) developed a 3D model based task to train prospective memory performance. In this study, the task environment is a virtual house with common household objects and garden. Participants perform tasks and interact with objects by various actions, such as turning a TV set on or off. However, Mitrovic only designed this 3D model based task and assuming that it is effective, but there are no training experiments in this study. As a training study, Debarnot (2015) used theta burst stimulation (TBS) techniques to stimulus left frontopolar cortex (BA10), which enhance prospective memory performance in aged subjects. In addition, the behavioral effects were measured by a 3D model-based task. In this task, Debarnot designed a virtual city environment that has 1-road and connected with 12 scenes, and included common city objects such as buildings and stores. After the TBS, participants were required to process learning phase, which ensure participants could be easily detect prospective memory cues. After that, action-intention was presented on the screen, participants were required to process testing phase that walk around in virtual city, and they were asked to stop walking at the appropriate time or place to tell experimenter what action they had to do. Debarnot successfully found the evidence that intermittent TBS might counteract the normal aging of prospective memory performance, which was confirmed by 3D model-based prospective memory task.

These studies show assessment of realistic prospective memory function using new graphics technology has significant possibility. In addition, for technical reasons, some of studies (Okahashi, 2013; Mitrovic 2014; Debarnot 2015) designed the task with 3D model based was claimed that they used the virtual reality (VR) technology to build-up the environment. However, such experiments were only using computer monitor to present the task, which may not be regarded as true “VR” experiment environment. In order to simulate realistic prospective memory function, using head-mounted display (immersive VR) to create a life-like experience is necessary. We consider the use of immersive VR device will enable us to create an environment that can test prospective memory performance in real-life condition more naturally and directly. Moreover, there are very few studies that compare the validity of VR task with typical laboratory experiments. Therefore, in our research, we developed a VR system with immersive VR device to evaluate prospective memory function under simulate daily life condition. This system is designing for routine daily life, therefore the task essentially similar as shopping in a shopping street. To make sure the validity of VR task, we also designed a standard slide-based task to compare with VR task.

3.2 Materials and Methods

3.2.1 Participants and procedure

10 healthy young participants were recruited from Kobe University, and their mean age was 25.4 years old. All participants performed both slide-based task and VR task. The whole experiment took 45-minute (15-minute for slide-based task and 35-minute for VR task), and finished in one day (figure3.1). Before slide-based task and VR task, participants were required to perform a demo training section so as to guarantee that the tasks can be performed in a stabilized condition.

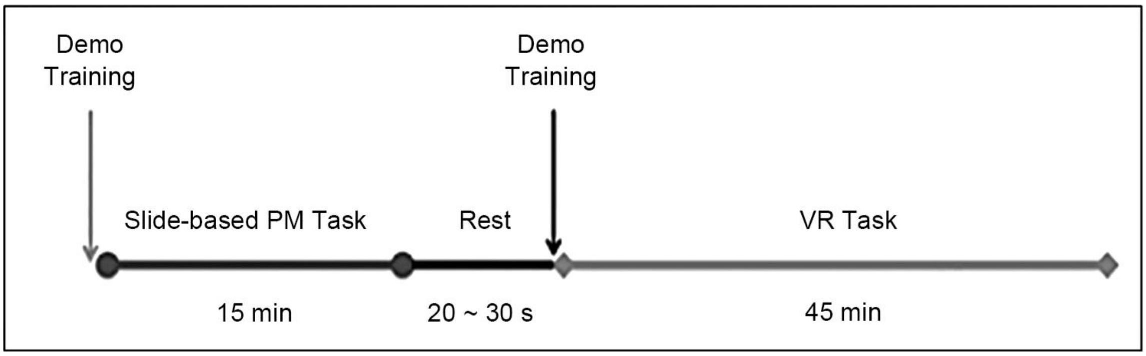


Figure 3.1 The experimental protocol.

3.2.2 Slide-based prospective memory task

The task is based on Burgess et al. (2001)'s number slide task. As shown in figure 3.2, a word "question" was displayed at the center of the black background. The font of figure was in Times New Roman, and font size was 256 pixels. The viewing distance was 57 cm to monitor. Each block of test had 30 trials. The rate of stimulus (one question) was 17 s, with 2 s as the inter-stimulus interval, 3 s for the stimulus and 12 s for a resting period (figure 3.3 and figure 3.4). Participants were required to make responses by pressing keys on the computer keyboard whenever a stimulus was shown. In the stimulus section, numbers were present to participants as stimulus between the center point, with a "." mark in the center of background as in figure 3.2. Whenever a pair of numbers appeared, participants had to press the "left" or "right" key. Press the "left" key when the number on the left side is larger, and press the "right" key when the number on the right side is larger. And when the numbers were both even numbers, press the "up" key instead. The block was designed such that each participant would press the "left" or "right" keys 75% of the time, and the "up" key 25% of the time. Participants would not need to press "left" or "right" keys simultaneously when both numbers are even numbers. This kind of judging number problem is attributed to event-based prospective memory (Burgess et al. 2001). The test task has 30 trials. Before the actual test task, an additional 6 demo trials were presented for practice demo.

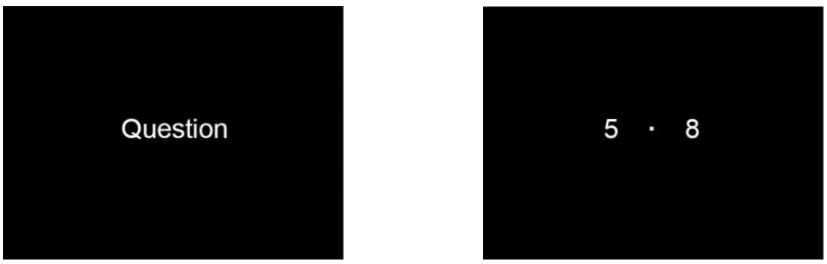


Figure 3.2 Inter-stimulus screen and stimulus screen.

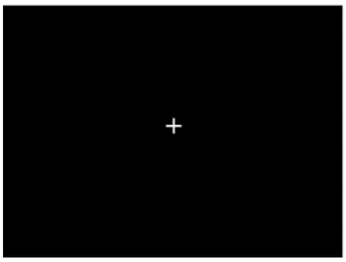


Figure 3.3 Resting screen.

3.2.3 VR prospective memory task

For the immersive VR experiment, the lights in the room were turned off in order to avoid vision interference and the laboratory room was kept quiet. The system includes a computer with a desktop monitor and immersive VR device (Oculus Rift Development Kit 2, with 960×1080 per eye resolution). The VR environment was created with Unity 5.0. Desktop monitor is used for the researchers to observe the participants' movement in the VR task. Participants were wearing the immersive VR device as shown in figure 3.4, and using joystick to move forward or backward. Turning around in VR task required natural body rotation on the chair. In VR task, VR environment was composed of a shopping street with 12 shops as in figure 3.4, two special action points and a bus station (exit). By using the joystick and making body rotation, participants moved in the VR shopping street, buying items and taking actions.

In the VR tasks, participants were asked to buy three items and take two special actions in the VR environment for prospective memory component. Shopping is regard as event-based prospective memory, and the three items are "banana, coke and steak" as in Fig. 6. Each item has both image and text to help participants to memorize it. The two special actions-intentions are event-based: “Send a letter” and “Throw a piece of trash into a dustbin” figure3.5. They were presented in text form. As ongoing errand task component, participants are required to press the joystick button then they read out the numbers when clearly saw the numbers under the shop signboard as in figure3.6.

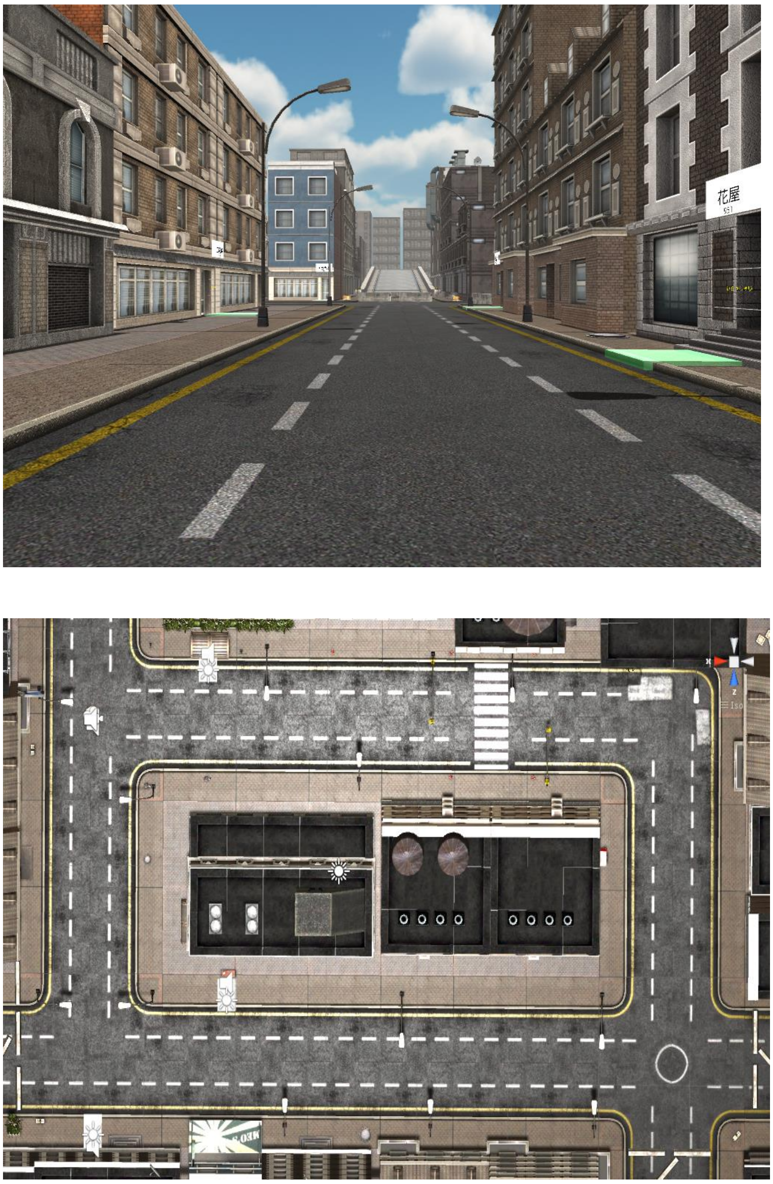


Figure3.4 The view of VR shopping street.

Figure 3.5 Shopping and action list.

Figure 3.6 The example of shop.

3.3 Results

In slide-based task, the score was determined whether a participant was able to press the correct key (incorrect or missed key is considered as an incorrect response). The RT of slide-based task was referred to the time period between stimuli had been shown on screen and the key had been pressed by participants.

In VR task, if a participant forgot to do the ongoing cue (read out signboard number) or do the prospective memory actions, it would be marked as an incorrect response. For example, participant who clearly saw the number under the coffee shop signboard, but forgot to press button or read out the numbers is also considered as an incorrect response. The RT of VR task referred to the time period between seeing the menu and buying an item.

SPSS was used to analyze the experimental data. Speaman's correlations were used to determine the association between slide-based task and VR task. Speaman's correlations were performed not only between task performance (correctness, as task score) of slide-based task and VR task, but also between the RT of slide-based task and VR task. However, the RT of slide-based task has two types in data analysis section. 1) The whole block slide-based task RT that include both ongoing component (judge which number is greater) and prospective memory component (judge whether numbers are even numbers); 2) the slide-based task RT only includes prospective memory component. Comparison between the two tasks was performed with Two-Tailed Test, and if $p < 0.05$, statistical significance differences were reported as significant.

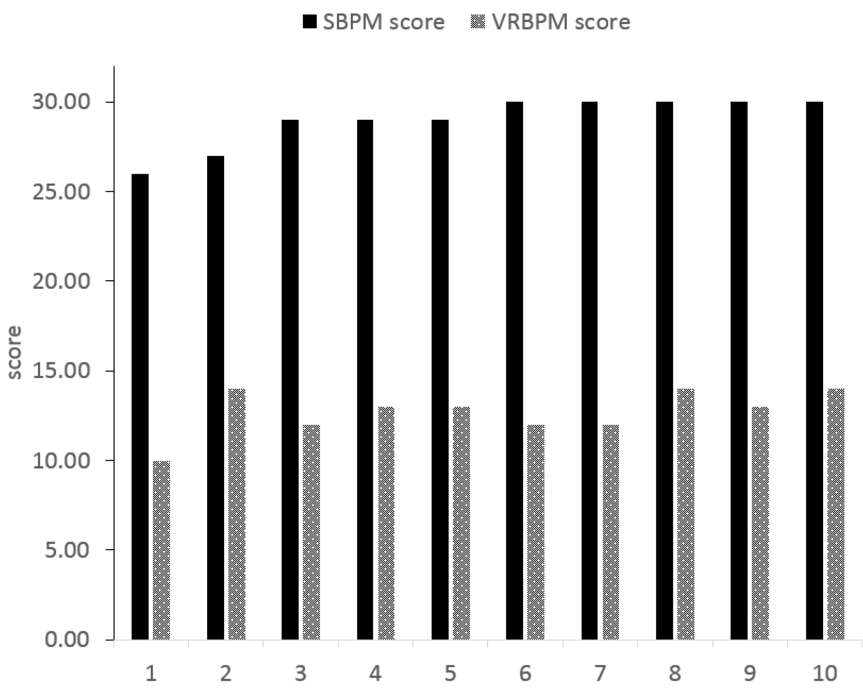
By comparing the slide-based prospective memory task score and RT, we found that there was no significant correlation between slide-based task score and whole block RT ($r = -0.32$, $p = 0.37$). Also, the slide-based task score and prospective memory component RT had no significant correlation ($r = -0.29$, $p = 0.41$). This result shows that performance has no relation with RT in slide-based task.

With regard to VR prospective memory task, the VR prospective memory task scores were significantly negatively correlated with the VR prospective memory task RT ($r = -0.66$, $p < 0.05$). This result indicates that the better the performance in VR task, the shorter the time will be cost in VR prospective memory task RT.

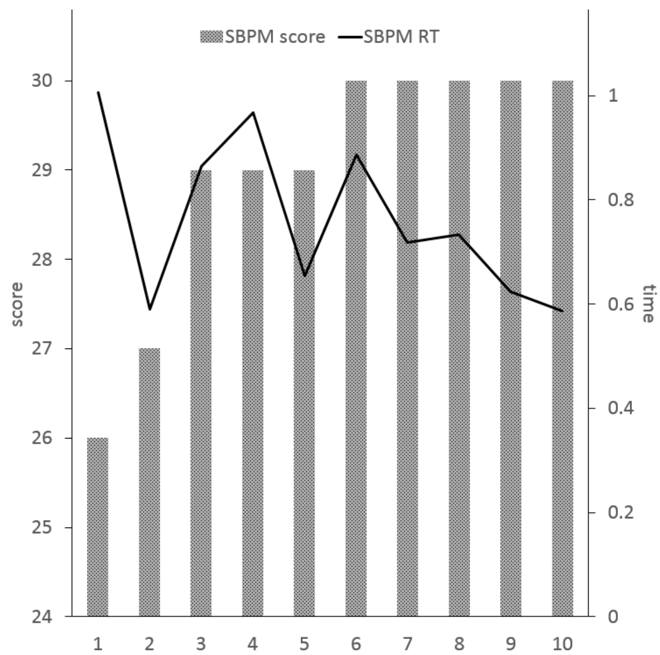
Comparing the slide-based prospective memory task and VR prospective memory task scores, we found that there was no significant correlation between the scores of slide-based task and VR task ($r = 0.22$, $p = 0.53$). The experimental data shows that the slide-based task performance was not related to VR task performance as shown in figure 3.7.

To examine the relationship between slide-based prospective memory task RT and VR prospective memory task performance, the analysis shows that there was significant negative correlation between slide-based task whole block RT and VR task score ($r = -0.81$, $p < 0.01$). Comparing the prospective memory component RT with VR task score shows significantly negative correlation ($r = -0.79$, $p < 0.01$). This result suggests that the shorter the RT cost in slide-based task, the higher the score in VR task.

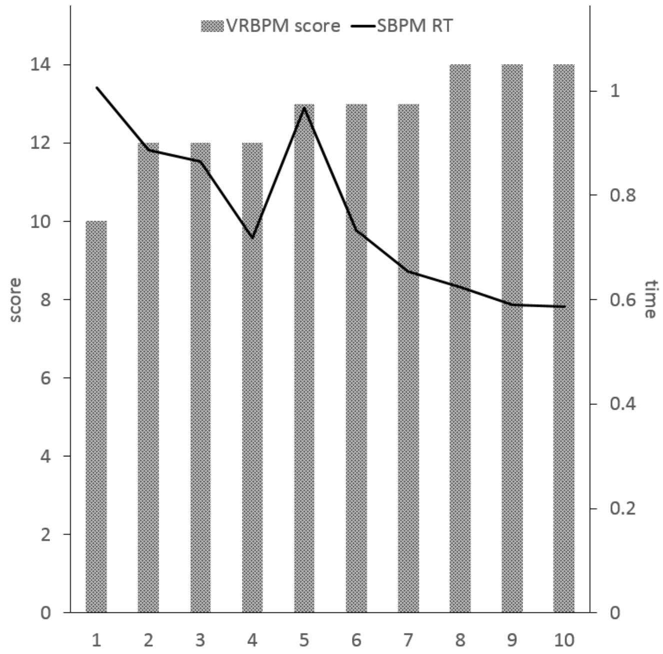
With regard to RT, there was significant positive correlation between slide-based prospective memory RT and VR prospective memory task RT ($r = 0.72$, $p < 0.05$). Also, there was significant positive correlation between prospective memory component RT and VR prospective memory task RT (r = 0.67, p < 0.05). The result indicates that the slide-based task prospective memory RT is correlated to the short time cost in VR prospective memory task RT.



Slide-based (SBPM) task score and VR (VRBPM) task score



Slide-based (SBPM) task score and RT



Slide-based (SBPM) task RT and VR (VRBPM) task score

Figure 3.7 The correlations between slide-based task and VR task.

3.4 Discussion

In prospective memory studies, slide-based prospective memory task was often used in evaluating prospective memory in laboratory environment. Our study developed a system that can simulate the shopping experience in a VR shopping street and evaluate prospective memory performance in daily life condition in a VR environment. Furthermore, thanks to the use of immersive VR device, the VR task environment is closer to real-life experience than previous studies.

For ongoing task control condition, participant was asked to read out the numbers when they can clearly see them under the shop signboard. This setup leads the participant to search for the perspective memory cue (name of shop), while he is performing the ongoing task. With this setup, we purpose that participant's searching behavior can be shown by the VR task.

Our study compares the slide-based task and the VR task with the aim to investigate whether traditional laboratory prospective memory task produces a similar result as prospective memory task for daily life condition in VR environment, and the potential relevance between the two tasks. Based on our result, prospective memory score performance in slide-based task is not relevant to the prospective memory score performance in VR task. Previous studies have shown that slide-based task, as a lab-based task, cannot fully reflect all the prospective memory processes in real world condition (Titov & Knight, 2001; Dismukes et al, 2008). Although our immersive VR task is also lab-based, it provides a more realistic environment and may reflect more prospective memory processes than the slide- based task. As a result, its score may not significantly correlate to the pure lab-based slide-based task. However, in our study, there is a strong negative correlation between the RT of slide-based task and the score performance of VR task. These results show that although slide-based task score performance cannot correlate with VR task performance, the RT of slide-based task is able to relate to the performance part of VR task.

By noticing-search model (Einstein & Mcdaniel, 1996), noticing is an automatic process, but searching process is requiring attention-demanding control and processing efficiency is decided by search ability. RT of slide-based task may be considered as the time cost in searching process. In other words, participant who shows lower RT in slide-based task has a higher "target" search ability, and the one who shows higher RT in slide-based task has a lower “target” search ability. According to the cognitive resource theory (Kahneman, 1973), the total of cognitive resource is limited. If the cognitive load cost increased exceeded the general degree of cognitive resource, the cognitive resource that can be allocate is lesser, so the information process would be affected. In our study, since slide-based task (laboratory environment) requires less cognitive resource than VR task (VR real-world environment), the search ability is not as apparently reflected in task score performance. It could also explain why there was no significantly correlation between slide-based task score and RT. In VR task, we developed a system to simulate and test prospective memory in daily life condition of VR environment. In this VR environment, the cognitive load of the participants was increased. It also consumed more cognitive resource than in laboratory environment. Therefore, in VR task, participants have less cognitive resource to allocate, and search ability differences are able to influence the VR task performance. In other words, by our VR task, we can observe how prospective memory “target” search ability influences task performance. Compared with slide-based task, VR task can accurately assess prospective memory in daily life. VR task RT, which refers to the time it takes to buy an item after the item list had been shown, can reflect prospective memory “target” search ability. That is, the faster the VR task RT is, which means shorter “target” search time cost, correspond to better “target” search ability. In addition, the correlation between VR task score and RT also supported this finding.

Chapter 4

Assessment of Prospective Memory using fNIRS in Immersive Virtual Reality Environment

In order to measure real life prospective memory (PM) ability in laboratory setting, previous studies have used photograph-based, video-based and virtual reality (VR)-based to simulate real life environment. In this study, we used the Functional Near-Infrared Spectroscopy (fNIRS) to record participants' brain activities when they are performing PM tasks in immersive VR environment. 10 participants were asked to perform PM tasks in a virtual environment while wearing a VR headset and an fNIRS device. By comparing the hemodynamic changes of rostral prefrontal cortex (BA10) of the PM component and the ongoing component, the result shows that VR PM task can induce the activation of BA10. In addition, by making use of the fNIRS technique, this study provides a feasible way to measure BA10 activity in simulated real life environment using immersive VR device.

4.1 Background

To ensure task design will not affect the experiment, a typical laboratory task for neuroimaging PM paradigms should have these features (Burgess, 2003): 1) The intention of taking one or more actions might be withheld to perform in some particular stimuli (cue). 2) The intended action should be performed after some period of time. 3) The delay period between creating the intention and occurrence of the appropriate time to act is filled with the activity known as the "ongoing component" of the task - participants are required to perform some other actions, which assure that they are receiving constant background stimulus. 4) The intention (PM) cue should not directly interrupt the process of the ongoing component. In addition, the participants need to recognize the PM cue for themselves. 5) The feedback that makes the participants able to evaluate their task performance is not necessary. Burgess designed three different tasks by following these features, and used positron emission tomography (PET) to find regional cerebral blood flow changes of the Bradman's area (BA) 10 during the tasks. In addition, Burgess found that the activation of BA 10 was related to the PM task performance. With the latter study of PM neuroimaging, Burgess (2003)'s finding has been repeatedly reproduced. At present, the performance of PM accompanied by activation in BA10 has become secure and generally accepted (Gilbert,2006; Gilbert,2010).

About PM tasks design, because the widespread use of slide-based task, some studies realize that basic laboratory psychological paradigm cannot reflect all PM processes in real-world condition (Titov & Knight, 2001; Dismukes et al. 2008; Kliegel et al., 2008). In order to measure the prospective memory performance of real world conditions in laboratory settings, Titov & Knight (2001) used video-based technology to design the Prospective Remembering Video Procedure (PRVP) for assessing prospective memory performance by stimulating everyday memory-based activities with video recordings.

In addition, Knight found that the PRVP task performance varied with task environment. Therefore, Knight (2008) linked a set of 1200 photographs to build a platform that can simulate a shopping street. In conclusion, Knight suggested that the use of the computer-based environments to measure functional cognition deficits should be encouraged. With the progress of 3D graphics technology, some studies (Okahashi, 2013; Mitrovic, 2014; Debarnot, 2015) used 3D modeling to measure the PM performance of real-life conditions by designing a virtual experiment environment.

Recently, with the increasing use of Virtual Reality (VR), VR has become the “hotspot”, and this technology is widely used in psychology, engineering and entertainment. VR refers to the environment we build by software, which can simulate the user's physical presence. Unlike 3D modeling technology, VR generally uses a head-mounted display to build immersive VR platform that can create a more life-like experience. To evaluate PM performance by using the immersive VR Task, Dong (2016) used the immersive VR technology to develop a real-life test environment. In addition, Dong compared the VR task with a typical slide-based task. As a result, a immersive VR task in a controlled virtual environment is able to more reliably assess real-life PM ability. To discover deeper potential relevance about VR PM task and PM performance, and to investigate the cognitive processes of VR PM task, we consider developing a methodology that involves the neuroimaging technique to explore the neural correlation of VR PM task is necessary.

On the other hand, to study the neural correlation of VR PM task, there are several limitations and problems of most neuroimaging technology (EEG, fMRI). Firstly, the immersive VR device is normally worn on the participants' head. The band for fixing the VR device will be on top and sides of head. Therefore, participants can hardly wear the EEG caps that covered with scalp electrodes precisely. In addition, with the EEG caps, participants cannot take any head movements, and head or body movements will also interfere with the EEG signal. Secondly, utilizing fMRI technique to study the neural correlation of immersive VR PM task will also cause some problems: 1) The fMRI machine is huge and expensive, the cost of experiment will greatly increase. 2) The noise of machine will probably disturb the performance of PM task, which has been proven by Knight's study (Knight, 2008). 3) The electro-magnetic field interference with almost all the electronic equipments, which makes it impossible to do experiments with immersive VR devices. To avoid the third issue, past studies used a mirror to reflect a monitor placed outside of fMRI machine. However, for using monitor to do neuroimaging study of VR PM experiments, the remaining problems still exist, and the experiment environment without the use of immersive VR device may not be regarded as a true VR experiment environment technically.

Therefore, using fNIRS to study the neural correlation of immersive VR PM task is a best choice at present. fNIRS is widely used to localize, measure the brain activation and the change in the hemoglobin oxygenation state. This technique is non-invasive, portable and inexpensive, and may competent to measure cerebral blood flow in real-time. fNIRS allows the participants to be almost free in movements, some study even used fNRS for outdoor studies (Pinti, 2015). Especially, fNIRS wears on the forehead, and that is just the prefrontal cortex of brain. In other words, when we are using the immersive VR device, wearing fNIRS is completely feasible simultaneously. Additionally, fNIRS technique is able to observe the activation of BA 10, which was verified that it may accompanied with PM performance (Burgess, 2003). Moreover, there are very few studies that used fNIRS to monitor brain activity when immersive VR PM Tasks is processing. In our study, we used a VR system with a immersive VR device to simulate PM function in daily life condition. The VR task also contains ongoing and PM components, and completely conforms to the task design request (Burgess, 2003; Burgess, 2011). The fNIRS system we used to monitor prefrontal cortex activity is primarily composed with a headset that connected to a processing box. The aim of this study was to investigate prefrontal cortex (BA10) function, during a PM task in the VR environment.

4.2 Materials & Methods

4.2.1 Participants

We recruited 11 healthy young participants from Kobe University (10 males, mean age:25.4 years old, age range: 23-34 years old), and because the hair covering rate of one participant is too much that interfered with fNIRS data (8 channels had no record), one participant's fNIRS data was excluded from experiment data. All participants wrote with their right hands, and had normal color vision, corrected-to-normal or normal vision. None of the participants was taking medication or had psychiatric disorders.

4.2.2 VR PM task and experimental procedure

All participants performed VR task, and wore fNIRS device in the whole experiment. The whole experiment took at least 40-minute (5-minute for training task, 10-second for fNIRS baseline, and 35-minute for VR task), also started and finished on the same day (figure 4.1). Before the VR task started, participants had been required to perform a training task section to ensure that they were able to follow the instructions and could perform the task in a stabilized emotional condition.

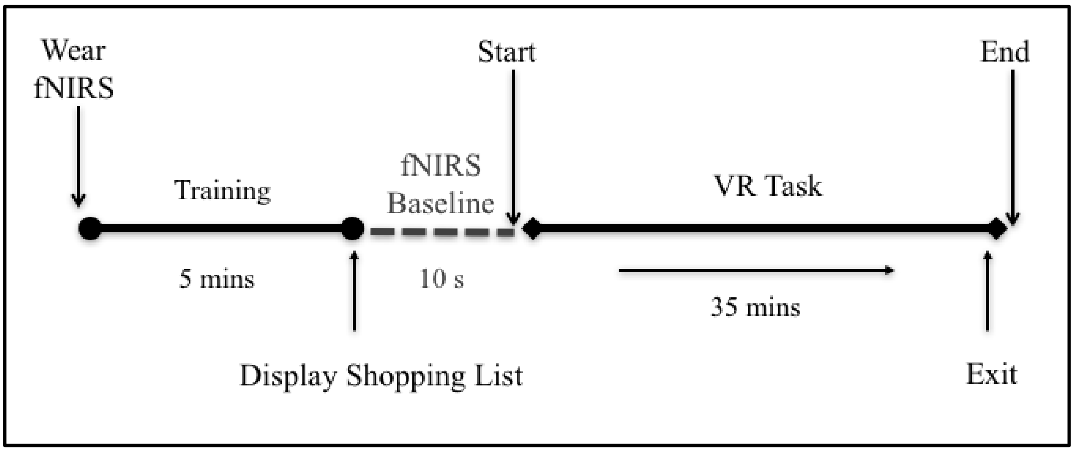


Figure 4.1 Time line of experiment.

To reduce the lights to fNIRS probe on disturbance and avoid vision interference, the lights in the room were turned off until the task been executed. The laboratory room was kept quiet, and the participants were seated in a comfortable chair.

For fNIRS recording session, after the experiments introduction is finished (figure 4.1), the researcher wore and adjusted the fNIRS device to participants' prefrontal cortex, then measured the placement of fNIRS according to manufacturer's instructions.

To obtain data more accurately, a headband with holding and light blocking functions was fixed to participants' head after the fNIRS device had been placed in correct position (figure 4.2).

Figure 4.2 fNIRS and immersive VR device.

The VR system includes an immersive VR device (Oculus Rift Development Kit 2) and a computer with a desktop monitor. The desktop monitor is used to observe the participants' movement in the VR task and view the status of task progress. Participants used a controller to move forward or backward, and turning around in VR task required natural body rotation on a rotatable chair. The VR environment was created with Unity 5.0. After fNIRS was adjusted, before the formal VR task began, participants needed to complete the training task (figure 4.1), which have the same basic components as the formal task. However, the training task only has two training shops and one special action point in the VR environment. In the formal VR task, VR environment was composed of a shopping street with 12 shops, two special action points and a bus station (exit).

In the VR tasks, as ongoing component participants were required to press a button and then read aloud the number under the shop signboard. When a participant read out the number on the signboard, we expected that he could also read the name of the store and determine what was available inside it. It was up to the participant to choose whether to enter the store to view the shopping window. Participants were asked to buy three items and take two special actions in the VR environment for PM component (three items such as "banana, coke and steak"). Each item had both image and text to help participants to memorize it. The two special actions were: "put a letter in the post box" and "throw a piece of trash into a dustbin", and they were presented in text form. In the VR task, just when the participant enters a shop, a shopping window is shown and all items are presented as images. The head movement of the Participant can move a yellow dot works as a selector to buy items. Item is purchased by aiming at the item icon with the yellow dot and pressing a button on the controller to confirm. Participants need move to a special action point such as a mailbox or a dustbin to take the action. The process was same as buying item.

The information of camera angle, buttons and timing during VR task were recorded automatically. To double confirm the time of ongoing and PM components, participants' voices of reading the number were also recorded. When experiment has finished, we asked the participants for permission to save the voice recording data, and all of them agreed.

4.2.3 fNIRS settings and data analysis

In this study, the fNIRS device (OEG-16, Spectratech Inc., Tokyo, Japan) was a multichannel fNIRS sensor of 16 measurement points, and one-point corresponding with one-channel (figure 4.3). The fNIRS system used the Beer-Lambert law to calculate the relative changes in HbO2 and HHb. Wavelengths of 770 nm and 840 nm were used to measure oxyhemoglobin(ΔoxyHb) and deoxyhemoglobin(ΔdeoxyHb) concentration. For baseline process, after confirming that participants understand experiment instructions, they were asked to stay still for 10 seconds as the fNIRS baseline.

For data analysis, in the baseline correction process linear fitting was used to correct the fNIRS data, and the individual of hemodynamic responses were corrected by baseline process. About measuring point-in-time of ongoing and PM components, the button log file was designed to simultaneously record the specific time that participants pressed the button for confirm action. In other words, the log file may present the point-in-time when participants read the name of the store and bought an item or took an action in the store. Then the 12 seconds (Schroeter, 2002)-six seconds before point-in-time and six seconds after point-in-time hemodynamic activity may be extracted from the overall fNIRS data (figure4.3). Extracted data has been classified into three categories, which were ongoing component fNIRS data (the data when participants read the name of the store, and the store is not required to buy items or take actions as ongoing component), PM component fNIRS data (the data when participants read the name of the store, and the store is required to buy items or take actions as PM component), PM hit component fNIRS data (the data when participants buy items or take actions). It is because that the PM component task in this study (do shopping and take action) is regarded as event- based PM. From past studies (Schroeter, 2002; Okuda 2007; Oboshi Y, 2015), brain activity of event- based PM may be biased towards left prefrontal cortex that in range of 10 to 15 channels (Figure 4.4). Therefore, in this study, we concentrated to analyze the ΔoxyHb signal changes in 10 to 15 channels. Subsequently, the difference between the maximum and minimum values (range), the mean values of difference, and the deviation of maximum values were calculated.

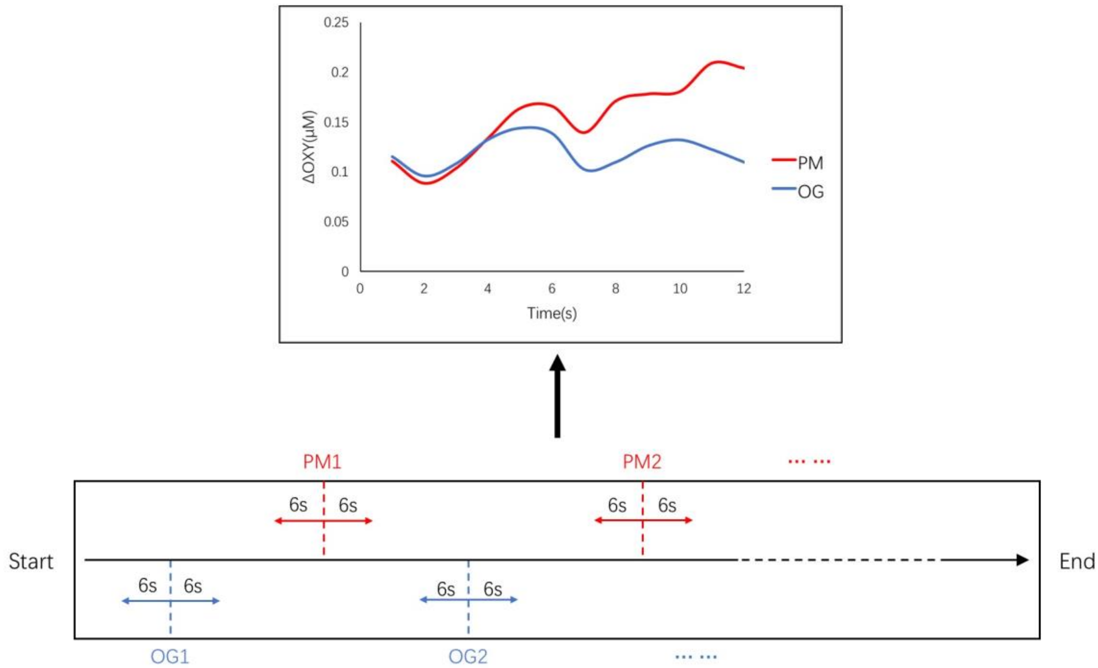


Figure 4.3 Extraction of fNIRS data.

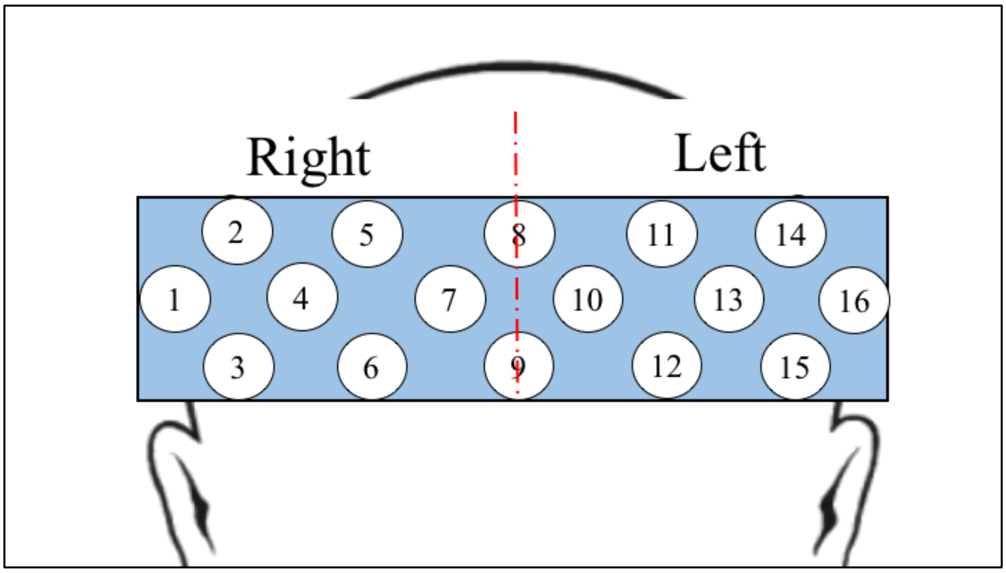


Figure 4.4 Schematic illustration of the 16 channels fNIRS sensor.

4.3 Result

SPSS was used to analyze the fNIRS data. For statistical analysis, we performed a series of 2-tailed paired-sample t-test on the ΔoxyHb to examine the hemodynamic change of ongoing component, PM component and PM hit component (figure 4.5, 4.6 and 4.7). In table 4.1, we observed the difference of PM component was significantly greater than the difference of ongoing component ($t = -2.37$, $p < 0.05$), which means the hemodynamic changes in PM component is obviously greater than the hemodynamic change in ongoing component. Whereas, by observing examine data of PM component difference and PM hit component difference, there was no specific statistically significance ($t = -0.46$, $p > 0.05$). In addition, the difference between ongoing component and PM hit component was very close to significance ($t = -1.98$, $p = 0.08$).

To enhance the study's rigor and persuasiveness, we also calculated the deviation of maximum values, and performed a series of 2-tailed paired-sample t-test on the ΔoxyHb to examine the hemodynamic change (table 4.1). The deviation of maximum values result is statistically similar to the difference between the maximum and minimum values (figure 4.4). By observing the deviation between ongoing component and PM component data, the deviation of PM component was significantly greater than the deviation of ongoing component ($t = -2.59$, $p < 0.05$). Then, the paired-sample t-test of PM component deviation and PM hit component deviation show no specific statistically significance ($t = -0.55$, $p > 0.05$). Also, the data of ongoing component deviation and PM hit component deviation are very close to significance ($t = -1.96$, $p = 0.08$).

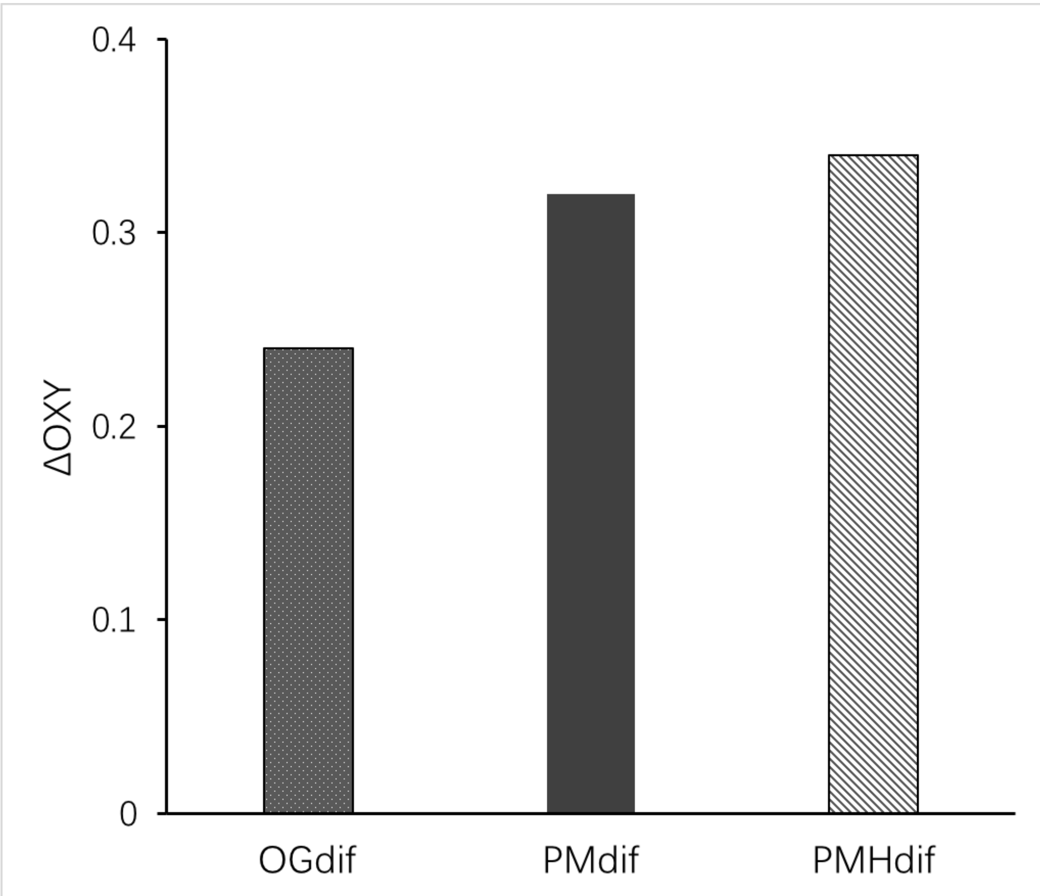


Figure 4.5 The mean of OGdif, PMdif and PMHdif.

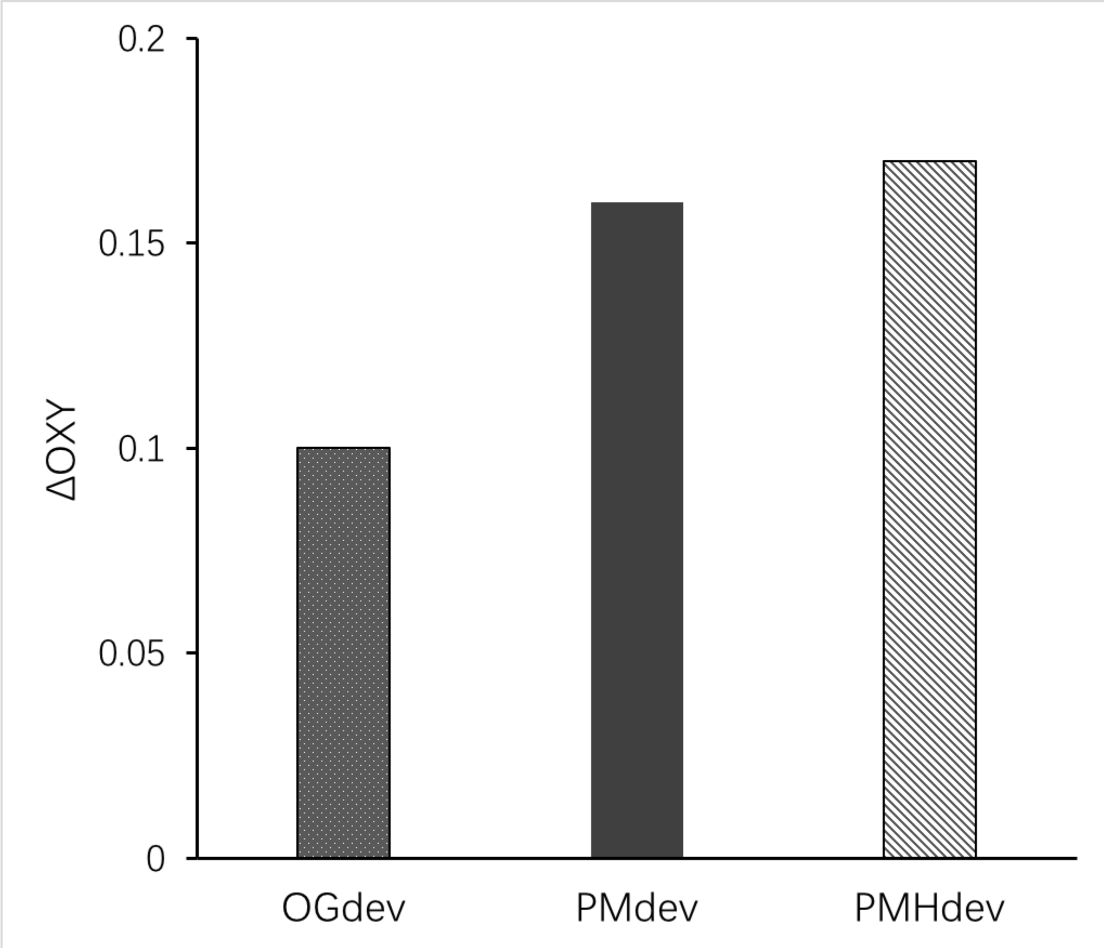


Figure 4.6 The mean of OGdev, PMdev and PMHdev.

	t	df	Sig. (2-tail)
Pair 1 OGdif - PMdif	-2.386	9	0.041*
Pair 2 PMdif - PMHdif	-0.455	9	0.660
Pair 3 OGdif - PMHdif	-1.982	9	0.079

	t	df	Sig. (2-tail)
Pair 1 OGdev - PMdev	-2.587	9	0.029*
Pair 2 PMdev - PMHdev	-0.546	9	0.598
Pair 3 OGdev - PMHdev	-1.956	9	0.082

Table 4.1 The 2-tailed paired-sample t-test on the ΔoxyHb.

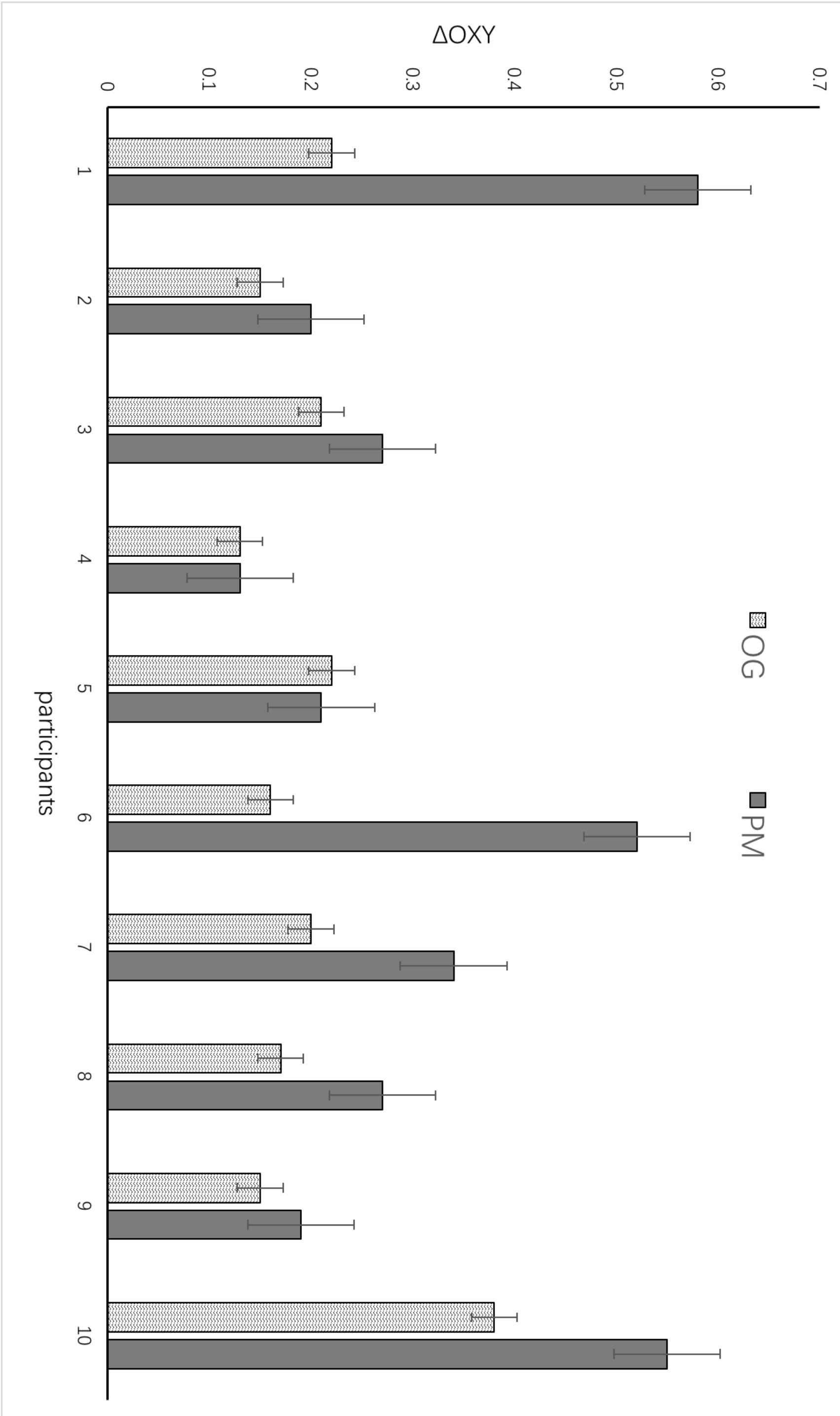


Figure 4.7 The data of OG and PM.

OGdif: difference of ongoing component, PMdif: difference of PM component, PMHdif: difference of PM hit component, OGdev: deviation of ongoing component, PMdev: deviation of PM component, PMHdev: deviation of PM hit component.

*$p < 0.05$.

4.4 Discussion

In this study, we used fNIRS technique to record ΔoxyHb data when participants performed immersive VR task, and analyzed by using the paired-sample t-test to six pair of task component. To enhance the persuasiveness of the experiment, we not only analyzed the difference between the maximum and minimum values, but also analyzed the deviation of maximum values. As our main result, the hemodynamic changes of BA10 in PM component significantly increased, and greater than the ongoing component. The activity of BA10, as a role in the maintenance and realization of delayed intentions of event-based PM was confirmed by a lot of past studies (Schroeter, 2002; Burgess, 2003; Gilbert,2006; Okuda 2007; Oboshi Y, 2015). This study first time confirmed the activation of BA 10 in the real-life like immersive VR PM task by using fNIRS technique in the best of our knowledge. Because of the measurement of BA10 activation, this result reconfirmed the potential to evaluate PM more accurately in a real-life like environment (Dong, 2016). In addition, this study probably become a new paradigm to measure BA10 activity in immersive VR environment by the use of fNIRS.

However, the fNIRS technique still has several limitations: 1) fNIRS uses near-infrared light to percolate the skull, the limited depth penetration of light is so shallow that only cortical of the brain, such as prefrontal cortex, can be examined by fNIRS. 2) The hair of participants can easily influence the detector of fNIRS, and concurrently influence the transmission of infrared light. Therefore, this is the reason why we excluded one of the participant's fNIRS data from experiment. 3) Although some study attempt to eliminate the motion noise from data by filtering with moving average data

(Hu, 2013). The influence of motion still cannot be avoided. Our study attempt to reduce motion noise by making participants turn around in VR environment only requires rotation on a rotatable chair, which can keep body movement as little as possible. Even with these limitations, the feature of fNIRS make this technique one of the most useful neuroimaging techniques for VR environment (Seraglia, 2011).

Our study also observed that the data of ongoing component is very close to significance with PM hit component. As a possible reason to this phenomenon, the PM hit component generally appeared after the PM component had ended. Therefore, the hemodynamic changes caused by PM component requires some time to return to a lower level. That means the increase of hemodynamic changes in PM hit component may be attributed to the not yet completely finished hemodynamic changes of PM component. However, as a more interesting hypothesis, we consider after PM component is accomplished, the PM hit component probability arouse additional hemodynamic changes of BA10. To confirm this theory, we are planning to develop a new experiment platform to control more variables.

Chapter 5

Assess BA10 Activity in Slide-based and Immersive Virtual Reality Prospective Memory Task Using fNIRS

To measure brain activities in laboratory setting prospective memory (PM) task, with the use of slide-based task, previous studies found that the activation of rostral prefrontal cortex (BA10) was related to the prospective memory performance. Immersive virtual reality (VR), as the technology that can create the realistic environment, has not yet been widely used in the PM neuroscience study. we used the immersive VR technology to simulate PM performance in real life environment, and used the functional near-infrared spectroscopy to record rostral prefrontal cortex activities in it. By comparing the results with the data from slide- based task, this study provides that the activation of BA10 in VR task is greater than slide-based task, and VR task have the potential to find the particular area of BA10 that connecting with the PM performance of our daily live.

5.1 Background

At present, slide-based task is widespread used in evaluating PM performance and PM neuroimaging studies. However, many researchers (Titov & Knight, 2001; Dismukes et al. 2008; Kliegel et al., 2008) came to realize that with the use of slide-based task, the experimental result cannot reflect all the PM processes under the real-life environment. As the main reasons, real-life PM behaviors are determined by the life experience, they are different from the PM demands in slide-based tasks (Dismukes et al. 2008). In addition, laboratory setup (such as slide-based task) experiments have generally focused on assessing brain damage, rather than appraising PM performance in the real world (Titov & Knight, 2001). Therefore, the laboratory setup has been useful in investigating basic processes related to storage, retrieval, and encoding of PM (Kliegel et al., 2008), that may not simulate the PM demands placed on the memory in real-life environment (Titov & Knight, 2001).

For measure the real-life environment PM performance in laboratory settings, the task is requiring real world based design, that means the settings should be the reasonable approximation of the real world, and also can be able to control. In order to overcome this obstacle, Titov and Knight (Titov & Knight, 2001) used video-based technology to constructed the Prospective Remembering Video Pro cedure (PRVP) task for assessing PM performance. The task was used video recordings to stimulate everyday memory-based activities. They found that video-based task can be used to measure the PM performance, and PRVP task performance varied depending on the task environment. In later study, Knight (Knight et al, 2008) linked a set of 1200 photographs to simulate street scenes that allowed participants to walk along. This task was designed for research the effects of old age and distraction in a “simulated naturalistic environment”. As the result, Knight found that even in simulated naturalistic environment, elderly people had difficulty remembering PM intention actions than young people. In addition, the noisy task environments also have an impact to the PM performance of elderly people. In this study, knight encouraged to use the computer-based environment to measure functional cognition deficits. In 2015, by using 3D graphics technology to assess PM performance after the stimulate of theta burst stimulation (TBS) on left frontopolar cortex (Debarnot et al. 2015), Debarnot used 3D model to designed a virtual city environment, that had 12 connecting scenes and one road. The environment included common city objects, and participants were asked to remember what action they were required to take at the appropriate time or place. The task successfully confirmed that the aging of PM behavioral effects can be counteract by intermittent TBS. With the significant advancement in immersive Virtual Reality (VR) technology, VR has been widely used in the field of engineering and psychology. Immersive VR refers to use the head-mounted display in order to present the virtual environment, that able to engage with the lifelike experience artificial environment. To evaluate PM performance with the use of immersive VR, Dong (Dong et al. 2016) designed a virtual environment shopping task and compared the task performance result with a traditional slide-based PM task. The result shown that the VR PM task was able to reliably better assess real-life PM ability.

In neuroimaging PM studies, with the use of slide-based task, Okuda (Okuda, 1998) published a PM neuroimaging study that shown rostral prefrontal cortex (BA10) was connected to the performance of PM. In 2003, for investigate the role of BA10 in PM, Burgess (Burgess, 2003) designed three different tasks, and made use of positron emission tomography (PET) to investigate the role of BA10 in PM. The result showed that by monitor the regional cerebral blood flow changes of BA 10 during tasks were performing. Burgess found the activation of BA 10 was related to the PM performance. This finding was later repeatedly reproduced in other studies (Gilbert, 2006; Gilbert, 2010). Also, several functional Magnetic Resonance Imaging (fMRI) studies are shown that the performance of PM will be accompanied by the activation in BA10. (McDaniel et al., 2013; Beck et al., 2014; Cona et al., 2015;). With the advancement of neuroimaging technology, new technique, such as functional near-infrared spectroscopy (fNIRS) have been widely used in research of memory studies, which is used to localize, monitor the brain activation, and measure the change in the hemoglobin oxygenation state. (Jobsis, 1977) In 2015, Oboshi (Oboshi Y, et al. 2015) used fNIRS to monitor BA10 activity when participants were performing a basic slide-based task. By compare the Δoxyhemoglobin (ΔoxyHb) of the ongoing component and the PM component, Oboshi found a definite relationship between left BA10 activity and PM performance.

Therefore, according to the increasingly recognized potential of VR task to test the PM in a real-life test environment, we consider that explore the neural correlation of slide-based PM task and VR PM task is necessary, and should discover deeper potential relevance about classical laboratory setup. In order to testify this idea, in our study, we used a VR system with an immersive VR device to simulate PM function in daily life condition, and a standard slide-based task to compare with the VR task. The VR task also contains ongoing and PM components, and conforms to the task design request (Burgess, 2003; Burgess, 2011). The fNIRS system we used to monitor BA10 activity is primarily composed with a headset that connected to a processing box. The aim of this study was to investigate BA10 function during a PM task in an immersive VR environment, and compare the ΔoxyHb with a slide-based task to observe the differences of BA10 activity.

5.2 Materials & Methods

5.2.1 Participants

10 healthy male young participants (mean age: 22.5) were recruited from Kobe University. All participants wrote with their right hands, and had normal color vision, corrected-to-normal or normal vision. None of the participants was taking medication or had psychiatric disorders. The informed consent agreement was signed by all participants before the experiment started. The whole experiment took 42 minute for each participant (12 minute for slide-based task and 30 minute for VR task). participants performed the training session before slide-based task and VR task for practice. The informed consent agreement was signed by all participants before the experiment started. All participants were wearing the fNIRS device during the entire experiment (figure 5.1).

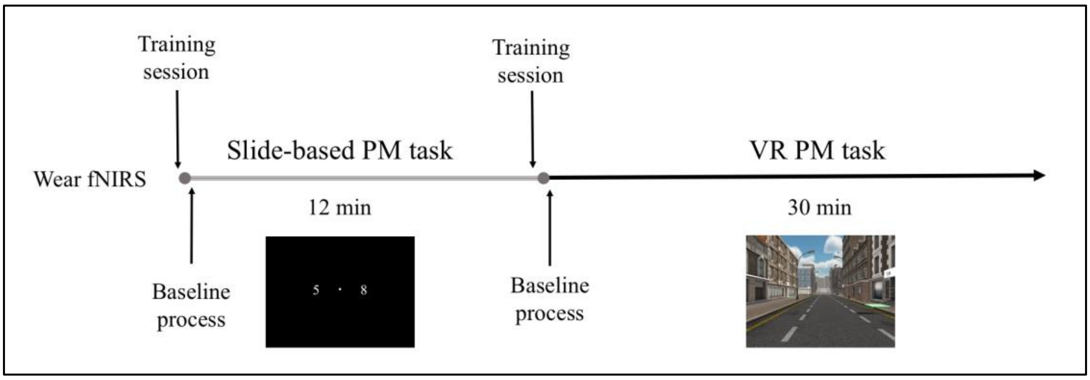


Figure 5.1 Timeline of experiment.

5.2.2 Slide-based task

The laboratory room was kept quiet, and the participant was seated on a comfortable swivel chair. Each participant was seated in front of a computer monitor, and use the keyboard to respond the stimuli. The resolution on the monitor was 1204 X 768 (Color Edge CX240). The whole task was developed by Unity 5.0, and the feedbacks were recorded to the computer in real-time.

The task is a number slide task that based on Burgess et al. (2001)'s task. In the task, Inter-stimulus section is a black background with a word "question" on the center (figure 5.2). In the stimulus section, as in (figure 5.2), the center point was marked with a "."in the center of background, and the stimulus numbers was present to participants between the center point. Whenever a pair of numbers was appeared, participants were required to press the "left" or "right" key for responses. Press the "left" key when number at the left side is larger than the right side, and press the "right" key when number at the right side is larger than the left side (ongoing component). In addition, responses with press "up" key to instead were necessary when a pair of numbers was signified even number (PM component). For the whole task, participants were required to press the “left” or “right” keys 75% of the time, the “up” key 25% of the time. The font size was 256 pixels, and the font of figure was in Times New Roman. The whole task had 30 trials. Each trial of stimulus was 17s, with 2s for the inter-stimulus interval, 3s for the stimulus and 12s for a resting period (figure 5.2). Before the task begin, participants performed a practice block with 6 demo trials (figure 5.1).

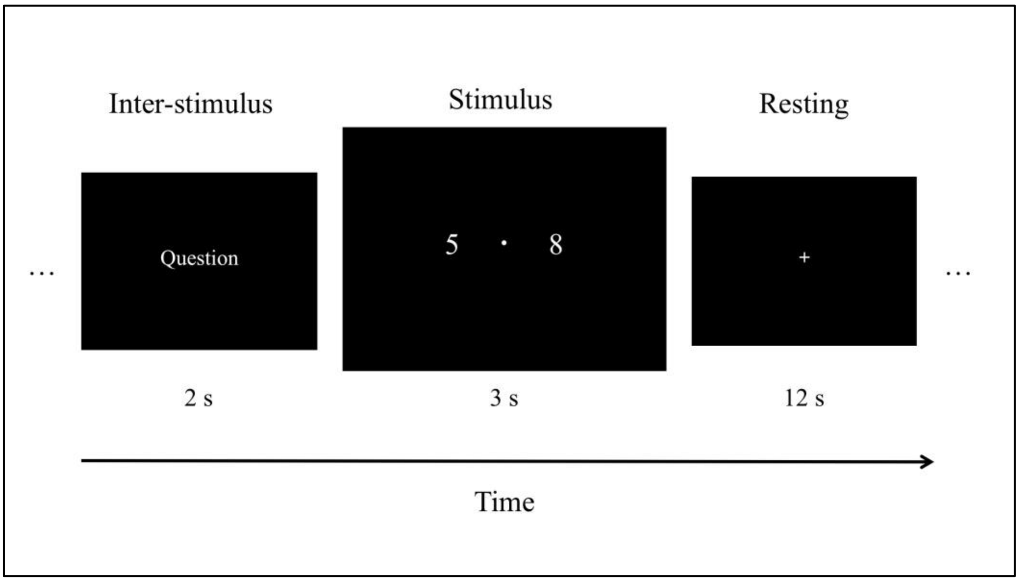


Figure5.2 One trial of the slide-based task.

5.2.3 VR task

To reduce the lights to fNIRS probe on disturbance and avoid vision interference, the lights in the room were turned off. The laboratory room was kept quiet, and the participant was seated in a swivel chair. The VR system includes an immersive VR device (Oculus Rift Development Kit 2) and a computer with a desktop monitor. The desktop monitor is used to observe the participants’ movement in the VR task and confirm the progress status of task. Participants used a controller to move forward or backward, and turning around in VR task required natural body rotation on the swivel chair. The VR environment was created with Unity 5.0.

At the beginning of task, the participant was shown a shopping list on the screen. The instruction described the shopping items and the described of special actions. The shopping items were described in both image and text. The actions were only described in text. The shopping items and special actions were both represented to the PM component.

As the ongoing component, the instruction also asked the participant to press a button and then read aloud the number under the shop signboard (figure 5.3). The font size of the number was set to small to prevent the participant from reading the number from afar. Thus, when a participant read out the number on the signboard, we could expect that he had also read the name of the shop and realized what was available in the shop. It was up to the participant to choose, whether to move to the green entrance to open the shop menu (figure 5.3). When the shop menu was opened, the participant can use the head movement to control a selector to choose an item to purchase. The mechanism was the same for the special action point. Before the actual VR task, the participant was asked to complete a training task (figure 5.1). As a demo of the VR task, the training task was contained the same basic components as the actual task. however, training task only had two training shops and one training action point. In the actual VR task, it composed by twelve shops and two special action points.

The data of camera angle, timing of button presses and walking path in VR task were recorded automatically into the csv file. Participants' voices of reading the number were also recorded for a double check. When experiment has finished, we received permission from all participants for the use of their voice data.

fNIRS and VR device

Example of a shop

Figure 5.3 The devices and the VR environment.

5.2.4 fNIRS settings and data analysis

In this study, the fNIRS device (OEG-16, Spectratech Inc., Tokyo, Japan) was a multichannel fNIRS sensor of 16 measurement points, and one-point corresponding with one-channel (figure 5.4). The fNIRS system used the Beer-Lambert law to calculate the relative changes oxyhe- moglobin (oxyHb) and deoxyhemoglobin (deoxyHb). Wavelengths of 770 nm and 840 nm were used to measure oxyhemoglobin(ΔoxyHb) and deoxyhemoglobin(ΔdeoxyHb) concentration. For baseline process, in the slide-based task, after the experiment instruction finished, participants were asked to stay relax for 10 seconds as the fNIRS baseline. In the VR task, fNIRS baseline was taken after participants finished reading the shopping list and relaxed for at least 10 seconds (figure 5.1). The baseline correction process linear fitting was used to correct the fNIRS data, and the individual of hemodynamic responses were corrected by baseline process. When an event occurred (figure 5.5), the ΔoxyHb from the previous 6 seconds and after 6 seconds were extracted and calculated to represent the component (Schroeter, 2002). This study had 4 types of events: the ongoing component and the PM component of slide-based PM task, the ongoing component (when participants read the name of the shop but the required item was not available in it) and the PM component (when participants read the name of the shop, and the required item was available in it) of VR PM task.

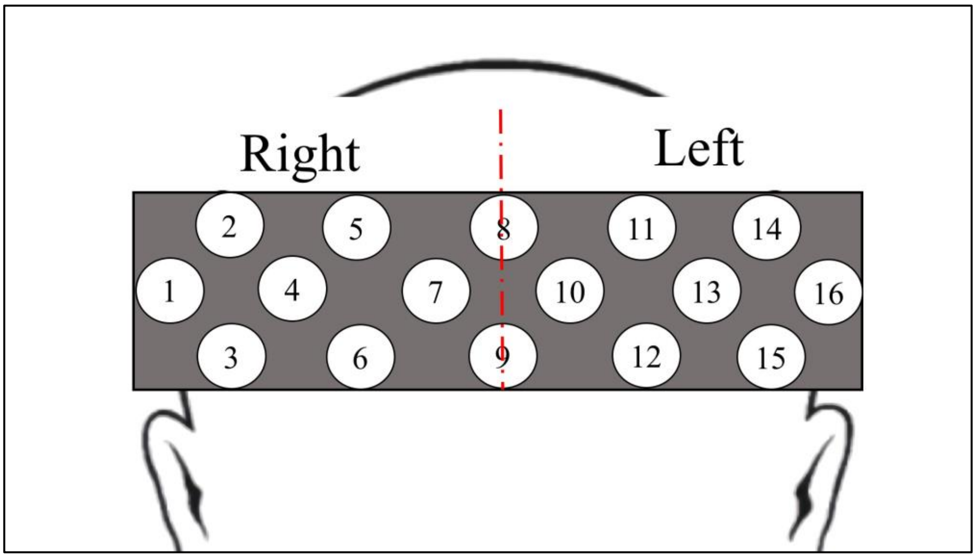


Figure 5.4 Schematic illustration of the 16 channels fNIRS sensor.

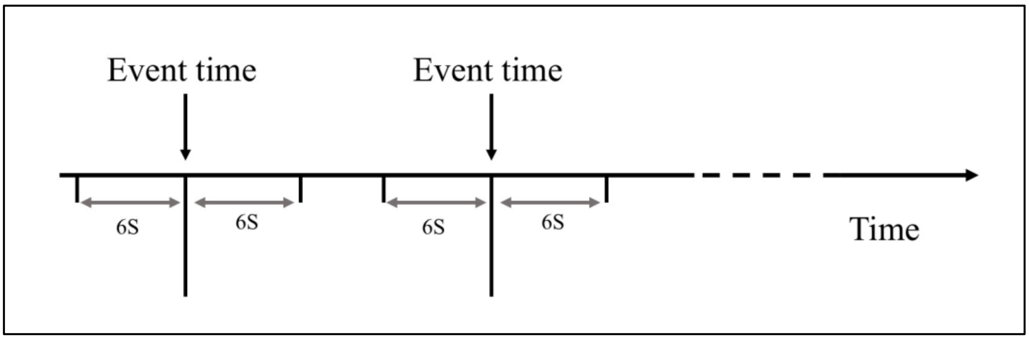


Figure 5.5 The process of data dividing.

5.3 Result

In slide-based task, if the participant pressed the incorrect or missed key was considered as an incorrect response. In VR task, if the participant forgot to read out signboard number or do the PM actions, would be marked as an incorrect response. All fNIRS data in the time of incorrect response event occurred, had been excluded from the experiment.

By past studies (Schroeter, 2002; Okuda 2007) suggested, the PM component of slide-based PM task and VR PM task in this study, may regarded as event-based PM. The brain activities of event-based PM should be biased towards left BA10, that in channel 11, 12, 13, 14, and 15 (figure 5.4). Therefore, in order to examine the variation of hemodynamic in BA10, we calculated the difference between the maximum and minimum values of the ΔoxyHb, and compared the data from channel 11 to channel 15. For statistical analysis, SPSS (version 22.0) was used to analyze the fNIRS data. We performed a series of 2-tailed paired-sample t-test on the ΔoxyHb to examine the hemodynamic change. The 2-tailed paired-sample t-test were performed not only between the ongoing component and the PM component in same PM task, but also between the same component of slide-based task and VR task (tables 1, 2, 3, 4), and if $p < 0.05$, statistical significance differences were reported as significant.

5.3.1 Slide-based task

By comparing the ΔoxyHb of ongoing component and PM component (table 5.1), we found that in slide-based PM task, the difference of PM component was significantly greater than the difference of ongoing component in all five channels (channel 11: $t = -6.09$, $p < 0.01$; channel 12: $t = -4.01$, $p < 0.05$; channel 13: $t = -4.52$, $p < 0.05$; channel 14: $t = -2.78$, $p < 0.05$; channel 15: $t = -6.87$, $p < 0.01$). This result shows that left BA10 activity of PM component is relatively larger than the ongoing component (figure 5.6).

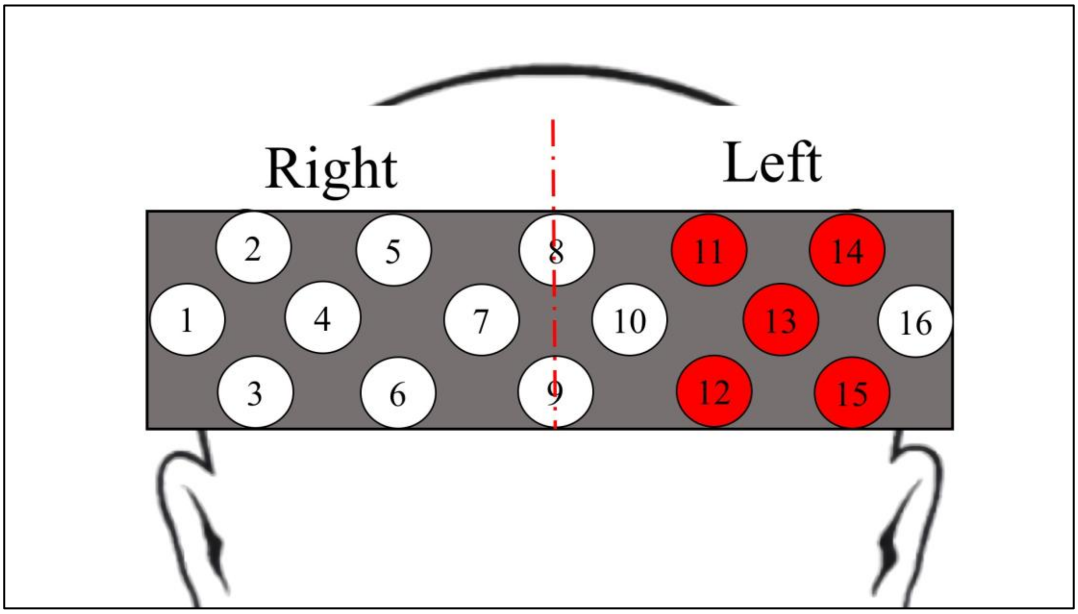


Figure 5.6 Statistically significant ΔoxyHb channel in the slide-based task.

5.3.2 VR task

For a comparison of ongoing component and PM component in the VR PM task ΔoxyHb data (table 5.2), we observed the difference of PM component was significantly greater than the difference of ongoing component in two channels (channel 11: $t = -3.01$, $p < 0.05$; channel 13: $t = -2.29$, $p < 0.05$). which means, in channel 11 and channel 13, the hemodynamic changes in the PM component is significantly greater than the hemodynamic change in the ongoing component (figure 5.7).

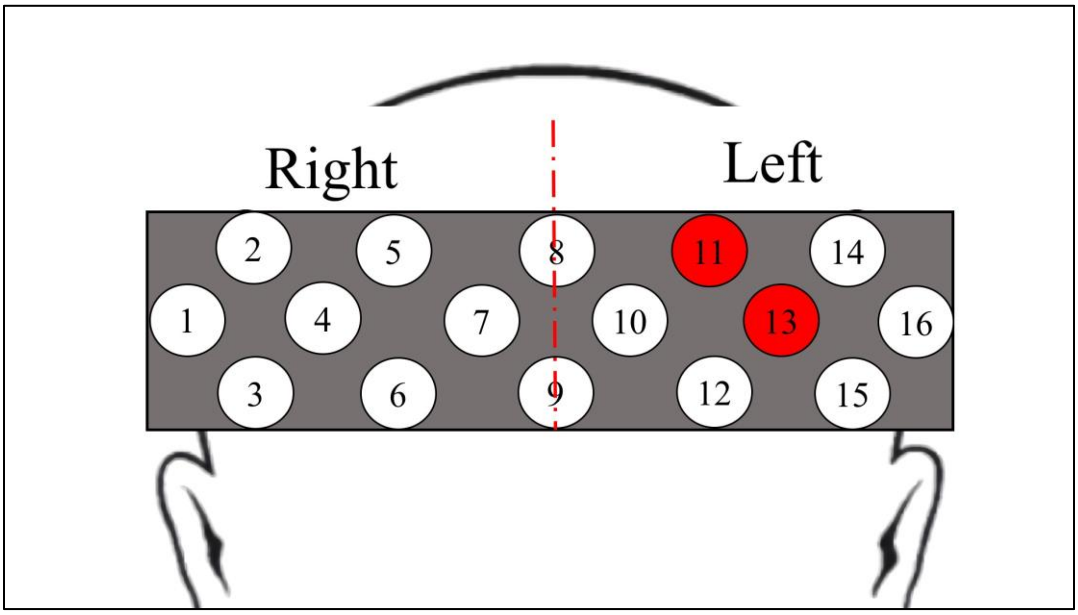


Figure 5.7 Statistically significant ΔoxyHb channel in the VR task.

5.3.3 Slide-based task vs. VR task

Comparing the ΔoxyHb of ongoing component in slide-based PM task and VR PM task (table 5.3), the analysis show that the difference of ongoing component in VR PM task was significantly greater than the difference of ongoing component in slide-based PM task with all five channels (channel 11: $t = -3.70$, $p < 0.01$; channel 12: $t = -2.91$, $p < 0.05$; channel 13: $t = -3.86$, $p < 0.05$; channel 14: $t = -4.17$, $p < 0.01$; channel 15: $t = -3.22$, $p < 0.05$). This result suggests that the hemodynamic changes in the ongoing component of VR PM task is relatively larger than the ongoing component of slide-based PM task.

With regard to the ΔoxyHb in PM component (table 5.4), we found that the difference of PM component in VR PM task was significantly greater than the difference of PM component in slide-based PM task with three channels (channel 11: $t = -3.99$, $p < 0.01$; channel 12: $t = -2.38$, $p < 0.05$; channel 15: $t = -2.74$, $p < 0.05$). The result indicates that, in channel 11, channel 12 and channel 15, the hemodynamic changes of PM component in VR PM task is relatively larger than the PM component in slide-based PM task.

Pair: ongoing-PM	Std. Deviation	t	df	Sig.
Channel 11	0.038	-6.085	9	0.000
Channel 12	0.086	-4.013	9	0.003
Channel 13	0.097	-4.515	9	0.001
Channel 14	0.127	-2.783	9	0.021
Channel 15	0.042	-6.871	9	0.000

Table 5.1 The paired-sample t-test in Slide-Based Task.

Pair: ongoing-PM	Std. Deviation	t	df	Sig.
Channel 11	0.148	-3.012	9	0.015
Channel 12	0.229	-1.850	9	0.097
Channel 13	0.115	-2.290	9	0.048
Channel 14	0.272	-1.394	9	0.197
Channel 15	0.283	-1.289	9	0.230

Table 5.2 The paired-sample t-test in VR Task.

Pair: ongoing-ongoing	Std. Deviation	t	df	Sig.
Channel 11	0.115	-3.703	9	0.005
Channel 12	0.283	-2.906	9	0.017
Channel 13	0.111	-3.858	9	0.004
Channel 14	0.168	-4.173	9	0.002
Channel 15	0.308	-3.221	9	0.010

Table 5.3 The paired-sample t-test on ongoing between the two tasks.

Pair: PM-PM	Std. Deviation	t	df	Sig.
Channel 11	0.161	-3.994	9	0.003
Channel 12	0.379	-2.377	9	0.041
Channel 13	0.148	-1.712	9	0.121
Channel 14	0.430	-1.690	9	0.125
Channel 15	0.389	-2.742	9	0.023

Table 5.4 The paired-sample t-test on PM between the two tasks.

5.4 Discussion

In past studies (Okuda, 1998; Burgess, 2003; Gilbert, 2006; Gilbert, 2010; McDaniel et al., 2013; Beck et al., 2014; Cona et al., 2015; Oboshi Y, et al. 2015), slide-based PM task was often used for investigate the role of BA10 in PM, and proved that the activation of BA 10 was related to the PM performance. Our study developed immersive VR system that can simulate the shopping experience in a daily life condition. Furthermore, we used fNIRS to record ΔoxyHb data when participants performed slide-based PM task and VR PM task, and analyzed the result by compare the ΔoxyHb of ongoing component and PM component. Thanks to the use of fNIRS, making it possible to investigate the cognitive processes of VR PM task.

Most neuroimaging technology such as EEG and fMRI are having several limitations when used in the immersive VR PM task. The immersive VR device is normally worn on participants' head and the head band for fixing the VR device will be on top and sides of head. This will make the participant barely wear the EEG caps that covered with scalp electrodes precisely. Using fMRI to study the neural correlation of immersive VR PM task also has several problems. Firstly, the fMRI machine is large and expensive, and the noise of the machine may affect the performance of PM, which has been proven by Knight's study (Knight, 2008). Secondly, the electro-magnetic field of fMRI will interfere with the immersive VR equipment.

However, using fNIRS can avoid the above problems. The fNIRS is non-invasive, portable and generally worn on the forehead, where is just the BA10 of brain that can be measure BA10 activation. In addition, the fNIRS leaves enough space allow worn the immersive VR equipment simultaneously. Although fNIRS is suitable to our study, this technique still has several limitations during the experiment: 1) the cables coming from the fNIRS may tangle and prevent participants' movement in VR shopping area, that we had to constantly monitor the movement of participants and adjust the cables carefully. 2) The hair of participants can easily influence the detector of fNIRS, and concurrently influence the transmission of infrared light, that makes the time of calibration greatly increases.

Our study compares the fNIRS data of slide-based PM task and VR PM task with the aim to investigate the neural correlation of this two tasks. Based on our result, to compare the ongoing component and PM component, the hemodynamic changes of BA10 in VR PM task is greater than the slide-based task. In slide-based task, the PM component of slide-based task further examined with fNIRS, and statistically significant hemodynamic changes of BA10 was observed. This result confirmed Oboshi's findings that using a common slide-based task (Oboshi Y, et al. 2015). In addition, it proved that the fNIRS settings and analysis method in our study are realizable and exactable. In VR PM task, the hemodynamic changes of BA10 in the PM component is greater than the ongoing component, and statistically significant in channel 11 and channel 13. Because VR PM task is providing a more realistic environment (Dong, 2016). It is possible that, the PM in more realistic environments is more activated the function area in channel 11 and channel 13. In order to confirm this hypothesis, it is required to comparing with slide-based PM task, VR PM task and real world condition PM, that means an outdoor experiment is necessary.

Chapter 6

Conclusion

6.1 Conclusion

In this study, firstly, we used immersive virtual reality technology to create realistic shopping street experience in a controlled virtual environment. To test the task performance, we used a slide-based task to compare with the VR task. Different from previous studies, our VR task not only highly simulated the real-life environment, but also considered the composition of the prospective memory task. In particular, the VR task contains both ongoing component (reading out the numbers) and prospective memory component (shopping and taking action). By comparing with the result of the slide-based task, it suggests that both VR task score and RT are related to the prospective memory "target" search ability, and this has not been discussed in previous VR studies. Therefore, comparing to previous studies, our VR task is able to more reliably assess real-life PM ability in con- trolled laboratory setting. In conclusion, these results suggest that comparison between prospective memory laboratory psycho- logical model and VR model is necessary, and the VR task can provide more detailed contrast with prospective memory in real-life.

Then, for measuring the activation of prefrontal cortex in VR prospective memory task, this study designs an experiment paradigm that recording hemodynamic changes when the participants perform VR prospective memory task. Different from previous studies, we used a fNIRS device to measure the prefrontal cortex activity, and a completely immersive VR device to present the event-based prospective memory VR task. By confirming the point-in-time when participants perform ongoing component, prospective memory component and prospective memory hit component, the fNIRS data of these three components has been extracted. The paired-sample t-test shows that hemodynamic changes of fNIRS data could observe the prefrontal cortex activity in our study. In conclusion, it has been proved that the immersive VR prospective memory task can be induce the activation of prefrontal cortex that accompanied by prospective memory performance. In addition, by the use of fNIRS. this study provides a feasible paradigm to measure prefrontal cortex activity in real-life like immersive VR environment.

Finally, for measuring the activation of rostral prefrontal cortex in slide-based prospective memory task and VR prospective memory task, this study designed an experiment that record hemodynamic changes when participants perform the slide-based task and the immersive VR task. Different from previous studies, we used the fNIRS device to measure the rostral prefrontal cortex activity, and not only compare the fNIRS data between slide-based prospective memory task and VR prospective memory task, but also analyzed the data of ongoing component and prospective memory component. The result suggests that VR prospective memory task, as a VR model task, can be induce greater hemodynamic changes in left rostral prefrontal cortex than the pure lab-based slide-based task, and this has not been discussed in previous studies. In addition, by comparing with the ongoing component to prospective memory component in VR prospective memory task, the hemodynamic changes in brain is more concentrate on the position of channel 11 and channel 13. In conclusion, these results suggest that neurological research on VR prospective memory task can provide more detailed contrast with prospective memory in laboratory setup, and also in real-life.

6.2 Future Works

The previous prospective memory studies show that, prospective memory performance is sensitive to environmental change and ages. For finding out more details of cognition process, future study should focus on how environmental changes and age differences may affect prospective memory cognition process not only in immersive VR environment, but also in the real-world environment. By such studies, that may search out the neurological reason of why laboratory psychological paradigm cannot reflect all prospective memory processes in real-world condition, and how much the VR task can be simulating the real-life prospective memory performance. Further, because the importance of prospective memory in the daily life. Elderly people may get the more benefit from a task that testing the real-life prospective memory performance in a safety environment. Therefore, developing the specialized VR task use for elderly people is necessary. For the elderly people study, we are planning to use the Mini-Mental State Examination (MMSE) for a contrast test experiment.

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