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PARAMETERS FOR DESIGN OF COMPUTER-BASED PROGRAM FOR PEOPLE WITH MENTAL RETARDATION

BY

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

"Universal design" is a fundamental approach to the development of the human-computer interface for modern technology. The principles of "Universal design" have largely improved the user-friendliness and utilization of technology for those in the mainstream population. The drawback however is the compromise of the functionality and even the marketability of these products, especially by the people who have had disabilities. Previous studies have revealed that the people with mental retardation had limitations in using the existing human-computer interfaces, e.g. web browser. Such findings are not surprising as the people with mental retardation are known to have an overall lowering of intellectual abilities. Previous studies have placed its focus on investigating the functional problems encountered by these people and the ways for improving their skills on using these technological products. However, it is a limited research to explore the mechanisms which hinder them from effectively using the technological products and how the interface design could be enhanced for bridging the theory-driven human-computer interaction gap.

This research project was aimed to examine the mechanisms behind the phenomenon that the people of mental retardation had problems using the human-

computer interface. In particularly, it focused on how the mental deficiencies of these people hindered their competence in operating the interface. It was consisted of three inter-related studies with each informed the research questions asked and methods to be used in the subsequent study.

The research question of the study 1 was: what was the performance level of the people with mental retardation on operating a common human-computer interface program? A total of 57 people with mild (n= 30) or moderate (n=27) mental retardation (39 males and 18 females; Mean Age=17.2 years (SD=3.3)) were recruited through convenience sampling to participate in an Internet Explorer (IE) competence test. The competence test was composed of 16 IE tasks (161 subtasks) which were verified by an expert panel. Participants' performances on each task were evaluated against a 4-point scale. The results of the participants' scores on each of the task were analyzed. Results of logistic regression (stepwise forward) procedure indicated that the "general motor function" (B=-3.43, SE=1.59) and "use customized bookmark" (B=-3.54, SE=1.06) were the most predictive of the participants' performance (χ^2= 38.35, df=2, p<0.001). Hierarchical cluster analysis, decision tree classification and one-way ANOVA further indicated that participants' performance varied which can be clustered into three performance groups. The "general motor function" was useful for differentiating subjects into the low and medium competence groups (F(2,54)= 89.54, p<0.001) whilst the "use customized bookmark" ($F(2,54) = 57.02$, $p < 0.001$) into the medium and high competence groups. Results of another expert panel review on analyzing the content of the task and subtasks composed of the IE comptence test indicated that comparatively less motor than cognitive abilities were required for performing the IE tasks. Among the list of the cognitive abilities, orientation, visual acuity, and attention had the highest frequency count followed by word recognition and working memory.

The research question of the study 2 was: with the performance levels derived from Study 1, what were the core cognitive abilities predictive of these people's performance level? A total of 62 people with mild ($n=33$) or moderate ($n=29$) mental retardation (40 males and 22 females; Mean Age: 17.4 years (SD=6.0)) were recruited to establish the cognitive and motor profiles of these people. They were invited to participate in the Internet Explorer (IE) competence test as well as complete 13 tests on attention, visual-spatial, memory, executive functions, frontal lobe functions, word recognition, and sensori-motor functions. The participants' scores on all of these tests were significantly correlated with their overall IE performance score ($r=0.36$ to 0.71, $ps \leq 0.01$). Results of stepwise multiple regression analyses indicated that, among all functions, the attention and visual search function measured by the Symbol Digit Modalities Test ($R^2 = 49.7\%$), fine motor functions measured by the

McCarron Assessment of Neuromuscular Development (R^2 = 5.8%), and Chinese word recognition functions measured by the Chinese Characters Test (R^2 = 3.2%) were the best three predictors on overall IE performance [total R^2 = 0.59, Model $F(3, 58) = 27.40$, $p<0.001$].

The question addressed by Study 3 was: what were the underlying mechanisms hindered these people from being competent on operating the interface of Internet Explorer? To further contain the scope of this study, based on the results obtained from Study 2, we selected only the visual search processes and designed an eye-tracking paradigm for comparing the efficiency on various distances and orientations between the people with mental retardation and their normal counterpart. A total 24 people with mild or moderate grade of mental retardation (16 male and 8 female; Mean Age=19.0 years (SD=5.4)), and 30 people without mental retardation (16 male and 14 female; Mean Age=20.8 years (SD=1.9)) as the reference group were recruited. We hypothesized that the people with mental retardation, with limited attention and working memory ability, would perform the visual search task differently than their normal counterpart. Their performances would be further modulated by the distances (close: 1 visual lobe, medium: 1.5 visual lobes, and far: 2 visual lobes) and orientation (vertical, horizontal and oblique) between the two target stimuli. This search task required the participant to visually search the target square (one) or squares (two) and

indicate as quickly as possible the number of target square(s) which they found. The total number of trials was 432 divided into 24 blocks. Their eye movements were tracked by the Eye-gaze Response Interface Computer Aid (ERICA) infrared corneal reflection system at the time of performing the task. Their visual lobe areas and shape characteristics were measured with the Visual Lobe Measurement System (VILOMS). Results indicated that participants with mental retardation had significantly smaller visual lobe areas ($t(38)=4.13$, $p<0.001$), and less likely using consistent search strategies ($p \leq 0.001$) and lower performances ($ps \leq 0.05$) on the visual search task, than their normal counterpart . The results on testing the *Distance* x *Orientation* effects indicated that, the *Distance* effect on the scanpath duration and overall fixation duration for both two groups were statistically significant (Pillai's Trace: $F(2,22)=11.81$, $p<0.001$ and $F(2,22)=7.71$, $p=0.003$ respectively for participants with mental retardation; and $F(2,28)=43.69$, $p<0.001$ and $F(2,28)=33.18$, $p<0.001$ respectively for normal counterparts). Similarly, the *Orientation* effect on these two variables for both groups was significant (Pillai's Trace: $F(2,22)=5.97$, $p=0.008$ and $F(2,22)=4.91$, $p=0.017$ respectively for participants with mental retardation; and $F(2,28)= 54.15$, $p<0.001$ and $F(2,28)= 41.38$, $p<0.001$ respectively for normal counterparts). The interaction effect between *Distance* and *Orientation* was not significant for participants with mental retardation (Pillai's Trace: $F(4,20)=1.70$,

$p=0.189$ and $F(4,20)=1.65$, $p=0.20$ respectively). However, this interaction effect was significant for normal counterparts (Pillai's Trace: $F(4,26)=4.85$, $p=0.005$ and $F(4,26)=4.65$, $p=0.006$ respectively). Post hoc analyses indicated that normal participants had significantly longer scanpath duration and overall fixation duration in far- than close-distance when the targets were arranged in vertical and oblique orientations ($ps<0.001$), and in medium- than close-distance when the targets were arranged in vertical orientation ($p<0.001$). In the close-distance condition, oblique and horizontal orientations had significant longer overall fixation duration than their vertical counterpart ($ps \leq 0.001$). The condition with a far-distance and oblique-orientation had the longest scanpath duration and overall fixation duration among all of nine conditions.

The findings suggest that a plausible account of why people with mental retardation, when compared with the normal counterpart, would have problems when using the human-machine interface. As the people with mental retardation have an overall lowering of motor and mental abilities, this study chose to focus on the mechanisms underlying the deficiencies in cognitive abilities. The most limiting factor as reflected from the findings is that the people with mental retardation had a decline in the visual search function. In the model which was adopted in this study, the problem possibly began in the comparatively smaller visual lobe in these people.

This would largely limit their visual attentional field. With a smaller visual field, the people with mental retardation would need to shift their attention (like a spot-light) from one to another field more often than their normal counterpart. This couples with the notion that they had a decline visual working memory. These deficiencies are reflected from their lack of search strategies and longer time for searching information from the visual display than the normal participants. The decline in working memory would prevent the people with mental retardation from recalling the locations which had been previously scanned through. The consequence was that these people took longer time to search for the second target stimulus. The longer fixation time also suggested that they took longer time to process the target stimuli which perhaps was also accounted for by their lower spatial working memory. The findings on the significant effects of distances and orientations on influencing participants' search and fixation times offers insights into the possibility of using these as guidelines for design of human-machine interface e.g. menus for the people with mental retardation. These also stimulate further research on the feasibility of an inclusive approach to universal design of modern technology for our population.

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CHAPTER I

INTRODUCTION

Many types of tasks are now being performed using the computer. Computers have been introduced into a range of tasks including word processing, statistical analysis, and financial accounting. As individuals become confronted by various computer technologies in banks, libraries, and homes, we are likewise confronted in many of our daily tasks with the choice of crossing over from conventional methods of working to performing the computerized and digitized form of these tasks. For example, we have shifted our modes of communication from wired telephones or fax machines to Internet-based electronic mail and mobile communication. Needless to say, these developments have led to an increasing demand for computer technology for use by a wide range of individuals. This has placed a greater focus on studies about the nature of human-computer interaction, as well as the variations between individuals in human-computer interaction (Jacko, Salvendy, & Koubek, 1995; Westerman, 1993).

Human-computer interaction (HCI) is concerned with the human performance of information-processing tasks. When an individual performs a task, this person is required to recognize displayed information, recall the commands that activate particular computer outputs, and execute the selected responses. Interacting with the computer places demands on various cognitive and motor functions of the individual. The design of human-computer interfaces should take into consideration the maximization of the match between an individual's information-processing capabilities and the requirements of the computer tasks (Proctor & Vu, 2003). In the modern world, however, the interfaces between the existing software and human-computer interfaces are designed for the mainstream population. Individuals who have lesser capabilities, such as people with cognitive deficiencies, have been found to have problems using some of these software and human-computer interfaces. People with mental retardation are part of these minority groups who have been identified to encounter substantial problems in utilizing these technologies (e.g., Davies, Stock, & Wehmeyer, 2001; Wehmeyer, 1998). As people with mental retardation are known to have a generally lower level of intellectual abilities, these findings are not surprising. To assist this group of potential users, the concept of *universal design* (Buhler, 2001; Stephanidis & Savidis, 2001) is useful for guiding the design of more inclusive interfaces that suit the needs of individuals with wide-ranging capabilities (Gwizdka & Chignell, 2004).

Previous studies have indicated the problems that people with mental retardation encounter when they operate computer interfaces. In addition, various ways of improving the competence of these people in operating computer interfaces have also been reported. However, there is a lack of research on exploring the mechanism that limits people with mental retardation from using human-computer interfaces effectively. This study was conducted to explore the mechanism that would possibly explain how people with mental retardation would have difficulties with operating human-computer interfaces and how such human-computer interfaces can be enhanced in order to bridge the theory-driven computer-human gap. I believe that the findings could contribute to the theory that underpins the universal design approach to constructing the human-computer interface for people with mental retardation. We place particular emphasis on the cognitive and motor factors critical in hindering their competence in using the computer interface.

Organization of the Research Questions

This study investigates the possible mechanisms behind the phenomenon of people with mental retardation having problems using an existing computer interface (e.g., a web browser) and is divided into three individual studies, with each study focusing on the research question asked and the methods used in the next study. The question addressed by Study 1 is: Given that we know that people with mental retardation have problems using existing computer interfaces, what is their performance level while operating a common computer interface program? Based on the survey, the computer program selected for this project is the Internet Explorer (IE), a web browser software program widely used by the mainstream population. The tasks and subtasks that formulate the basic steps for operating the IE program are developed. The performance levels on these tasks and subtasks, as well as the relevant cognitive and motor demands for these tasks and subtasks are likewise developed for participants with mild to moderate grades of mental retardation.

The question addressed by Study 2 is: If we know the performance levels of the IE tasks and subtasks of these people obtained from Study 1, what are the core cognitive and motor abilities predictive of these people's performance levels? To answer this question, 13 standardized cognitive and motor tests are used to establish the ability profiles that are relevant for the operation of the computer by these people. Further, the test results are used to predict their competence level in operating the IE program. The cognitive ability which best accounts for the participants' competence in using the IE program is selected for an in-depth investigation in Study 3.

The question addressed by Study 3 is: Given that we know that the visual search function, the Chinese language-processing function, and the psychomotor function were the three main abilities that accounted for the competence of the people with mental retardation in operating the IE program, what then are the mechanism(s) that would limit the competence of people with mental retardation in operating the IE program? To further contain the scope of this study, we selected only the visual search process for in-depth study in the last part of this project. We designed a serial search experiment using an eye-tracking methodology for comparing the efficiency on various distances and orientations of two target stimuli in people with mental retardation and in their normal counterparts. These results can be used to bridge the theory-driven computer-user gap and thus offer insights into the optimal design of human-computer interfaces for people with mental retardation.

Statement of Purpose

The purpose of this project is to investigate the possible mechanisms behind the phenomenon of people with mental retardation having problems in using computer interfaces. In particular, it focuses on how cognitive deficiencies hinder these people from operating the computer interface. There are three studies in this research project and the respective objectives of these three studies are as follows:

1. a) To select a widely used computer interface program that was also frequently used by people with mild to moderate mental retardation;

   b) To identify the cognitive and motor tasks and subtasks that were relevant for the operation of the selected computer program; and

   c) To identify the performance levels of these people when operating the selected computer interface;

2. a) To establish the cognitive and motor ability profiles of people with mental retardation that are relevant for operating the selected computer interface; and

b) To identify the core cognitive and motor abilities for predicting the computer performance of people with mental retardation;

3. a) To design an eye-tracking paradigm for comparing the efficiency at various distances and orientations of people with mental retardation and of their normal counterparts; and

   b) To explore a possible mechanism for explaining how people with mental retardation would have difficulties in operating the selected computer interface, i.e., the visual lobe, visual search strategies, and oculomotor behaviors, as well as working memory and attention demands on the conjunctive search task.

Organization of Chapters

This thesis consists of six chapters including the present one. Chapter II provides a literature review of mental retardation, computer operation by people with mental retardation, issues concerning human-computer interaction in relation to human information processing, and the importance of universal design. Various theories on attention, memory, and visual search, as well as an introduction to visual lobe measurement and eye-tracking technology, are likewise presented. Chapter III describes the method of investigation and includes task development for computer performance and identification of the core cognitive abilities for predicting the computer performance of people with mental retardation. This is followed by an outline of the procedures in designing the eye-tracking paradigm for comparing the efficiency at various distances and orientations among people with mental retardation and their normal counterparts. Chapter IV summarizes the results of Studies 1, 2, and 3. Chapter V discusses the results generated by the three individual studies, and Chapter VI presents the overall conclusions of this study.

CHAPTER II

LITERATURE REVIEW

Overall Introduction

This chapter reviews the theoretical framework and previous work done in other aspects of this field related to this project. It begins by introducing the term *mental retardation* and studies on the utilization of computer technology by people with mental retardation. Issues of human-computer interaction related to human information processing, especially the extents upon which cognitive functions are important for computer utilization will be discussed. The concepts of *design for all* and universal design for human-computer interaction will also be reviewed. A brief introduction to visual lobe and visual lobe measurement will also be given. In addition, the contributions of various theories on visual attention and memory, as well as visual search and how these factors relate to the human-computer interface will likewise be discussed. The chapter ends with a description of eye-tracking technology.

Mental Retardation

Definition

The American Association on Mental Retardation's (AAMR, 2002) *Mental Retardation: Definition, Classification, and System of Supports (10th ed.)* defines mental retardation as a disability characterized by significant limitations in intellectual functioning and hence adaptive behavior. This disability should originate before the age of 18. Meanwhile, the fourth revised edition of *Diagnostic and Statistical Manual of Mental Disorders (DSM-IVTR)* (American Psychiatric Association, 2000) characterizes the diagnosis of mental retardation as follows: (1) significantly subaverage intellectual functioning (an Intelligence Quotient (IQ) of approximately 70 or below on an individually administered IQ test); (2) concurrent deficits or impairments in present adaptive functioning in at least two of the following areas: communication, self-care, home living, social and interpersonal skills, use of community resources, self-direction, functional academic skills, work, leisure, and health and safety; and (3) onset before the age of 18.

Heterogeneity among People with Mental Retardation

An Intelligence Quotient of 70 has been commonly used as the criterion for diagnosing mental retardation. As intelligence covers a spectrum of abilities (or functions), the use of IQ as the cut-off criterion means that people with mental retardation tend to be heterogeneous in their characteristics in terms of their etiology, degree of ability and disability, and behavioral characteristics (AAMR, 2002; Graziano, 2002). As a result, recent approaches do not support using IQ as the sole criterion for making a diagnosis of mental retardation. Instead, the clinician nowadays depends not on IQ alone for diagnosing mental retardation, but also on the functioning of adaptive behaviors of individuals including communication, self-care or community living skills, social and interpersonal skills, and school or work skills. Nevertheless, the general consensus is in favor of using IQ score as a guide to differentiate individuals with mental retardation within their group. Individuals classified as having a mild mental retardation have IQ scores within a range between 50-55 to around 70; moderate mental retardation between 35-40 to 50-55; severe mental retardation between 20-25 to 35-40; and profound mental retardation with a score below 20 or 25 (American Psychiatric Association, 2000).

Mild mental retardation. About 75% of the people diagnosed with mental retardation fall within this level of functioning. The DSM-IVTR lists the IQ range from 50-55 to approximately 70 (American Psychiatric Association, 2000). In general, the individuals are mostly physically indistinguishable from their normal counterparts. Moreover, for most of their cases, there are no known discernible organic etiologies. However, they manifest significant delays in cognitive development, putting them far behind their average-intelligence age counterparts (Graziano, 2002). People with a mild grade of mental retardation are referred to as educable and can acquire academic skills up to the fifth- or sixth-grade level (comparable to Primary 6 in the Hong Kong system) by their late teenage years. During their adult years, they may develop sufficient social and vocational abilities to work and live independently or in a supervised setting and need a minimum of external support (Harris, 2006).

Moderate mental retardation. About 10% of individuals with mental retardation fall within this level of functioning. The DSM-IVTR describes their IQ scores as being between 35-40 and 50-55 (American Psychiatric Association, 2000). However, their IQ scores are deceptive because various cognitive profiles of abilities are commonly observed in this group. For example, some of them may have better visual-spatial skills than language skills. In addition, some functions of this group may be underestimated as a result of their apparent physical anomalies (Harris, 2006). Typically, developmental delays across many functions are found and their school achievement is limited, but those who are in the higher functioning range can learn basic skills in arithmetic and reading by 16 years old. As adults, they may participate in simple, practical work that is carefully structured, but they generally need consistent supervision by others (Graziano, 2002; Harris, 2006).

Severe and profound mental retardation. About 3-4% and 1-2% of individuals with mental retardation are of severe grade and profound grade, respectively. The DSM-IVTR describes their IQ as being between 20-25 and 35-40 for the severe grade and below 20-25 for the profound grade (American Psychiatric Association, 2000). This is the lowest functioning group, and individuals in this group have significant motor impairment and other associated deficits such as blindness, cerebral palsy, or other brain damage. Furthermore, adaptive behavior, speech, language, and social skills are usually significantly impaired. In most cases, they live in a hospital-like, residential environment and remain gravely dependent on others. In addition, lifelong support services are usually necessary (Graziano, 2002; Harris, 2006).

Conclusion

The characteristics of people with mental retardation are not totally the same as those of the mainstream population, at least not in terms of their lower intellectual functions and their deficits in some adaptive behaviors. It is believed that the utilization of existing computer interfaces is one of the adaptive behaviors from which people with mental retardation may also encounter problems. Therefore, in the next section, the literature of the past few decades on the use of technology by people with mental retardation is reviewed.

Computer Technology for People with Mental Retardation

With the increasing importance of the use of technology in our daily lives, the focus of this section is to familiarize the reader with the possible effects of the recent developments in computer technology on people with mental retardation. This section covers advances in computer technology and computer utilization by people with mental retardation.

Advancements in Computer Technology

In the information age, access to human-computer interfaces has become increasingly important in our daily lives and is regarded as an important survival skill

(Dumont, Vincent, & Mazer, 2002; Hammel & Smith, 1993; Lane & Ziviani, 1999). Information technologies have become an integral component of our lives as almost everyone, including people with disabilities, has increasingly relied on technologies for obtaining up-to-date information, completing work tasks, as well as employing the technology for entertainment and communication (Li-Tsang, Yeung, Chan, & Hui-Chan, 2005; Subrahmanyam, Greenfield, Kraut, & Gross, 2001).

Evidence from local and overseas sources indicates that there has been a rapid growth and development of information technology in the past few years. In the United States, the number of computers installed in schools was reported to have increased more than threefold from 1984 to 2000. The number of websites operating on the Internet had grown to over 170 million by 2003 (Downing, Moore, & Brown, 2005). There were around 10 million users of the World Wide Web and 35 million email accounts in 1995, but these numbers were projected to grow to 200 million users of the World Wide Web and 300 million email accounts by 2000 (Stanford University, 1998). A similar trend was also observed in Hong Kong; it was ranked fifth in the world with respect to access to the Internet per household in 2001. From 2000 to 2001, the percentage of households with computers increased from around 50% to around 60%, and the percentage of households using the Internet increased from 36% to 49% (Hong Kong Special Administrative Region Government, 2001). The implication of these numbers is that more and more people have opportunities to access these information technologies. In addition, some of our traditional work modes have changed, and many tasks exist that could now be hardly performed without computers (Abascal & Nicolle, 2005). For example, people are shifting their mode of communication from conventional methods such as wired telephones and fax machines, to Internet-based and mobile communications. Possessing the knowledge and skills for accessing and using these new interaction platforms is a key to survival in the world of the future (Hammel & Smith, 1993; Mazer, Dumont, & Vincent, 2003).

Computer Utilization by People with Mental Retardation

In the past few years, advances in computer technology have enabled minority groups or disability groups such as people with mental retardation to have more opportunities to be exposed to information technology (Li-Tsang et al., 2005). These advances in computer technology seem to be useful in enhancing the functions and hence increasing the independence and maximizing the community integration of people with mental retardation (Davies, Stock, & Wehmeyer, 2001, 2002a, 2002b; Dumont et al., 2002; Lane & Ziviani, 1999). Previous studies have gathered evidence on the benefits of using the computer as a common medium in the training of cognitive skills (Mastropieri, Scruggs, & Shian, 1997; Mechling, Gast, & Langone, 2002), enhancement of learning (Dube, Moniz, & Gomes, 1995; Langone, Shade, Clees, & Day, 1999; Podell, Tournaki-Rein, & Lin, 1992), and training of vocational skills (Davies et al., 2002a).

The benefits of using technology for people with mental retardation are, it seems, well documented in the literature. Nevertheless, various studies have revealed that the existing human-computer interfaces were too complex and often not appropriate for use by people with mental retardation (Wehmeyer, 1998, 1999). For example, a previous study indicated that people with mental retardation had substantial problems in using the existing computer technology; for example, web browsers (Davies et al., 2001). Such findings are not surprising as people with mental retardation are well known to have a generally low level of intellectual or cognitive abilities. Some examples of these lower abilities include attention (Tomporowski, Hayden, &

Applegate, 1990), memory (Henry & MacLean, 2002), visual-spatial processing (Vicari, Albertini, & Caltagirone, 1992), language processing (McCauley, 2001), and sensory-motor functions (Lee & Tsang, 2001). It is hypothesized that these lower cognitive and motor functions demonstrated by people with mental retardation would in turn interfere with their use of, and even make it impossible for them to learn to interact with, most of the existing commercial computer interfaces. In fact, it is not difficult to visualize the problems encountered by people with mental retardation in using existing human-computer interfaces in the information society. Most of the production of commercial hardware and software is targeted at the mainstream population and has been designed without taking into account that they might be used by people with disabilities (Abascal & Nicolle, 2005). A previous study revealed that differences in ability between users have not been a major concern of commercial software designers, so that many existing applications were produced without much sensitivity to the wide range of capabilities of different potential users (Egan, 1998). Given that the hardware and software would be suitable for use by the mainstream population, they are probably too complex and too demanding for people with mental retardation, because the requirements for carrying out the tasks exceed the ability characteristics demonstrated by individuals with mental retardation (Cress, French, & Tew, 1991; Cress & Goltz, 1989).

Conclusion

This section has revealed that people with mental retardation have substantial problems in using existing computer technology. Furthermore, a review of the literature indicates that research in this area has focused on investigating the functional problems encountered by these people and the ways by which their competence in using computer technology can be improved. There is a lack of research, however, on exploring the underlying mechanisms that restrict people with mental retardation from effectively using computer technology, as well as on how the machine-interface design could be enhanced for bridging the theory-driven machine-user gap. The next section, therefore, attempts to focus on examining the mechanism that obstructs individuals with mental retardation from accessing human-computer interfaces.

Human-Computer Interaction (HCI) and Human Information Processing

We speculate that the mismatch between the task demands of the existing computer interfaces and the abilities of people with mental retardation accounts for people with mental retardation being barred from access to the technology. In this section, the human information-processing model for HCI, individual differences particularly with respect to cognitive abilities, and the compatibility between the cognitive functions of people with mental retardation and those required by the HCI, will be reviewed.

Human Information-Processing Model for HCI

Searching the web for information can be mediated by an information process that involves visual perception, decision-making, working memory, and long-term memory (Wickens & Hollands, 2000). An information-processing model would provide a basis for understanding the mental processes experienced by the user when browsing the web and also the processes in the interactions between the users and the web (Preece, Rogers, & Sharp, 2002).

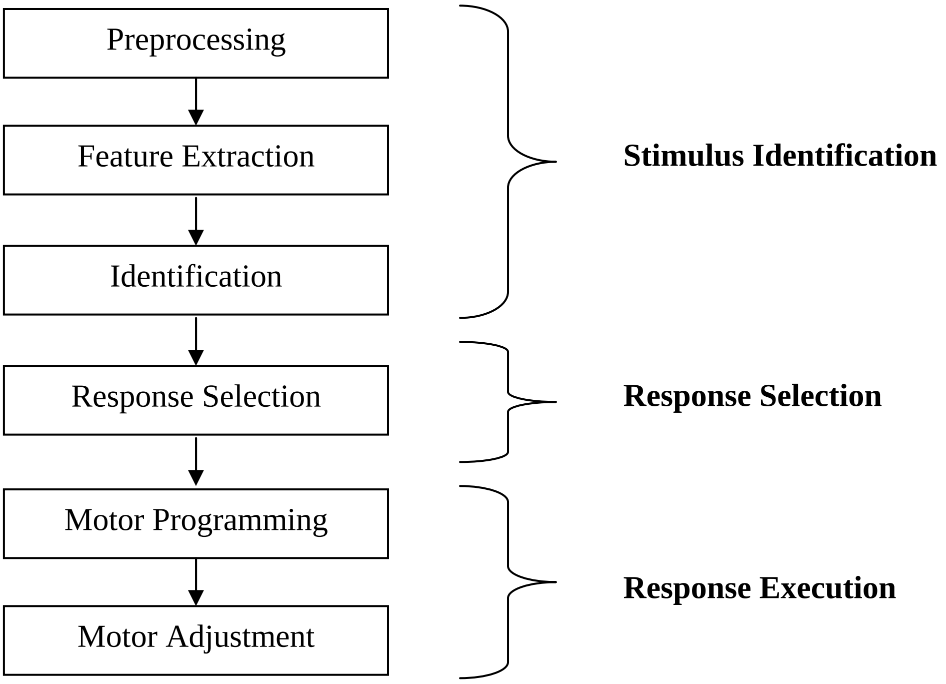
The human information-processing mode for human-computer interaction is based on the idea that a human being is like an active information processor in which the human performance, from displayed information to a response, is a function of several processing stages including stimulus identification, response selection, and response execution (Figure 2.1; Proctor & Vu, 2003; Sanders, 1998).

The stimulus identification stage involves processes that are entirely dependent on properties of the stimuli. At this stage, the user is required to identify the displayed information when interacting with the human-computer interface. Sanders (1998) further divided this stage into three substages including preprocessing, feature extraction, and identification. Basically, the preprocessing stage of stimulus identification refers to peripheral sensory processes involved in the conduction of the sensory signal along the afferent pathways to the sensory projection areas. Feature extraction involves lower level perceptual processing based in the primary visual cortex, while identification involves the recognition of object representation. These three subprocesses will be discussed in-depth in the subsequent section on topics related to the human visual system and feature integration theory. The response selection stage refers to those processes involved in determining what response to make to a particular stimulus.

The response execution stage refers to motor responses and their execution. At this stage, the user is required to use the keyboard, mouse, and joystick to move a cursor to a target position on the screen. Sanders (1998) further divided this stage into two substages, including motor programming and motor adjustment. The motor programming substage refers to the specification of the physical response that is to be made, which involves loading the movement sequence into a buffer before initiating the movements. The motor adjustment is the last stage of information processing and deals with the transition from a central motor program to peripheral motor activity.

Figure 2.1

Stages of the information-processing model for HCI (Proctor & Vu, 2003; Sanders, 1998)



According to this theory, interacting with a human-computer interface would require users to use different amounts of cognitive resources. When opening the web browser and bringing up the web page, users would search for information displayed on screen, such as menus, scrollbars, icons, or web hyperlinks, and then orient their attention to the appropriate spatial location on the screen (stimulus identification). When the users try to find the target icon or item, they would decide on their own ways of searching for the potential icon or item. Sometimes, the users would be required to recognize words that appeared on a toolbar menu or web page in order to identify the target icon for the task functions to be performed. At the same time as this visual searching process would be taking place, the users would require working memory to enable them to visualize the menu and web structures, to keep track of the previously examined paths to avoid becoming lost, and to work out which path to choose next. If such an icon or item could not be found, the user would plan alternative paths. When the users selected the responses (response selection), they would retrieve the commands stored in their long-term memory and use them for different task functions. During this interaction, some problems would suddenly appear which would require the users to make decisions and solve them. The users would program their motor sequence to initiate the response; for example, by clicking the icon via the mouse button (response execution). This information search would be an interactive process between the users searching for the required information and the design and visual presentation of the web page or web browser. The performance of this information search would also demand a variety of perceptual, cognitive, and motor functions, including orientation, attention, visual search, visual-spatial function, memory, language processing, frontal lobe function (e.g., decision making and planning), as well as motor control. This interaction process could only be facilitated if the design of the web could be matched with the information-processing capabilities and styles of the users (Preece, Rogers, & Sharp, 2002; Proctor & Vu, 2003). The information-processing capabilities of the participants with mental retardation, including attention, visual-spatial function, memory, language processing, frontal lobe function, and motor function will be assessed by different cognitive and motor tests in order to cater to the special profiles of this population that match with the demands of performing the web-browsing tasks. The construct and psychometric properties of these tests are to be found in the method section.

Individual Differences in HCI-Cognitive Abilities

Egan (1988) indicated that there are substantial individual differences in computer-based performance. In order to accommodate an expanding and increasingly heterogeneous computer-user population, it is necessary for designers to understand the interaction between user characteristics and computer-based tasks. Previous studies have gathered evidence that the cognitive function is strongly associated with the performance of computer-related tasks (Egan, 1988; Rozell & Gardner, 2000; Westerman, 1993), and subsequent research has considered the effect of a variety of individual cognitive differences on computer-based task performance. Egan (1988) carried out a systematic review of documents related to individual variations in computer-based performance. She further concluded that spatial and reasoning abilities are more important than verbal ability in current human-computer interaction. Spatial ability is defined as the ability to locate objects in a display and evaluate detailed spatial patterns (Egan, 1988), while spatial ability can also be defined as the ability to visualize figures in different orientations. In a more recent review of the literature on human-computer interaction, spatial ability has received considerable attention. For example, Westerman and Cribbin (2000a, b) indicated that users with a high spatial ability had an overall better performance in information retrieval in virtual environments. Similarly, Modjeska and Chignell (2003) also found that people with a high spatial ability had significantly faster performance when searching for information in a desktop virtual-reality environment.

Previous studies have suggested that visual-spatial memory also plays a very important role when subjects use a menu for retrieving information or making decisions on options when operating the interface (e.g., Gwizdka & Chignell, 2004; Westerman, 1997). Gwizdka and Chignell (2004) defined visual memory as the ability to remember the configuration, location, and orientation of figural or visual stimuli. As this memory is related to short-term retention ability for visual material, they concluded that people with lower visual memory were slower when browsing for information on an email interface which consisted more of graphics-based representatiosn than of text-based designs. They further explained that the lower performance was due to the graphics-based email interface, which required users to switch across different displays when browsing for information, and thus required them, in particular those with lower visual memory, to use more effort to retain a greater quantity of visual information. Similarly, Westerman (1997) studied the effect of spatial memory on generating command using a file management task with command lines and menu. The result indicated that spatial memory was predictive of the user’s performance on the tasks.

Meanwhile, Zhang and Salvendy (2001) further revealed that visualization (the ability to mentally construct and rotate a spatial configuration in the short-term visual memory and to perform a serial operation) predicted users’ performances when visually searching the web for information. In their study, they assumed that the process of visualizing the website structure during the information search was conducted and held in the working memory. Therefore, both the working memory, as well as visualization abilities, played very important roles in the information search on the web. They found that the users with a higher ability to mentally visualize the website structure in their working memory showed significantly better performances than those with lower ability when searching visual items was required.

Actually, the process of searching a website for information is very similar to the process of information retrieval from a menu structure, in which working memory and visualization ability play very important roles (Zhang & Salvendy, 2001). Both the menu and web hyperlink have hierarchical structures. The term "hierarchical structure" refers to the the structure of the menu or web page consisting of several hierarchical levels, in which a number of items exist together on the same level. For example, on an 8 x 8 x 8 hierarchical menu structure, there are eight top-level categories, and under each of the top-level categories, there are eight sublevels. In addition, there are a further eight items below each sublevel (Larson & Czerwinski, 1998). We expect that with the hierarchical design of the web pages or menu, an individual search for information from one layer is only meaningful when the information is combined with information from another level. What this means is that greater loads are placed on the working memory of individuals performing the task. Thus, people with a lower working memory may have more difficulty in mentally visualizing the website or menu structures. Therefore, those with lower working memory ability would lose track of the search activities when browsing the web page or menu.

Earlier studies commonly used the term "depth" to describe the number of hierarchical levels and "breadth" to describe the number of items grouped at the same level. Previous studies examined the depth/breadth tradeoff on structure design on the menu and the web page (e.g., Jacko & Salvendy, 1996; Miller, 1981; Snowberry, Parkinson, & Sisson, 1983). Most of these studies concluded that breadth was better than depth when it came to organizing the menu contents. Although our study did not examine the depth and breadth tradeoff issues in the graphical user-interface menu design, the results of Study 3 may suggest some guidelines regarding the possible number of items that would be the best choice for searching for target items as far as the depth of menu structure for the users, particularly those with mental retardation, is concerned. The results could also provide additional information on how we organize the orientation of the items across the menu contents.

In short, cognitive abilities have been recognized as an important predictor of computer-based performance. In particular, the visual-spatial function and working memory seem to play a very important role in accounting for individual performance variation in human-computer interaction, specifically in those tasks involving a visual search for target information on the menu and web structures.

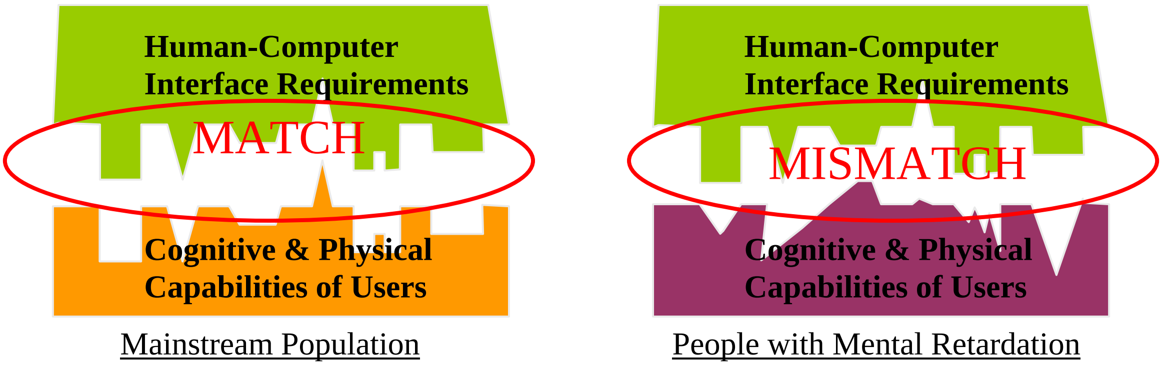
Cognitive Compatibility between People with Mental Retardation and HCI

The terms of software psychology or human-computer interaction embrace the concept that the technological design should explicitly consider the cognitive compatibility of the users (Carroll, 1997; Chignell, Hancock, & Takeshita, 1999). The Drug Model of Technology Fit developed by Chignell et al. (1999) provides a useful metaphor which describes how technology should fit the users. An appropriate metaphor for technology fit as described by this model is that the cognitive and physical demands required by the human-computer interface (technology drug) should match the profile of the user’s capabilities and needs (receptor sites in the brain). The task of design is to find a suitable interface that is within the cognitive and physical capabilities of the users. Therefore, the usability, productivity, and satisfaction of the human-computer interface would reflect the degree of fit between the two aspects.

People with mental retardation have lower cognitive and physical capabilities when compared with the mainstream population, such as lower working memory and attention functions. The cognitive and physical demands of the human-computer interface originally designed for the mainstream population most probably do not fall within the capabilities of people with mental retardation (Figure 2.2).

Figure 2.2

A schematic representation of the Drug Model of Technology Fit for human-computer interface of web design



Note: Cognitive and physical demands required by the human-computer interface match the cognitive and physical capabilities of the mainstream population but do not match those of people with mental retardation.

Importance of Universal Design

When we design or redesign mass-produced computing products to accommodate those who have cognitive limitations, it may simultaneously reduce the functionality and even the marketability of these products. Therefore, our question is whether there are any approaches that designers can adopt to make the products usable by people with the widest possible range of abilities and at the same time, meet market demands of the products. In this section, the principles of universal design are described in order to highlight this issue.

Principles of Universal Design

Accessibility and a high quality of interaction with products, applications, and services by anyone, anywhere, and at any time are fundamental requirements for universal access (Stephanidis & Savidis, 2001). Ideally, the design of products or environments should take into account everyone's needs, including those with restricted functions due to disabilities or aging, as well as those with average abilities (Buhler, 2001).

All along, the issue of accessibility has been regarded as a common theme demonstrating the dilemma between universal design and *functionality*. The rapid development of technology has made accessibility a problem, not only for people with disabilities but for almost all of us as well. This accessibility problem is due to the changing global view of people with disabilities and older adults, and the rapid pace of technological change, both of which lead to technological products and services demanding particular skills and abilities of users before they can be operated (e.g., experience in the use of advanced technologies). Although the utilization of advanced technologies, such as the automatic teller machine (ATM), has brought greater convenience and cost-effectiveness for all potential users without their requiring assistance, the operation of an ATM requires the user to make relevant responses to sequential prompts displayed on the screen of the machine, which demands considerable perceptual, cognitive, and motor abilities (e.g., Jamieson & Rogers, 2000). As a result, individuals who have lower perceptual, cognitive, and motor functions, and those who have a lack of experience in using these advanced technologies may be restricted from utilizing them. In other words, as a result of recent technological developments (e.g., proliferation of diverse interaction platforms, such as wireless computing and wearable equipment), the range of the population that may gradually be confronted with accessibility problems extends beyond the population of users with disabilities and older adults to include everyone. In view of these considerations, there is a need to search for a promising approach to universal design for those from every walk of life (Buhler, 2001; Stephanidis & Savidis, 2001).

However, the development of a universal design for a new product or environment would have to be acknowledged as possibly becoming very costly and even leading to a loss of market share to competitors. This is because the design of a product based on universal solutions requires a more advanced technology to generate solutions for those with functional limitations. For example, the development of many built-in enhanced features and their incorporation in conventional designs would require the company developing the product to pay for extra financial and human resources in order to add some hardware and some technological facilities to the product. Adding extra audio-prompting features to the Internet access software in order to guide the user as to the most probable next step in a web-browsing task would require the engineer to build in extra sound output facilities that would increase the overall cost of the software. On the other hand, the market-driven approach would exclude particular groups of users from utilizing the product or environment. For example, despite their sophisticated designs, some existing human-computer interfaces have launched many modifications that enable advanced users to perform some functions with simpler and more efficient steps, yet many of these modifications may not be useful and may even be too complex for citizens of average ability, let alone those with cognitive disabilities. Such conflicts are inevitable when a balance must be struck between the accommodation of the variation in user specification across different user groups and the considerations of aesthetics and marketability of the design (Beecher & Paquet, 2005; Buhler, 2001).

Due to the great diversity of user characteristics, it is almost impossible to consider all users when we design products or environments, but using this approach, it is nevertheless possible to enhance the usability of the products. In addition, it is also extremely beneficial for the mainstream population to be able to use the product under special conditions. For example, recommendations on web accessibility have suggested that eliminating unnecessary web design features that are not accessible for people with disabilities would also enhance the ability of the mainstream population to access the web under special conditions, such as when working in noisy or mobile environments (Abascal & Nicolle, 2005).

The contemporary universal design principle refers to the process which takes account of the abilities and limitations of the users when a product or environment is designed. The outcome of using a universal design is that the product or environment developed can be used by people with the widest possible range of abilities, operated within the widest possible range of situations, and ultimately reach most, if not all, potential users (Buhler, 2001). The value of universal design can be further enhanced by placing emphasis on redesigning mass-produced products or environments to accommodate those who have physical or cognitive limitations and have previously been excluded from effectively using the products in specific environments (Beecher & Paquet, 2005). Individuals who are commonly excluded by existing universal designs are people with temporary or permanent physical disabilities, people with mental illness, people with mental retardation, and older adults (Stephanidis & Savidis, 2001; Zajicek & Brewster, 2004). By including consideration for people with disabilities in the universal design, as well as by designing more inclusive interfaces for the mass-produced products and environment, not only will the utilization of the products and environments be increased, but also the process of reintegrating people with disabilities into mainstream society will be facilitated. Furthermore, the design of such inclusive interfaces helps to maximize the benefits of using the interface or system for all user groups with a wide range of abilities (Gwizdka & Chignell, 2004).

Lastly, it is important to clarify that universal design does not solve all accessibility problems. Some people will still need special equipment or assistive technology to access their computer. There are even those who think that universal design is a substitute for and excludes the use of assistive technology, although it is clear that both are necessary and complementary (Abascal & Civit, 2001).

Basics of Visual Perception and Visual Search

Visual search is an important part of many human activities, including those involved with human-computer interaction. We will use an individual searching for information on the web as an example. When the person opens the web browser and brings up the web page, his visual system is exposed to a multitude of stimuli of different shapes, sizes, colors, depths, and speeds of movement. Confronted with this array of information, he is still able to focus on one or on a few items, such as the icons or web links, and is still able to process the relevant information. If the required item cannot be found, he will shift the search from one location on the visual screen to another and continue the search. This is a typical visual search task on the web page interface.

The search on a web page mentioned in the last paragraph would involve some important perceptual and cognitive processes within the individual's brain. First is the focus on a few items or only one item on the screen. This would require the individual to attend to a particular location, like putting on a spotlight on the particular information which can be extracted. This attentional spotlight is often called the *attentional field, effective visual field, useful field of view,* or *visual lobe* (Ball, Beard, Roenker, Miller, & Griggs, 1988; Kraiss & Knaeuper, 1982). In this research, the term *visual lobe* is preferred because it refers to the sensitivity limit for a particular target and its background characteristics. The content within a visual lobe can readily be extracted and processed. The content outside the region of the visual lobe cannot be easily detected. The second important cognitive and visual process occurs when searching with the eyes; this relies on the propagation of the gaze position which is also known as the saccade. Each saccade movement is thought to be preceded by a shift of attention to the goal of the upcoming saccade which demands spatial attention capacity (Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995). The attentional process associated with searching with eye movements is called *shift attention* or *orienting attention*. Third is the involvement of spatial memory which captures the information that we extract when the visual search goes from one location to another (Findlay & Brown, 2006; Findlay & Walker, 1999). One important function of spatial memory is to prevent the observer from repeating the same locations that have already been scanned (McCarley, Wang, Kramer, Irwin, &

Peterson, 2003; Shore & Klein, 2000). Each of these concepts will be described in more detail in subsequent sections.

Peripheral Vision and the Visual Lobe

Peripheral vision plays an important role in many human visual tasks. Courtney and Guan (1994) indicated that the size and shape of the visual field are two core parameters modulating performance on peripheral vision. This visual field is restricted by the anatomy of the eye, the facial bone structure, the curvature of the cornea, the distance between the cornea and the iris, and the physiology of the retina, that is, the distribution of photoreceptors in the retina. The visual lobe is defined as the area around the center of visual fixation within which information can be extracted within the single fixation (So, 2003). The differences between the meaning of visual field and visual lobe are explained by Rantanen and Goldberg (1999). They defined the visual field as the area in which a stimulus can be simply detected and the visual lobe (or functional field of view) as the area where information on the stimulus can be extracted, that is, recognition or categorization. As one would anticipate, the area covered by a visual lobe is considerably smaller than that covered by the visual field. The former has a radius of around 2 to 4 degrees extending from the point of fixation, while the latter is about 60 degrees upward and inward, 70 to 75 degrees downward, and 100 to 110 degrees outward (Harrington & Drake, 1990; William, 1982). As the visual lobe has the function of extracting additional information from the stimulus, it is also known as the functional useful field of view. It is the space in which retinal sensitivity is good enough to distinctly see small stimuli within a single fixation (Ball et al., 1988).

The visual lobe is restricted by the uneven photopic cell distributions throughout the retina. When a person fixates at a point, the photopic visual sensitivity is at a maximum along the line of sight and decreases approximately linearly toward the periphery (Chan & So, 2006). The visual lobe is a useful concept to define the limit of peripheral sensitivity for specific target and background characteristics, and it represents the probability of target acquisition as a function of eccentricity from fixation (Chan & So, 2006; Courtney & Chan, 1985).

Visual Lobe and Visual Search

Previous studies have suggested that the size of a visual lobe or its area is a key determinant for visual search performance (Courtney & Chan, 1993; Gramopadhye, Drury, Jiang, & Sreenivasan, 2002). In general, subjects who had a larger lobe size exhibited shorter search times. In addition, the larger the lobe size is, the fewer fixations are needed to cover an area, and hence a larger lobe size gives a more efficient search (So, 2003).

Over the last few decades, theories and models of visual search have assumed a regular and homogenous functional visual lobe area, as well as a circular or elliptical lobe shape boundary (Chan & So, 2006). However, previous studies have revealed that the area of the binocular visual lobe is irregular in shape. Furthermore, there are apparently insensitive areas in the peripheral region of the visual lobe (Courtney & Chan, 1985, 1993). These findings imply that the use of visual lobe size alone does not necessarily predict search performance. Instead, the precise quantification of visual lobe shape is also needed for predicting search performance, as well as for understanding the search strategies, and analyzing eye movement phenomena (Chan & So, 2006; So, 2003).

Visual Lobe Measurement

A variety of apparatuses have been developed or adapted to quantify the visual lobe in order to suit the special settings of visual search and lobe measurement experiments over the last several decades (Courtney & Chan, 1993; Rantanen & Goldberg, 1999; So, 2003). In this study, we adopted the Visual Lobe Measurement System (VILOMS) (So, 2003) for mapping the visual lobe of subjects. The details of the operation of VILOMS will be described in the method chapter. This section, meanwhile, explains the shape indices that we used to quantify the shape of the visual lobe of subjects, which were based on the two studies conducted by Chan and So (2006) and So (2003).

Sixteen shape indices are expressed in the VILOMS program, and these shape indices are categorized as sphericity, boundary smoothness, symmetry, elongation, and regularity (Table 2.1). Sphericity is used to compare the shape of an object to a circle, which represents the most compact shape among all geometric figures. Boundary smoothness is a measure of the abrasiveness of the lobe boundary and is used to measure how smooth the actual outline of the shape of an object appears in the visual lobe. On the other hand, symmetry refers to how similar two halves of a shape are when it is divided by imaginary vertical or horizontal axes. Elongation is the measurement that indicates how far the shape of an object is horizontally or vertically elongated, and regularity is used to directly compare a shape with a standard. The standard shape is the circle because the lengths of all spaced radials from the center of the circle are equal. The measurement consists of drawing a set of equally spaced radials from a location within the shape to its perimeter. Detailed descriptions of these 16 shape indices are given in Appendix I.

Table 2.1

Five categories of visual lobe shape indices expressed in VILOMS

Category	Shape Indices
Sphericity	Form Factor Perimeter-Area Ratio Perimeter-Area Ration of Convex Hull Area-Maximum Area Ratio Ratio of Radii
Boundary smoothness	Global Convex Deficiency Rugosity Spike Parameter
Symmetry	Horizontal Vertices Symmetry Vertical Vertices Symmetry Left-Right Area Symmetry Top-Bottom Area Symmetry Horizontal Symmetry of Convex Hull Vertical Symmetry of Convex Hull
Elongation	Length-Width Ratio
Regularity	Boyce-Clark Index

Comments

The area of the visual lobe is an important factor which influences visual search performance. Subjects having a larger visual lobe area may exhibit shorter search times because they require fewer fixations to cover the area and can hence make a more efficient search. Our review indicates that there is no research on the visual lobes of people with mental retardation. It is hypothesized here that the area of the visual lobe of people with mental retardation would be smaller than that of their normal counterparts. Following this line of thought, which we can describe as being concerned with the visual area, people with mental retardation would be expected to encode less visual information. In this study, the area of the visual lobe of subjects with mental retardation will be obtained and compared with the area of those without mental retardation.

Attention and Memory in Visual Search

An understanding of the underlying mechanisms of normal visual search provides explanations on how people with cognitive disabilities, such as those with mental retardation, would modulate their visual search behaviors. This section begins by focusing on the human visual system, and then on theories of attention and memory in visual search.

Human Visual System

The visual system is composed of the retina, the visual pathways from the retina to the brainstem and visual cortex, and the cortical area devoted to higher visual functions. Light enters the eye through the iris and pupil, and reaches the retina, which is lined with photoreceptors in the form of rods and cones. Rods function only in dim light and are not sensitive to color. They are scarce in the outer part of the fovea and absent from its center. Cones respond to the bright light and are sensitive to color and shape. In addition, they are most abundant in the fovea (Martini, 1998). Quantitative values for cone and rod densities indicate that the maximum rod density is about 150,000 rods/mm^2 around 20 degrees from the fovea, but falls to under 100,000 rods/mm^2 in the periphery. Rod density falls to zero in the center of the fovea and the rod-free area is about 300 μm (1 degree of visual angle) in diameter (So, 2003).

The construction of the retina produces an inverted image. As light passes through the layers of optic nerve fibers, ganglion cells, and bipolar neurons before reaching the photoreceptors, the photoreceptors send messages to the bipolar cells and then the ganglion cells. The action potentials generated by the ganglion cells are then transmitted through the optic nerve formed by the axons of the ganglion cells to the brain (FitzGerald & Folan-Curran, 2002; Kalat, 2004).

Detailed vision involves the location of an object at the fovea because of two features. First, blood vessels at the fovea are almost absent and cone cells at the fovea are almost not overlapped by ganglion cells that create the least impeded environment. Thus, the light reflected from the object can strike the cones in the fovea without any diffraction. Second, each cone cell at the fovea connects to a single bipolar cell, and then to a single ganglion cell, resulting in higher resolution of the synaptic connections to the brain. These enable a large amount of information on details of the object to be transmitted at the fovea which maximizes perception (FitzGerald & Folan-Curran, 2002; Kalat, 2004).

The ability to transmit information on details of vision declines as it moves away from the fovea (Findlay & Gilchrist, 1998). There are two factors that contribute to this decline. First, a maximum density of cone cells is observed in the fovea, and their density decreases sharply with respect to eccentricity, while with the density of rod cells, the reverse is the case. The distribution of the cone cells contributes to the decline of visual resolution, and visual acuity, color discrimination, and contrast sensitivity show steady deterioration as the target is presented away from the fovea. Other visual functions, however, increase with eccentricity from the fovea, as their perceptions depend on rod cells (Kalat, 2004; So, 2003). For example, sensitivity to light and temporal discrimination increase as the target moves away from the fovea.

Visual discriminatory power, that is, the ability to perceive the details of visual stimuli, is a function of the extent to which the target falls within the fovea. This power can also be significantly enhanced if visual perception is accompanied by the individual’s attention being drawn toward the target (Mort & Kennard, 2003). Previous studies have indicated that manipulations of a subject’s attention improve the performance of visual tasks in terms of the quality of sensitivity and spatial resolution, including contrast sensitivity (Carrasco, Penpeci-Talgar, & Eckstein, 2000), texture segmentation (Yeshurun & Carrasco, 2000), and visual search (Carrasco & Yeshurun, 1998). It is important to gain an understanding of the mechanism by which visual attention mediates the visual search performance, because such an understanding would shed light on possible disadvantages experienced by people with mental retardation.

Attention in the Visual Search Task

Our brain has inherent limitations on the amount of information that can be processed at any one time. In order to perform any task effectively, there must be a means of selecting specific information for further processing (Banich, 2004). This process is called *attention*, which can be conceptualized as the gateway for information flow to the brain (Cohen, 1993). Recent theories on attention have indicated that attention is not considered a unitary function, and that it is commonly divided into several component processes such as alertness, vigilance, selective attention, and divided attention (Strauss, Sherman, & Spreen, 2006; Sturm, Willmes, Orgass, & Hartje, 1997). Alertness is defined as the capability to enhance response readiness following a warning stimulus (Sturm et al., 1997). That is, when the warning cues are presented preceding the target stimulus, the rate by which the attention can respond to that stimulus is increased because the warning cue serves as an indicator of alertness. Vigilance is defined as the ability to maintain an attentional capacity over a period of time (Lezak, Howieson, & Loring, 2004). For the experimental paradigm to measure vigilance, the subject is required to stay alert for prolonged periods of time in order to detect the relevant but very infrequent stimuli which appear at irregular intervals during the task (Kinsella, 1998; Sturm et al., 1997). Selective attention is the ability to focus on certain features of a task and at the same time suppresses responses to irrelevant features voluntarily (Sturm et al., 1997). This kind of selective attention is similar to other concepts such as orientation in extrapersonal space (Berlucchi & Rizzolatti, 1987) and orienting attention (Posner, 1980). Divided attention involves the ability to respond to more than one task at a time or to multiple elements or operations within a task, as in a complex mental task (Lezak et al., 2004). Although identified as distinct processes, it is important to note that the abovementioned processes are highly interdependent and are discerned with overlapping or synonymous processes (Kinsella, 1998; Strauss et al., 2006).

Actually, tasks that need interactions with the human-computer interface, such as searching for information on the web, require different components of attention. While we are opening the web browser window to bring up a web page, a variety of stimuli of different shapes, sizes, colors, depths, and speeds of movement are displayed on the screen. Despite the number of stimuli, such as the web page title, icons, links, and advertisement banners that appear on the screen, we are still able to focus on one or only a few items on the screen, and at the same time suppress responses to irrelevant ones voluntarily. This process brings one’s attention to a particular location, like putting a spotlight on a particular location from which the information can be extracted (alerting). However, the target stimuli are unlikely to be found with the first fixation. The next task is to delimit the search by moving our eyes to a location potentially containing the target until we are able to detect the target stimuli. This attentional process associated with searching with eye movements is called *shifting attention* or *orienting attention*. After the first fixation, we propagate our gaze position (i.e., saccade) to the potential region for further processing. At this time, much more information is available for selecting the potential region. For example, task goals, expectations of web element locations, global visual properties of the page, and local visual characteristics of the currently fixated region all contribute to how fixations are placed (Oulasvirta, 2004). The determination of the potential region to be placed in the next fixation, as one works from the preceding fixation, is associated with divided attention and more executive function, because the user has to perform multiple operations at this time. For example, the user is required to remember the previously scanned locations, and at the same time analyze the information available for selecting the potential region, as well as plan the next saccade for further processing.

Due to the fact that attention is so important in the visual search tasks involved in human-computer interaction, several influential information-processing models of attention have been proposed.

Feature integration theory. In a visual search task, participants are required to detect whether a target is present among distractors. The feature integration theory of visual attention could perhaps explain how attention would modulate the visual search (Treisman, 1986, 1999; Treisman & Gelade, 1980). This is also the theory that we adapted to conceptualize and develop the visual search experimental task used in this study. Treisman and Gelade (1980) developed feature integration theory to explain the behavioral results from visual search studies. When the target is distinguished from the distractors by a basic feature such as color or orientation (feature search), the reaction time and error rate often show as independent of the number of distractors. However, when two or more features such as color and orientation are combined to distinguish the target from the distractors (conjunctive search), the reaction time and error rate increase sharply as the number of distractors increases. To explain these results, this theory assumes that the basic features are encoded into feature maps or modules in parallel across the visual field at a preattentive stage (Figure 2.3). The features can be extracted automatically at the preattentive stage because a target-present response requires only detection of the feature. Thus, a target which is distinct from its neighbors in its preattentive representation in the brain should "pop out" of the display. The second stage involves focusing attention on a specific location—in other words, the spotlight focuses on a particular location—and combining features that are present in this specific location into objects. Attention is required for a conjunctive search, because the response cannot be based on the detection of a single feature. Based on this theory, the performance in conjunctive search tasks decreases as the number of distractors increases, because spotlight attention must be moved serially across the search field until a target is detected or all items present have been searched. At a later stage, the integrated information serves to create and update files on perceptual objects. In turn, these file contents are compared with descriptions stored in a recognition network. The network then incorporates the attributes, behavior, names, and significance of familiar objects. Figure 2.4 shows two typical search tasks: single feature (feature search) and multiple features (conjunctive search). In the left-hand panel of Figure 2.4, the target "red line" has a single feature (a red color) which pops out preattentively among the distractors ("green lines") during the feature search task. In the right-hand panel of Figure 2.4, the target "red and horizontal line" has two features: a red color and horizontal orientation, among different types of distractors, and "red and vertical lines" and "green and horizontal lines," during the conjunctive search task. During this conjunctive search task, spotlight attention is used to select and integrate the features present at a particular location. Afterwards, spotlight attention is moved sequentially across the search field until the target “red and horizontal line” is detected.

Figure 2.3

Feature integration model of visual attention (Treisman, 1986)

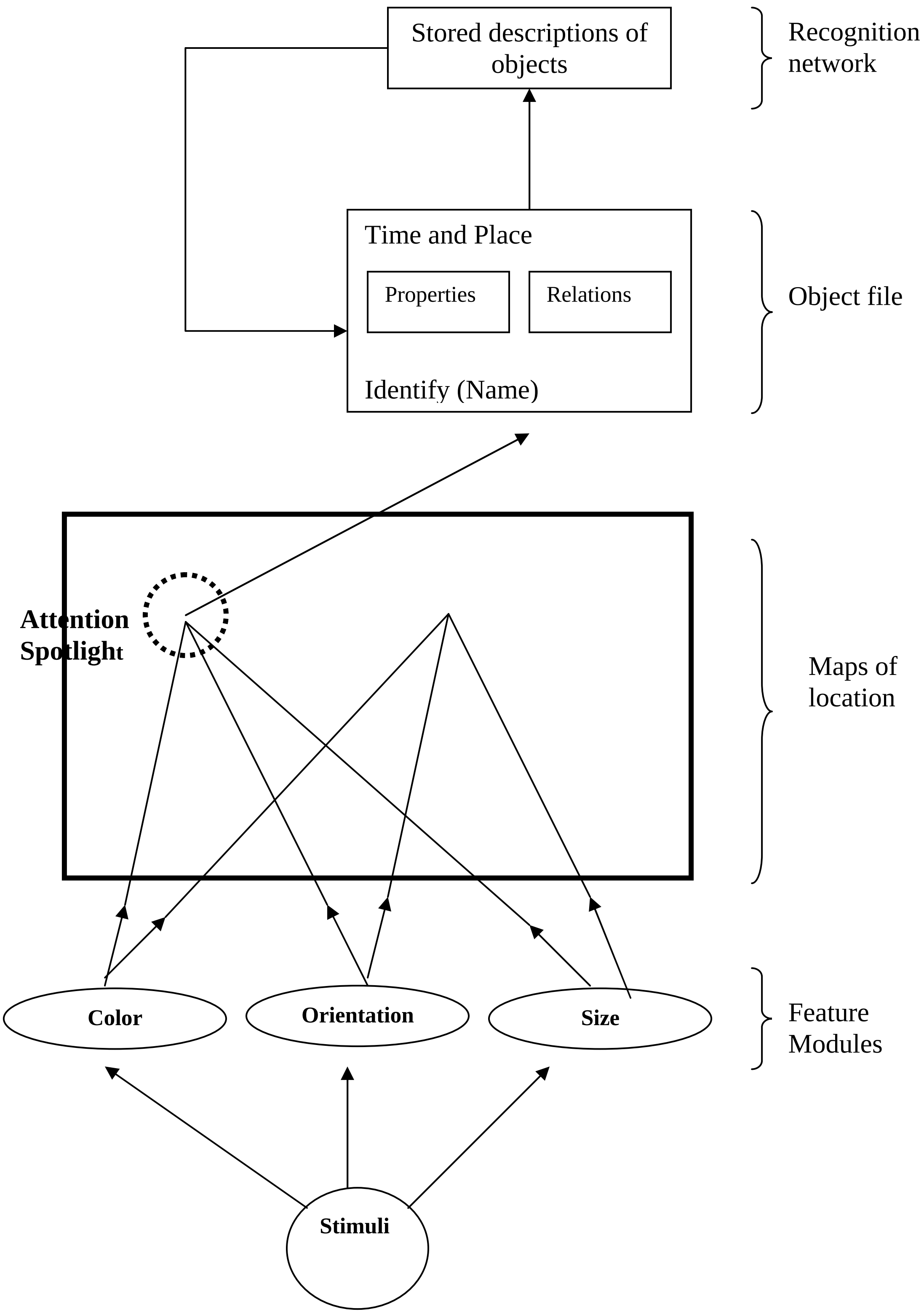
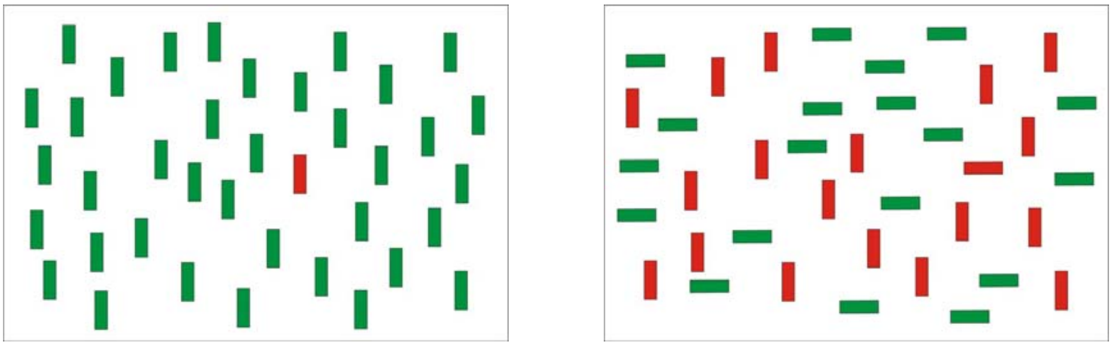


Figure 2.4

Example of feature and conjunction search tasks



Feature search   Conjunctive search

Neuronal model for visual attention. The neural mechanism of spotlight attention as proposed in the feature integration theory (Treisman & Gelade, 1980) has originated from the afferent visual pathways connecting to the primary visual cortex, namely, the parvocellular (P), magnocellular (M), and koniocellular (K) neurons. As the functions of K neurons are still not fully known, they will not be covered in this section. Meanwhile, the P neurons are located mostly in or near the fovea (Kalat, 2004). They have a mall cell body which captures a relatively smaller receptive field, and they can detect visual details and colors. The P-dominated ventral and temporal pathways extending from the primary cortex and into area V2, area V4, and the inferotemporal cortex (TEO and TE) mediate object discrimination of features like color, form, and texture (Figure 2.5; Vidyasagar, 1999). The M neurons are distributed throughout the retina. They have a large cell body which captures a relatively large receptive field. They respond strongly to moving stimuli (Kalat, 2004). The M-dominated dorsal pathway, also extending mainly from the primary visual cortex (V1) to the middle temporal area (MT) and further to the parietal and prefrontal cortices, mediates visual perception of attributes related to space, movement, depth, and positional relations. Although there are crossovers between these two pathways at various cortical levels, the dorsal stream going into the parietal cortex is largely driven by the magnocellular channel, while the ventral stream is predominately driven by the parvocellular channel with substantial magnocellular input (Ferrera, Nealey, & Maunsell, 1992, 1994).

Meanwhile, Vidyasagar (1998, 1999) suggested that the information on spatial locations of objects for the purpose of spotlighting is provided by the M-dominated dorsal pathway, which mediates the P-dominated ventral stream in conjunctive searches. The information in the dorsal stream is processed preattentively, that is, in parallel, over the whole visual field. The information that can thus be extracted about object locations can be used for spotlight purposes. This spotlight attention obviates the need to process information over the entire visual field in the ventral stream, because it restricts the ventral stream to a limited spatial region of interest in order to reduce the computational load and enable features of the object to be bound together. Therefore, this selective attention focusing serially on specific locations in the visual field is provided by the neurons in the dorsal pathway, and then only those neurons in the ventral pathway that respond to the features present in the object under attention would be excited at any one instant. This is the basis of the perceptual binding of features that belong to one object proposed by the feature integration theory (Treisman & Gelade, 1980).

It is a fact that the receptive fields (RF) of neurons in the ventral pathway beyond V1 become progressively larger (Vidyasagar, 1998, 1999). This progression of the RF gradient along the ventral pathway determines at which level a display of a particular target size is processed by spotlight attention. That is, when there is a number of small competing objects present in the visual scene, spotlight attention would be mediated in V1 (which has the smallest RF along the ventral pathway), whereas when the targets are larger and fewer, the search is perhaps mediated at a higher region: V2, V4, TEO, or TE. The mechanism for this differential attentional response perhaps helps formulate the hierarchical processing in the visual cortex to reduce the computational overload while binding features of the object together in the complex visual scene.

In our visual search task, all the relevant target features (i.e., color and size) that define the conjunction for detecting the target are entirely processed in the P-dominated ventral pathway; the M-dominated dorsal pathway is hypothesized to be responsible only for undertaking a serial spotlighting over the entire visual field in the display. The only task left for the M-dominated dorsal pathway would be the positional information of objects in the visual search task. Based on this neuronal model of spotlight attention, we would expect to undertake the classical Treisman-type serial visual search in our experimental task.

Figure 2.5

Neuronal model of visual attention (Reprint with permission, Vidyasagar, 1999, p. 69)

Note: Blue arrows indicate spotlight attention provided by the dorsal pathway mediated the ventral pathway for enabling the binding of features in the conjunctive visual search.

Alternative models of visual attention. According to the feature integration theory, the detection of stimuli with a single feature is a parallel process. The search time (or the processing time per item that a search entails) should be independent of the number of distractors embedded in the task. In contrast, establishing conjunction is a serial process which by itself is an inefficient search. The search time of stimuli with more than one feature should increase with the number of distracting items embedded in the displays. The results obtained from some researchers, however, did not concur with those obtained by Treisman (e.g., Duncan & Humphreys, 1989; Palmer, Verghese, & Pavel, 2000; Wolfe, Cave, & Franzel, 1989). For example, Duncan and Humphreys (1989) and Palmer et al. (2000) argued that the processes which occurred in a conjunctive search were parallel in nature, and that identification of the target and the distractor stimuli was simultaneously initiated. The increased reaction time which came with an increase in the number of distractors, as they explained, could have been due to an increase in competition for the finite resources of the visual short-term memory of the brain (Duncan & Humphreys, 1989) and the increase in the internal-to-external signal-to-noise ratio (Palmer et al., 2000).

The results from Treisman's conjunctive search experiment indicated that the individual parts or aspects of a scene must be processed in a serial manner. However, Duncan and Humphreys (1989) and Palmer et al. (2000) gathered evidence that the search process in the conjunctive search task can be initiated in parallel and that all comparison processes are simultaneously initiated. According to these models, the increasing reaction time as the number of distractors increases, may either reflect the increase in the competition for finite computing resources in the visual short-term memory of the brain (Duncan & Humphreys, 1989) or the change in the internal-to-external signal-to-noise ratio (Palmer et al., 2000). Although some alternative models of visual attention have been proposed, the basic idea suggested by Treisman of a spotlight of attention guiding a visual search is central to the theory advanced in this thesis.

Memory in a Visual Search Task

Memory is the capacity to retain information for adaptive purposes (Lezak et al., 2004). It refers to the complex processes by which the individual encodes, stores, and retrieves information. Encoding refers to the processing of information to be stored. For a memory to be useful, one must be able to retrieve it (Banich, 2004). There are two main types of memory system, namely short-term (working) memory and long-term memory (Strauss et al., 2006). The primary difference between the two types of memory is in terms of duration: long-term memory refers to the permanent or more stable storage of memories (minutes ago or years ago), whereas working memory (a relatively newer term to replace short-term memory) is conceived of as a limited-capacity storage for retaining information in the short term (from a few seconds to 1-2 minutes) and for performing mental operations with the contents of this store (Proctor & Vu, 2003; Strauss et al., 2006).

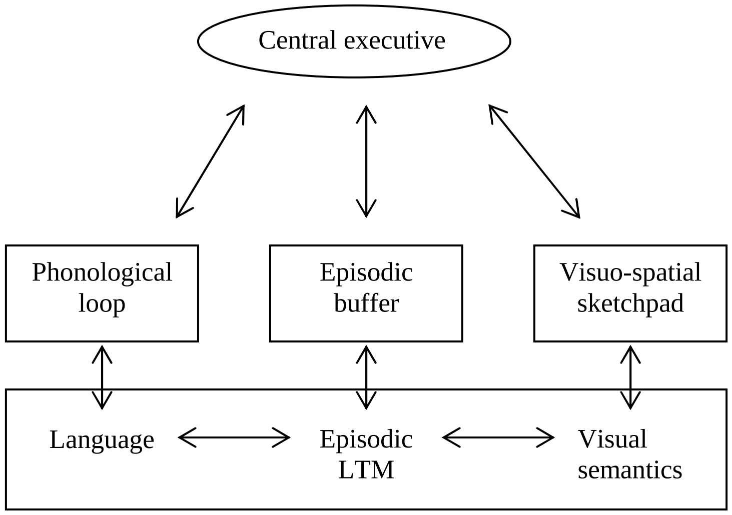
Long-term memory is generally split into two major divisions: explicit memory and implicit memory. Explicit memory refers to the conscious recollection of previous experiences (Strauss et al., 2006). It is further divided into two systems: episodic and semantic memory. Episodic memory refers to memory of a specific event and the contexts (time and place) in which it occurred, such as going to see an opera last night, while semantic memory refers to general knowledge about the world, including facts, concepts, and vocabulary, such as what the name of the opera was (Proctor & Vu, 2003; Strauss et al., 2006). Implicit memory refers to the influence of past events on cognition and behavior in the absence of awareness of that influence (Oulasvirta, 2004). It involves a heterogeneous collection of abilities that are manifested across a wide range of situations, such as priming, skill learning, procedural memory, and habit formation. Implicit memory involves the facilitation of a task or the change in its performance that is attributable to information or skills acquired during a prior study episode, even if the individual has not made any explicit reference to this prior study episode. An example of priming is when an individual is better able to generate words from fragments if the words were seen previously. Learning to ride a bicycle is an example of procedural memory (Strauss et al., 2006).

The best-known model of working memory is Baddeley’s (2000) revised working memory model. In this model, working memory is segmented into three components: a supervisory controlling system (the central executive), two peripheral slave systems, and the episodic buffer (Figure 2.6). The slave systems include the phonological loop, which is involved in the temporary storage and processing of speech-based materials, and its visual equivalent, the visual-spatial sketchpad

(Baddeley, 2000). The episodic buffer is a limited-capacity temporary storage that integrates information from the phonological loop, the visual-spatial sketchpad, and the long-term memory. The central executive controls the slave systems and forms strategies for using the information that they contain. Therefore, it is regarded as a limited-capacity attentional control system or a supervisory attentional system responsible for strategy selection and control of cognitive processes to facilitate complex cognitive activities (Shallice, 1982; Strauss et al., 2006). Based on this schema, it has been concluded that there is a kinship between the attention process and the working memory (Cowey & Green, 1996).

Figure 2.6

Baddeley’s revised working memory model (Baddeley, 2000)



In fact, interacting with the human-computer interface—for instance, by searching the web for information—involves different memories. For example, long-term memory is involved in memorizing the name of a website. Working memory is also involved when temporarily remembering the information obtained from the menu bars or previous web page, and at the same time, reading the information contained in the new menu options or new web page. Furthermore, when users retrieve information from a website, they have to visualize the structure held in the working memory when searching for information on a website (Zhang & Salvendy, 2001). Moreover, we also need memory to hold the locations of icons that we have previously examined in order to facilitate our search of new items in the display (Beck, Peterson, Boot, Vomela, & Kramer, 2006; Beck, Peterson, & Vomela, 2006). This special process, which involves remembering the locations of previously examined stimuli, is called *inhibition of return* (IOR; Klein, 2000). Previous studies have indicated that IOR is mediated by the spatial working memory system (Castel, Pratt, & Craik, 2003). It is described in detail in a later section called inhibition of return and retrospective memory.

Due to the fact that memory is so important in the information-searching task when users perform the web-browsing task, several types of memory that are believed to play an important role in the visual search tasks will be described in subsequent sections. Prior to this, the relationship between attention and memory during the visual search task will be described first since there is a kinship between attention and memory (Cowey & Green, 1996).

Relationships between Attention and Memory in Visual Search Performance

Visual attention and memory are related cognitive processes involved in visual search tasks. Russell and D'Hollosy (1992) suggested that certain aspects of memory are strongly related to attention. Furthermore, evidence from animal studies indicates that attention and memory share common neural substrates. For example, the dorsolateral frontal cortex contributes both to memory and to attention control processes (Funahashi, Bruce, & Goldman-Rakic, 1989; Goldman-Rakic, 1987, 1988). These findings concur with a frontal supervisory attentional system proposed by

Shallice (1998) that is very similar to Baddeley's notion of a central executive in working memory. The strong connection between attention and memory was also pointed out by Baddeley (1993) in which "one is attending with one's working memory." In addition, Posner and Raichle (1997) indicated that the area of the anterior cingulate that is the main neural substrate mediates the executive attention network associated with the control of working memory.

For the visual search task, Oulasvirta (2004) indicated that attention is necessary for accurate visual memory of perceived elements in the display, when for example the task involves searching for a target while the individual is engaged in the web interaction. The visual search involves the use of memory for holding the previously examined items, so that the deployment of attention is inhibited by being oriented to such previously examined items (Klein & MacInnes, 1999). It is therefore speculated in this thesis that attention and working memory processes are linked, and that both of them play very important roles in the visual search task. As people with mental retardation have both lower attention and working memory functions, it is anticipated that these would have a direct nonfacilitative effect on their performance on the visual search task conducted in this study.

Retrospective and Prospective Memory in a Visual Search Task

Recent studies have revealed that most researchers agree on a limited-capacity model of memory in a visual search (Beck et al., 2006a, 2006b; Klein & MacInnes, 1999; McCarley, et al., 2003; Takeda, 2004; Thornton & Horowitz, 2004). Two memories, namely, retrospective and prospective memories, were commonly reported in the visual search experiments conducted in these studies. Retrospective memory refers to the ability to recall past events. Examples include remembering what activities one did last weekend and recalling what movie one watched last night

(Schmitter-Edgecombe & Wright, 2004). Prospective memory refers to the ability to remember to perform actions one intends to carry out in the future. Examples include remembering to take medication every night at bedtime or to ask a friend about a lunch date (Schmitter-Edgecombe & Wright, 2004).

In a visual search task, the participant examines the items in the display until the target item has been found. Keeping the search efficient involves the participant's remembering where he or she has previously inspected. Furthermore, the participant must also remember the plan of where he or she intends to look in the display. The former is regarded as retrospective memory, which is then used to hold the previously examined items in the display (Beck et al., 2006a, 2006b), whereas the latter is regarded as prospective memory and is used to remember a scanpath strategy plan for examining future (new) items (Beck et al., 2006a, 2006b). Both of them are found to be useful in guiding attention toward the new items during a visual search task (Beck et al., 2006a, 2006b; McCarley et al., 2003; Thornton & Horowitz, 2004). The phenomenon that the return of the previously examined locations is inhibited, resulting in a less efficient response to the objects embedded in these previously examined locations, is called *inhibition of return*. It was first observed by Posner and Cohen (1984). This phenomenon is related to the attention shifts (orienting attention) contained in Posner's networks of attention (Posner & Peterson, 1990; Posner & Raichle, 1997). In the following paragraphs, the networks of attention are described, followed by detailed descriptions of the inhibition of return and scanpath strategy planning which mediate the visual search performance.

Networks of attention. Neuroimaging studies have systematically shown that a wide variety of cognitive tasks can be seen as activating a distributed set of neural areas, each of which can be identified with specific mental operations (Posner &

Raichle, 1997). Attention is usually viewed as involving specialized networks to carry out functions such as achieving and maintaining an alert state (*vigilance network*), shifting attention toward sensory events (*orienting network*), and controlling in situations that involve planning or decision making, error detection, novel responses, and overcoming habitual actions (*executive network*).

Individuals move the eyes and fixate them on a specific location that allows the image to fall on the fovea with the highest acuity in order to see an object in more detail. To be able to shift attention to a new object to observe its detail, one first has to disengage attention from the current focus and move it to the new location where the target can be engaged. The brain network which brings the operation to the specific location in order to provide a relative enhancement of the target at that location in comparison with other items presented in the visual field is called *the orienting network*. This operation involves the shifting of attention with the eye movement to bring the stimuli to the fovea to improve the efficiency of the processing of the targets. This is called *overt orienting of attention*. On the other hand,there are situations where individuals shift attention toward a point of interest but without producing an overt change in the eye position. This is called *covert orienting of attention* (Kinsella, 1998; Posner & Petersen, 1990). Previous studies concerning the neural substrates mediating the orienting network have focused on the parietal lobe (disengagement), superior colliculus (moving), and pulvinar (engagement).

The brain network that undertakes a more executive function while also being involved in the control of brain areas in order to perform complex cognitive tasks is called *the executive attention network* (Kinsella, 1998; Posner & Petersen, 1990). The common tasks involved in the executive function of attention include error monitoring, conflict resolution, control of working memory, planning, and decision making

(Posner & Raichle, 1997). Although these two networks show considerable independence of each other in some situations (Fan, McCandliss, Sommer, Raz, & Posner, 2002), the executive network is capable of commanding the orienting network. In addition, this network is responsible for the supervisory attentional control of goal-directed tasks, in which it supervises and coordinates the lower level attention processes and resources to perform complex cognitive tasks (Kinsella, 1998). The main brain structure that mediates this network is the frontal cortex, in particular the anterior cingulate and lateral prefrontal cortices (Bush, Luu, & Posner, 2000; Duncan et al., 2000; MacDonald, Cohen, Stenger, & Carter, 2000).

The brain network that maintains a sustained state of alertness over long periods is called *the vigilance network*. The vigilance task commonly uses a continuous performance paradigm that requires the participants to make a response to a target that appears only infrequently when the participants are presented with a list of stimuli. For example, the participants are presented with a series of numbers (e.g., digits 1 to 9), and are required to make a response, such as pressing a key, to the frequently presented nontargets (digits 1, 2, 4, 5, 6, 7, 8, and 9), but with the requirement to withhold the key responses to infrequently presented targets (digit 3). Posner and Rothbart (1992) relate this network to the norepinephrine system (NE), which may provide the mechanism for sustained attention, and have argued for a significant role of the right hemisphere. This network has been associated with the frontal and parietal activities in the right hemisphere (Fan et al., 2002; Posner & Petersen, 1990).

Retrospective memory and inhibition of return. In performing a visual search task, it is very important for individuals to keep track of the targets and locations that they have actively searched and at the same time proceed to new targets and locations. When the individuals search for the targets, their visual search performances are inhibited to avoid returning to previously examined locations. This involves IOR, which is inhibitory in nature as it prevents individuals from returning to previously inspected locations; it is mediated by spatial working memory (Castel et al., 2003). IOR was first proposed by Posner and Cohen (1984) and Posner and Raichle (1997) who observed that when attention is moved from one location to another in a visual array, processing of stimuli at a previously attended location is somewhat inhibited in comparison to a location that has not recently been attended. This inhibition effect involves an increase in response time to an object embedded in a previously attended region and presumably reflects the difficulty of returning attention to a previously attended location.

Some previous studies have used the eye movement measurement to study the effect of inhibition of return (e.g., Abrams & Dobkin, 1994; Klein & MacInnes, 1999; Ro, Pratt, & Rafal, 2000). The results of these studies revealed that participants are slower in initiating eye movements in a previously attended location than in a previously unattended location. Hooge and Frens (2000) examined the duration of fixations preceding the saccades that the eyes took to return to previously fixed targets. They designed an experiment, in which the participants were asked to repeatedly fixate on a maximum of four dots in a specific sequence as fast and as accurately as they could. They manipulated the task, in which some saccades took the eyes to a new (previously unfixated) target while some saccades took the eyes back to a target that had just been fixated. Their result showed that the duration of fixations preceding the return saccades (i.e., saccades returning to the previously fixated position) was up to 40% longer than that for previously unfixated positions. They called this effect *the inhibition of saccade return* (ISR), and suggested that the IOR and the ISR might share the same underlying neural mechanism (for a review, see Hooge & Frens, 2000).

With respect to the ISR, Rayner, Juhasz, Ashby, and Clifton (2003) suggested that the inhibition of return effect was generalized to the reading task performance, in which they found that the fixations preceding the saccades returning to the previously fixated words were longer than those returning to previously unfixated words.

The IOR encourages the individuals to take their eyes to the new locations and hence facilitate the visual search behaviors (Klein, 2000). For the general population, this is evidence that IOR in a visual search could persist for up to 2 seconds (Posner & Cohen, 1984). In other words, an individual from the normal segment of the population can remember four to five objects that he or she previously examined (McCarley et al., 2003).

Prospective memory and planning search. The visual search task also demands that individuals keep track of the scanpath, which could again prevent the participants from repeatedly scanning the positions that were previously searched. This function is called *prospective memory*. *Prospective memory* is also known as intention memory, remembering intentions, memory for future actions, and remembering that something has to be done (Graf & Uttl, 2001). Recent research has argued that prospective memory is closely related to supervisory attentional control and has something in common with executive functions of attention, such as planning, initiation, and inhibition of some ongoing behaviors; switching between activities; and controlled utilization of attentional resources (Graf & Uttl, 2001; Graf, Uttl, & Dixon, 2002; Kinsella, 1998).

Findlay and Brown (2006) collated the different strategies that are commonly used in visual search tasks. They are direction based, perception based on local information, and perception based on global information. It is important to note that these strategies can be used interdependently, independently or both.

For the direction-based strategies, participants tended to use a regular and systematic search by scanning through each stimulus (Gilchrist & Harey, in press, cited in Beck et al., 2006b). The scan conducted under this strategy can be a “left-to-right scan,” such as in reading English texts, or a “top-down scan” such as in reading Chinese texts. When the participants read sentences or short passages of English texts, they started to scan the words in the rightward direction across the same row, and then at the end of the same row, they moved their eyes in an oblique downward and leftward direction to the new row. Consequently, this search strategy led to more horizontal saccades. When the participants read the Chinese texts, they started to scan the words at the top of the column and continued to the bottom of the same column, and at the end of the column, they moved their eyes in an oblique upward and leftward direction to the new column, leading to more vertical saccades. In addition, Ponsoda, Scott, and Findlay (1995) argued that the saccades of the eye movements possibly indicated a preference for the use of a reading-like strategy (from left to right). These strategies are likely to be employed if the visual arrays are arranged on a regular basis.

For the perception strategies based on local information, most participants using these strategies do not have an overall strategy but use a scanning method based on an immediate heuristic decision made during each fixation. That is, the participants move and fixate their eyes to a particular location of the visual display during scanning. At this fixation, the participants perform visual analysis on the fixated part and then formulate the saccade program for the next location in which they are interested. The participants would normally start the search at the nearest location and proceed to the next location that has not been scanned (Findlay & Brown, 2006). Findlay (1997), and Findlay, Brown, and Gilchrist (2001) demonstrated that visual proximity (distance of the target from the fixation preceding the saccade) is a major factor which predicts the saccade's hitting of the target.

For the perception strategies based on global information, the strategies adapted by the participants would depend on their known global perceptual capacities. For example, the classic Gestalt phenomenon of grouping, that is, proximity or colinearity, can facilitate the choice of a scanpath (Findley & Brown, 2006). Thornton and Horowitz (2004) indicated that their participants tended to develop an internal map of the spatial layout of the display, which promoted a more efficient visual search. This means that the participants could construct a representation or layout map of the display and deliberately restrict their search to the relevant areas of this map.

Zihl and Hebel (1997) indicated that the posterior parietal and frontal cortical regions are part of a widely distributed neural network underlying the intended eye movement and search path planning. They concluded that their participants firstly processed and coded the spatial properties of the stimulus patterns and then constructed the internal visual-spatial representations or layout maps of the displays, a process which was mainly mediated by the posterior parietal cortex. Subsequently, the participants used these visual-spatial representations to plan the saccade activities. In addition, the prefrontal cortex was responsible for storing and updating the executed and intended movements.

Summary

A review of the literature indicates that visual search involves orienting attention and executive control of attention. Moreover, the visual search task is also enhanced by retrospective memory and prospective memory. In this research, retrospective memory refers to "what you did" which could inhibit the participant from repeatedly reexamining the stimuli scanned in the previous fixation, whereas the prospective memory refers to “what you intend to do” which could enable the participant to plan the use of the most appropriate search strategy and scanpath in advance. The manipulation of the locations between the two target stimuli in terms of distance and orientation is expected to test the extent to which attention and memory functions could modulate participants’ performance of the visual search task.

Eye-Tracking Analysis in the Visual Search Task

Eye tracking has gained in popularity over the past decade and is regarded as opening a window to directly study the observer’s visual and cognitive processes. It captures an individual’s eye movements within a visual scene by measuring the orientation of the eye in space, called *the point of regard* or *eye gaze* (Duchowski, 2003). Most current eye trackers use the pupil center corneal-reflection method to determine the subject’s point of regard (Surakka, Illi, & Isokoski, 2003). Researchers have utilized the eye-tracking method to study behavior in the fields of psychology (psychophysics), marketing and advertising, and human factors and ergonomics (Duchowski, 2003). Eye movement-based analysis enhances the observation of the strategies of subjects when using the graphical user interfaces. In this thesis, the taxonomy of eye movements is described. The basic mechanism of eye-monitoring techniques on eye-tracking studies is then introduced, followed by descriptions of some commonly reported eye-tracking-derived metrics in studies, especially in the fields of human-computer interaction and usability research.

Taxonomy of Eye Movement

Our eyes move continuously while keeping the projected visual image on a specialized and high acuity area of the retina (fovea). Sibert and Jacob (2000) indicated that the two most important elements in the behavior of the eye in human-computer interaction (HCI) are fixations and saccades. They are the general mechanisms used for searching and exploring the visual scene. *Saccades* are rapid ballistic movements used in repositioning the fovea to a new location in the visual environment. The destinations of saccades are preprogrammed so that their trajectory cannot be altered once begun (Duchowski, 2003). Saccades can last between 30 ms and 120 ms and cover a range from 1 to 40 degrees of visual angle (Sibert & Jacob, 2000). Furthermore, saccades have a very high rate of acceleration with a velocity of 500 to 900 degrees/second. Due to their rapid velocity, there is a suppression of most vision during a saccade to prevent blurring of the perceived visual scene (Goldberg & Wichansky, 2003). After the saccade, the observer fixates on a new object of interest. *Fixations* are periods of eye movement that stabilize the retina before a stationary object of interest (Duchowski, 2003). During the fixation, the visual information can be processed. Figure 2.7 shows a typical fixation and saccade sequence on an eye-tracking machine. Actually, other types of eye movement exist that are more specialized and useful for other applications, such as smooth pursuit and nystagmus, but we have not made use of them in this thesis. Goldberg and Kotval (1999) suggested that there are at least three processes taking place in a typical fixation (Figure 2.8). Each saccade is followed by a fixation. Several saccade fixations form a scanpath, which provides rich information about the visual attention of an observer to a visual display (Goldberg & Wichansky, 2003). Moreover, a saccade-fixation sequence can be quantified in order to provide information about the extent or complexity of the visual search of a display (Goldberg & Kotval, 1999).

Figure 2.7

<u>Example of fixation and saccade of a scanpath</u>

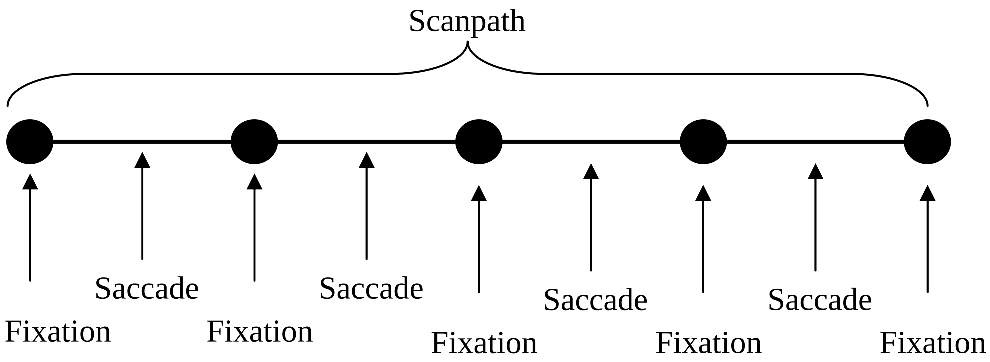
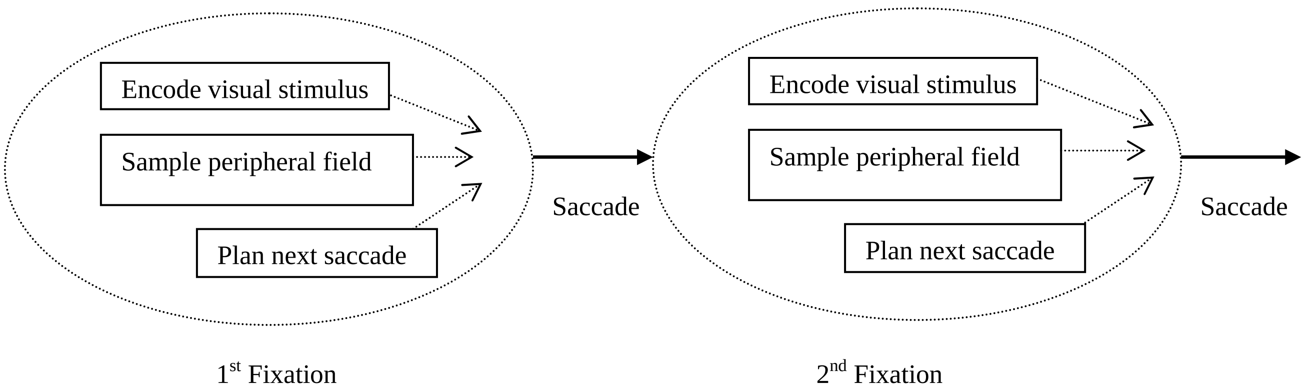


Figure 2.8

<u>Processes occurring within a typical fixation</u>



In eye-tracking applications, several algorithms have been developed for analyzing fixations (times when the eye is essentially stationary) and saccades (rapid reorienting eye movements) from the data captured by the eye tracker. These algorithms typically use either eye position (computing dispersion of a string of eye position data points) or eye velocity (change in position over time) for the process of fixation identification; that is, separating and labeling the saccades and fixations in the eye-tracking experiments. (Readers who wish to gain an in-depth understanding of these algorithms can refer to Goldberg and Kotval (1999) or Salvucci and Goldberg (2000)). Automated analysis software that enables researchers to conduct analyses of eye-tracking data has also been developed by manufacturers of eye trackers and research laboratories (e.g., Lankford, 2000). Nevertheless, there is no standard method for identifying these basic oculomotor parameters (Inhoff & Radach, 1998; Jacob & Karn, 2003).

Basic Mechanism of the Eye Movement Monitoring Technique

The most widely used technique for analyzing eye movements is the pupil center corneal-reflection method, which is based on the point-of-regard concept. To track an observer's eye movements properly, the head must, as a first step, be fixed so that the positions of the eye relative to the head and to the point of regard coincide. A chinrest or headrest designed for the purpose are normally used (alone or in combination) to reduce the motion of the head. To calculate the observer's point of regard, two basic features, the corneal reflection of an infrared light source (Purkinje reflection) and the pupil center, are important (Figure 2.9).

An infrared-type corneal reflection eye-tracking system together with its components are illustrated in Figure 2.10. This system is composed of a video camera located near the computer screen. The infrared light emitter (LED) located near the camera lens illuminates the eye to generate the corneal reflection which lies on the surface of the cornea. Eye- tracker software identifies and locates the center of the pupil and the center of the corneal reflection. The point of regard is then calculated as a gaze vector on the basis of the position of the pupil center and corneal reflection. The point-of-regard coordinates are collected and stored in a data file for later analysis.

Before the eye-tracking system can track an observer's eye movements properly, the system has to be calibrated individually for each observer. This calibration procedure is critical because it helps match the observer's point of regard to the corresponding locations in the visual display (Goldberg & Wichansky, 2003). Thus, the system should be adjusted to the observer's attributes in order to calculate the gaze vectors and onscreen intersections according to eye movements. In general, the calibration routine uses a set of objects located at fixed points on different parts of the screen. Each observer is requested to look at each of the fixed locations and decide that he or she is looking at a certain point by pressing a hardware button or by fixating the fixed location long enough. Typically, the minimum-variance criterion for a successful calibration equates to residuals that are less than 0.5 visual angles from the actual target location in most commercial eye-tracking software (Goldberg & Kotval, 1999; Surakka et al., 2003).

Figure 2.9

Example of corneal reflection illuminated by infrared light and the pupil center

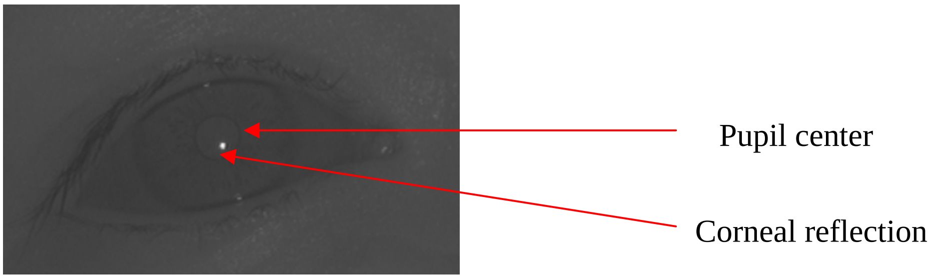
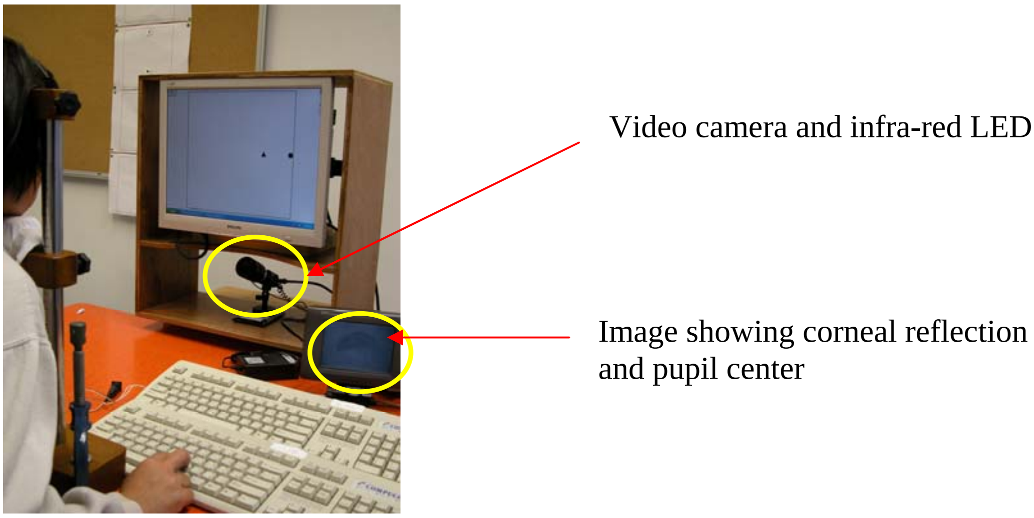


Figure 2.10

Eye-tracking system, with camera optics at the bottom of the computer display



Common Eye-Tracking-Related Measures

The raw eye-tracking data has to be preprocessed to extract the eye movement information, i.e., fixations and saccades. Specific eye-tracking metrics, such as fixation duration and number of fixations, are computed to quantify the scanpaths and their dynamic change. Computation of these metrics has been found to be critical because they can be associated with the possible cognitive and perceptual processes involved in the manipulated tasks (Inhoff & Radach, 1998; Jacob & Karn, 2003). Findings drawn from these metrics prompt further recommendations for improving the existing user interface architecture of software applications (Goldberg & Wichansky, 2003).

Previous studies used the eye-tracking methodology to study the cognitive processes, such as the attention and working memory functions of the participants when they engaged on the manipulated tasks. Previous studies regarding the reading performance correspond with eye-tracking measurements to study the working memory capacities of the participants. For example, Osaka and Osaka (2002) designed an eye-tracking experiment by using fixation duration to examine the working memory capacities of the participants while reading the Japanese text. They used the moving-window technique so that the participants could only read the texts within this moving-window, whereas the participants were obstructed to read the texts outside this window. They decreased the size of this moving-window in order to increase the task demands of participants' working memory to maintain the intermediate textual data for subsequent information integration during reading. They found that the participants with lower working memory capacities experienced more difficulty in maintaining successive information obtained from the text until these data can be integrated, which was evident in longer fixation durations in reading texts that appeared in the smaller moving-window region. Similar reading experiments conducted by Kennison and Clifton (1995) indicated that the participants with lower working memory capacities experienced more difficulty during reading than did those with higher working memory capacities, which was also evident in longer total fixation durations in reading on both the boundary and target words. Aside from the reading studies that commonly used eye-tracking measurements to study the task-related cognitive and perceptual processes, some researchers also used eye movements to reflect the impaired face processing in participants with schizophrenia.

Gordon et al. (1992) examined eye movements in response to a neutral face stimulus and found that people with schizophrenia, compared with their normal counterparts, had reduced fixation durations for the salient facial features such as eyes, nose, and mouth in the first three seconds of processing. In addition, Loughland, Williams, and Gordon (2002) as well as Manor et al. (1999) also indicated that paricipants with schizophrenia, compared with the non-psychiatric control participants, exhibited restricted scanpaths and fewer numbers of fixations on the salient features for facial recognition. These two studies revealed that the underlying cognitive disturbances of the eye movement abnormalities in schizophrenia were possibly explained by the dysfunctions of spatial working memory (Park & Holzman, 1993), reduced capacities of selective attention (Streit, Wolwer, & Gaebel, 1997), and/ or deficits in orienting of attention towards salient visual information when viewing faces (Posner, Early, Reiman, Pardo, & Dhawan, 1988; Posner & Raichle, 1997). Researchers from the field of human-computer interaction and usability have also incorporated eye tracking in their studies. Jacob and Karn (2003) revealed a total of 21 studies that have incorporated eye tracking in human-computer interaction and usability research. Jacob and Karn have summarized the user, the task, and the eye-tracking-related metrics used by each of these 21 studies. (For details, we refer the reader to the study written by Jacob and Karn (2003, pp. 582-584)). Based on this summary, we have selected the eye-tracking metrics that are relevant to the tasks of searching for and selecting specified items from graphics-based user interfaces, such as computer menus or web pages. The eye-tracking metrics selected for this thesis include the overall number of fixations, the scanpath duration (overall search time), the overall fixation duration, and the fixation duration on each area of interest (fixation duration on first target and fixation duration on second target). Each of these metrics is discussed below in order to indicate how each of them could possibly reflect the cognitive processes of the task, in particular, how it is associated with attention and working memory, as well as visual search processes associated with our experiment.

Overall number of fixations. This is thought to be negatively correlated with search efficiency. A large number of fixations indicates that the participant had to search many other visual stimuli prior to selecting the target item (Goldberg & Kotval, 1999), reflecting a less efficient search (Jacob & Karn, 2003). In addition, more fixations might reflect the failure of orienting visual attention when viewing the stimulus (Posner et al., 1988; Posner & Raichle, 1997). This suggested that the participant who had an ongoing difficulty in directing the attention towards the target items at a particular distance or in a particular orientation or both would require that he form more fixations before he was able to discover both target stimuli, reflecting relatively less efficient search.

Overall fixation duration. This metric indicates how much time the participant spends on interpreting and extracting information from a visual display (Goldberg & Kotval, 1999; Jacob & Karn, 2003). It is the key eye tracking measurement used in this study, because it is highly associated with the working memory capacity of participants while searching the visual items (Kennison & Clifton, 1995; Osaka & Osaka, 2002). Therefore, in our study, a lengthier fixation duration found at a particular distance or in a particular orientation or both may possibly reflect the fact that the participant had more difficulty remembering information, such as what target to look for and at where targets / distractors were previously searched, before he identified both two target items. This larger value is also an indication of poorer working memory capacity of this participant during visual search, reflecting less visual search efficiency (Gibson et al., 2000; Oh & Kim, 2004). Therefore, it is hypothesized that the participant with sufficient capacity of working memory for processing and storage during visual search would be able to identify two target items with a short fixation duration. Conversely, those without sufficient capacity are assumed to have difficulty processing and remembering the previously examined items before he could identify both targets, which was evident in longer fixation durations manifested.

Scanpath duration. This measure is more related to processing complexity than to visual search efficiency. The scanpath duration, a composite eye-tracking-related measure is the sum of the duration of saccades (search components) and fixations (processing components) within a scanpath (i.e., total time spent within a scanpath). In our study, the selected scanpath for this measure is the overall search time between the two target stimuli, which includes all fixation durations (processing component) spent on each of the target or nontarget items, as well as all saccade durations (search component) between these items. Longer scanpath duration (overall search time) is generally believed to reflect the complexity of information searching and processing from that display (Goldberg & Kotval, 1999). Therefore, a longer scanpath duration found at a particular distance or in a particular orientation or both may possibly reflect the fact that the participant had more difficulty in searching by orienting his attention towards the target items as well as memorizing information such as what target to look for and at where targets/distractors were previously searched until the participant successfully identified both target items. It was suggested that, without sufficient attention and working memory capacity, the participant assumed to have difficulty directing his attention to search for target items and/or maintaining the successive scanned information. This shows that the participant would need longer scanpath durations in searching and identifying both target items.

Fixation duration on each area of interest. Area of interest (AOI) is defined as the area of a display or visual environment that is of interest to the research team (Jacob & Karn, 2003). In our study, the designated AOI is each of the two target stimuli. Therefore, a longer fixation duration on each area of interest (fixation duration on first target and fixation duration on second target) should reflect the longer time spent in fixating on the first target and the second target, indicating difficulty in information processing from each of these targets.

Conclusion

This section has discussed some basic oculomotor events that are found to be useful in computing specific eye-tracking-related metrics, in particular saccade and fixation. In addition, the procedures and mechanism of eye movement measurement, that is, the pupil center corneal-reflection method, have also been described. The section has also considered the use of these eye-tracking metrics for indexing the perceptual and cognitive processes that allows the objective estimation of an observer's strategies and evaluation of the interface design. Particular attention has been given to viewing duration measures as these are used as the primary indicator of cognitive processes in this eye movement study.

CHAPTER III

METHOD OF INVESTIGATION

Introduction

This chapter describes the methods used for investigation in the three interrelated studies.

Study One

Task Development for Computer Performance

Objectives of Study 1

The aim of this part of the research was to develop a list of computer tasks that were commonly and frequently used by people with mental retardation. These tasks were used in the subsequent experiments as the test items in the computer competence test. The first phase involved selecting a computer interface program and its task contents for testing. The second phase involved formulating the task components of computer operation in the computer competence test for the people with mental retardation and quantifying the physical and mental demands of the selected computer tasks. The third phase involved administering the computer competence test to a group of people with mental retardation to investigate the performance level of people with mental retardation on operating the existing computer programs.

Phase 1: Small-Scale Survey—Utilization of Computer Technology

The purposes of the survey were: (1) to select a computer program that was commonly used by people residing in Hong Kong with a mild to moderate grade of mental retardation; and (2) to identify the task functions of the selected computer interface program that were commonly used by people with mental retardation.

Sampling

All those recruited had a mild to moderate grade of mental retardation. They were all participants in the Information Technology Training Program for people with mental retardation organized by the Hong Kong Polytechnic University. Convenience sampling (Portney & Watkins, 2000) was used, and the selection criteria were as follows.

1. The subjects had been clinically diagnosed as having mental retardation or intellectual disability;
2. The subjects had been classified as having a mild level of mental retardation, with an IQ range of 50-55 to approximately 70, or a moderate level of mental retardation, with an IQ range of 35-40 to 50-55 according to the fourth and text-revised edition of the DSM-IVTR (American Psychiatric Association, 2000);
3. The subjects had not been diagnosed as having autistic features or other types of developmental disabilities; and
4. A parent was willing to give consent for his or her son or daughter to participate in the study.

The aim of the recruitment was to select participants with varying levels of functional capability in order to acquire a relatively broad picture of the use of computer technology by people with mental retardation. The purpose of the survey was explained to all the subjects who filled in the Consent Form (Appendix II).

Study Design

A structured interview was used to solicit opinions from the participants.

Data Collection Procedure

A questionnaire on computer utilization by people with mental retardation was developed for the structured interview (Appendix III). The structured interview was composed of 29 items. There were 8 items on demographic characteristics, 17 items on prior experience of using a computer (example: "Have you used a computer before?"), 2 items on prior problems encountered when using a computer (example: "Have you encountered any problem when you use the computer?"), and 2 items on the potential utilization of the modified software (example: "What kind of computer function will you use if the modified software is developed?"). The interviews took 15 to 25 minutes each. The survey was conducted by a team of trained staff from the Information Technology Training Program. The interviews were conducted at the research laboratory adjacent to the venue in which the Information Technology Training Program was held.

Data Analysis

Demographic information about the respondents, such as age, gender, grade of mental retardation, and education, was reported. In addition, descriptive statistics on the responses of the respondents concerning their experiences when using the computer, and the activities that they engaged in when using web browsers, were likewise reported.

Phase 2: Content Review and Task Analysis—Expert Panel Review

The purposes of this phase were: (1) to conduct a content review to verify the list of the five web-browsing activities based on the information from Phase 1 and to identify the tasks and subtasks required for performing the five web-browsing activities using the Internet Explorer (IE) computer program; and (2) to conduct a task analysis to analyze the physical and mental abilities associated with the performance of these IE tasks.

Sampling

The expert panel was recruited by snowball sampling from the centers that serve people with mental retardation (Portney & Watkins, 2000). Those who met the selection criteria were identified and invited by telephone to participate in the study. After they had agreed to participate, they were asked to identify further potential participants who had the requisite characteristics. These potential participants were then contacted. This process of snowballing continued until the number of expert participants had reached 10.

The selection criterion for the other participants was that they should be healthcare professionals who had experience working with people with mental retardation for at least two years.

Study Design

A structured interview was used to solicit opinions from the experts. In addition, panel members were prompted to provide suggestions using open-ended questions.

Data Collection Procedures

The expert panel review was conducted at the research laboratory of The Hong Kong Polytechnic University. Before the review, the panel members were briefed on the purpose and procedure of the review. Demographic data on gender, years of experience, and affiliation were then gathered. The panel members were shown video clips showing the operation of the hardware and software involved in each of the five functions selected earlier from the survey results. The panel members conducted a content review to verify the potential tasks, and they were allowed to discuss among themselves before consensual decisions were made on the tasks.

After the IE tasks were collated, they were asked to analyze each IE task by breaking it down into sequential steps (subtasks). To facilitate this process, the "modeled" step sequence developed for the IE task was distributed to the panel members. They were also allowed to discuss among themselves before consensual decisions were made on the subtasks grouped under each task. They were then asked to rate each subtask in terms of its physical (e.g., stabilizes and reaches) and mental (e.g., orientation and sustained attention) components. To facilitate their decisions, they were given a list of different abilities (or ability items): 28 and 23 on mental and physical functions respectively. The list of abilities was collated from textbooks and research papers on aspects of human-computer interaction, rehabilitation related to technology use, as well as cognitive psychology. The operational definitions of the selected ability items were also extracted from the literature and distributed to the panel members for review (Appendix IV). Most of them are included in *Assessment of Motor and Process Skills* (Fisher, 2003), *Task analysis: An Occupational Performance Approach* (Watson, 1997), and the *Dictionary of Cognitive Psychology* (Stuart-Hamilton, 1995). Before the panel members rated each of the subtasks, they were asked to comment on whether any ability item(s) should be modified, added, or deleted. Final decisions were made after a group consensus was reached. During the review process, the panel members were involved in evaluating all the ability items for each of the subtasks by making a check mark when the ability was involved in accomplishing a particular subtask.

Data Analysis

Demographic information about the participants, such as years of experience, gender, and professional background, was reported. The IE tasks involved in the operation of the five web-browsing functions suggested by the panel members were collected. The subtasks, which were the sequential steps for operating on the IE tasks, were also reported.

The abilities suggested by the panel members were added to the original list of ability items, resulting in a total of 53 items. Based on the check marks made by the expert panel review, the percentage of agreement among the 10 panel members on each ability item for each subtask was computed. The summated number of subtasks was arrived at by adding up the number of individual subtasks that had a percentage of agreement equal to or above 0.5. The percentage-of-ability item required for performing the 161 subtasks was computed by dividing "the summated number of the subtasks" by "the maximum number of subtasks (161 subtasks)." The percentage-of-ability item of 0.4 or above (indicating "important" as required by successful performance of the IE tasks) was extracted. The reason for using 40% as the cut-off value was that it was deemed to cover more cognitive and motor abilities that were relevant for computer utilization for the ability testing used in Study 2.

Phase 3: Field Test—Internet Explorer (IE) Competence Test

The purpose of the IE competence test conducted during this phase of the study was to investigate the extent to which people with mental retardation were able to operate the most widely used IE functions. It involved the participants' performance of the standardized IE tasks and their performances of tasks were rated according to the test-rating scale devised by the expert panel review.

Sampling

All participants were individuals with a mild to moderate grade of mental retardation. They were registrants of the Information Technology Training Program launched by The Hong Kong Polytechnic University. Convenience sampling (Portney

& Watkins, 2000) was used, and the participants were screened according to the following inclusion criteria:

1. They had been diagnosed as having mental retardation or intellectual disability;
2. They had been classified as having a mild level of mental retardation, with an IQ range of 50-55 to approximately 70, or a moderate level of mental retardation, with an IQ range of 35-40 to 50-55 according to the fourth and text-revised edition of the DSM-IVTR (American Psychiatric Association, 2000);
3. They have an ability to follow test instructions;
4. They have an ability to communicate verbally;
5. They have a pattern of using a computer and web browser program for at least 2 hours a week;
6. They have voluntarily consented to participate in the study; and
7. They have normal or corrected-to-normal visual acuities as reported in school or medical reports.

The participants were excluded from participating in the study if they fell into the following categories:

1. They had been diagnosed as having autistic features or other types of developmental disabilities;
2. They had presented with another medical condition or identified organic etiology that may be unsafe in the study, such as epilepsy;
3. They had presented with severe physical impairment; and
4. They are color blind as reported in school or medical reports.

To those participants who fulfilled the selection criteria, Researcher A presented and explained the Client Information Sheet and Consent Form (Appendix V).

Study Design

A cross-sectional design was adopted, the aim of which was to capture the performance of the tasks in the IE competence test.

Instrumentation

IE competence test. The 16 IE tasks established in the expert panel review became the test items of the IE competence test. The 161 subtasks were the task components on which the performance of each participant was rated (please refer to the results section—Phase 2 of Study 1—for the details of the development of tasks and subtasks for the IE competence test). A 4-point rating scale was used for assessing the performance of the participants on the subtasks, with 1 = “complete assistance,” 2 = “performance with verbal and physical prompts,” 3 = “performance with verbal prompts only,” and 4 = “full performance.” The IE competence test form can be found in Appendix VI. In addition, standardized instructions for the IE competence test were likewise developed (Appendix VII).

Test of Nonverbal Intelligence (TONI-3). TONI-3 was administered to the participants as a measure of general intellectual functioning (Figure 3.1). TONI-3 is a language-free measure which taps primarily into abstract reasoning and problem solving (Brown, Sherbenou, & Johnsen, 1997). According to the test manual, a quotient score of 85 or below would be indicative of mental retardation, developmental disabilities, or other cognitive disorders (Brown et al., 1997). In this part of the study, the TONI-3 scores were used to classify the intellectual functioning of the participants into higher and lower groups. A cut-off score of 70 was used since this score was used in the TONI-3 text manual as the criterion to differentiate between those with relatively high and relatively low levels of mental retardation. The test contained 50 test items of increasing difficulty. In each test item, the participants were required to select the appropriate figure out of four to six choices in order to fill in the missing figure in an array of pictures. The test was discontinued if the participant committed three errors in five consecutive items or completes all test items. The validity and reliability data can be found in the test manual (Brown et al., 1997).

Figure 3.1

Test of Non-Verbal Intelligence (TONI-3)

Data Collection Procedures

The entire testing procedure was conducted in the research laboratory at The Hong Kong Polytechnic University as this laboratory was free of distraction. A computer workstation was placed at one corner for the IE competence test.

At the beginning of the test session, the participants were asked for demographic information. TONI-3 was then administered to the participants, and each participant took about 5 to 10 minutes to complete the test. The IE competence test was the last to be conducted. Before the commencement of the test, each participant sat comfortably at a computer workstation which was equipped with a 15-inch color monitor, a standard keyboard, and a mouse. The operation system was Windows XP and the web browser used was Microsoft's Internet Explorer 6.0. The participants began the test by completing the three test items in the general task category: orientation and recognition, motor functions, and language functions. These tasks covered the basic skills for operating a computer. The remaining hardware- and software-related tasks were then administered in a random sequence across the participants. Standardized instructions were given by Researcher A before each task began. For each task item, there was a maximum of four performance trials. In the first two trials, the participants did not receive assistance from Researcher A. If the participant did not manage to complete the task in both trials, Researcher A would offer verbal prompts at the time when the participant attempted the third trial. Both physical and verbal prompts would be offered in the last set of trials. Each participant's performances were observed throughout all four trials, and scores were assigned for each of the subtasks grouped under the task item. The entire test took about 1 hour to complete. Figure 3.2 shows a participant carrying out the IE competence test at a computer workstation.

Figure 3.2

A participant sits at a computer workstation and performs the IE competence test

Data Analysis

Interrater reliability of IE competence test. The interrater reliability of the IE competence test was estimated by recruiting a second rater to rate the performance of selected participants. Ten participants were randomly selected for the videotaping of their performance at the time when their performances were assessed by Researcher A. The second researcher (Researcher B), who had a healthcare background, was trained on the breakdown of the tasks and subtasks, and the rating criteria. The video playback was shown to the second researcher and the rating was conducted for all the participants. The mean item score on the subtask was computed for each of the 16 tasks. Intraclass correlation coefficients (ICC) using a two-way mixed model (absolute agreement) were then computed.

IE task performance. Descriptive statistics on the demographic data of the participants were reported. The task scores of the participants on the IE competence test were computed by taking the mean of the subtask scores classified under that particular task. To further understand the participants' performance on the IE tasks, attempts were made to classify participants into different performance levels. Their classifications were verified with one-way ANOVA, cluster analysis, and decision-tree methods. To compensate for the small sample size, the logistic regression (forward stepwise) procedure was used to further reduce the number of tasks for entering into the classification procedures. In addition, the goodness-of-fit of the logistic regression model was assessed by using the Hosmer- Lemeshow test (Hosmer & Lemeshow, 1989). All analyses were then conducted using SPSS 12.0.

Study Two

Cognitive and Motor Functions Relevant for Computer Performance

Objectives of Study 2

The aim of Study 2 was to establish the cognitive and motor profiles of the participants with mental retardation, and examine the relative importance of cognitive and motor measures in predicting their performance level when operating the IE program. The results established in this study would inform the research question of Study, 3 because the cognitive ability that best accounted for the participants' computer performance as established in this study would be selected for investigation in Study 3.

Sampling

All participants were individuals with a mild to moderate grade of mental retardation. They were registrants of the Information Technology Training Program launched by The Hong Kong Polytechnic University. They completed the testing before they started attending the program. Convenience sampling (Portney & Watkins, 2000) was used to recruit potential participants with the following selection criteria:

1. They had been diagnosed as having mental retardation or intellectual disability;
2. They had been classified as having a mild level of mental retardation, with an IQ range of 50-55 to approximately 70, or a moderate level of mental retardation, with an IQ range of 35-40 to 50-55 according to the fourth and text-revised edition of the DSM-IVTR (American Psychiatric Association, 2000);
3. They have an ability to follow test instructions;
4. They have an ability to communicate verbally;

5. They have a pattern of using a computer and web browser program for at least 2 hours per week;
6. They have voluntarily consented to participate in the study; and
7. They have normal or corrected-to-normal visual acuities as reported in school or medical reports.

The participants were excluded if they fell into one or more of the following categories:

1. They had been diagnosed as having autistic features or other types of developmental disabilities;
2. They had presented with another medical condition or identified organic etiology that might have been unsafe in the study, such as epilepsy;
3. They had presented with severe physical impairment; and
4. They are color blind as reported in school or medical reports.

To those participants who fulfilled the selection criteria, Researcher A presented and explained the Client Information Sheet and Consent Form (Appendix VIII).

Study Design

A cross-sectional design was adopted, the aim of which was to capture the performance level of the subjects with mental retardation in operating the IE program, as well as their performances on the tests in the cognitive and motor assessment.

Instrumentation

IE competence test. The IE performance test used in Study 2 was the same as the one used in Phase 3 of Study 1. The task content was developed in Phase 2 of Study 1 and the task evaluation criteria were set in Phase 3 of Study 1.

Test of Nonverbal Intelligence. The TONI-3 used in Study 2 was the same as the one used in Phase 3 of Study 1.

Tests of cognitive and motor functions. Based on the results from the expert panel reviews during Phase 2 of Study 1 and a review of the literature (e.g., Sutcliffe, Fickas, Sohlberg, & Ehlhardt, 2003; Vicari et al., 1992), six cognitive domains that have an impact on the design of technologies were identified. These include attention, visual-spatial function, language function, memory or working memory, frontal lobe or executive function, and psychomotor function. A total of 13 instruments were used to capture these six domains, and they were the Digit Span Test, the Digit Vigilance Test, the Color Trails Test, the Chinese version of the Stroop Color-Word Test (Victoria version), the Hooper Visual Organization Test, the Symbol Digit Modalities Test, the Judgment of Line Orientation, the Chinese version of the Neurobehavioral Cognitive Status Examination, the Sustained Attention to Response Task, the Chinese Characters Test, the McCarron Assessment of Neuromuscular Development, the Development Test of Visual-Motor Integration, and the Purdue Pegboard. Examples of these instruments are shown in Figure 3.3.

Figure 3.3

<u>Examples of the tests of cognitive and motor functions used in this study</u>

<u>Note:</u>

1: Digit Span Test
2: Digit Vigilance Test
3: Color Trails Test
4. Chinese version of Stroop Color-Word Test (Victoria Version)
5: Hooper Visual Organization Test
6: Symbol Digit Modalities Test
7: Judgment of Line Orientation
8: Chinese version of the Neurobehavioral Cognitive Status Examination
9: Chinese Characters Test
10: McCarron Assessment of Neuromuscular Development
11: Developmental Test of Visual-Motor Integration
12: Purdue Pegboard

Digit Span Test. The Digit Span Test (DST) is a subtest of the Wechsler Memory Scale-Revised (Wechsler, 1987). It includes the Digit Span Forward (DSF) and Digit Span Backward (DSB), with increased levels of difficulty, that is, one extra digit is added at each level, with two trials per level. The DSF is a test to measure the efficiency of attention and the passive span of apprehension (Lezak et al., 2004). The DSB is a test of mental tracking which involves some perceptual tracking or a more complex mental operation (Lezak et al., 2004), and a test to measure working memory (Lee, Yuen, & Chan, 2002). The participants are required to complete the second trial if they fail the first trial because of either a span or sequence error. The ceiling is considered to have been reached only when the participants have committed two consecutive mistakes in span at the same level of difficulty. The data recorded are the sequence (the number of digits and sequences that are correctly recalled) and span (the number of digits successfully recalled even if there are mistakes of recall of the sequence of presentation) scores. Carpenter, Georgopoulos, and Pellizzer (1999) indicated that using both the sequence and span scores likely has a stronger differentiating power for people with subtle temporal sequencing difficulty, which is frequently observed in frontal pathologies resulting in the impairment of memory of the temporal order of information. The study by Lee et al. (2002) of a group of normal adults revealed significant main education effects. These were found on the Digit Forward Span Test ($F(4,246) = 5.53$, $p = 0.0005$) and the Digit Backward Span Test ($F(4,244) = 4.463$, $p = 0.002$). These results demonstrated that the Digit Span Test was sensitive to education level among Chinese adults. As far as other demographic characteristics were concerned, the DSF was not sensitive to age as it was affected only minimally beyond age 65 or 70, while the DSB was more sensitive to age as the span score typically decreased after the seventh decade (Lezak et al., 2004).

Digit Vigilance Test. The Digit Vigilance Test (DVT), a subtest of the Lafayette Clinic Repeatable Cognitive Perceptual-Motor Battery, was used to assess sustained attention (Lewis, 1995). The DVT is a paper-and-pencil test to measure the visual vigilance of participants when performing rapid visual tracking tasks. Here, participants are asked to cross out as quickly as possible a specific target number (6 or 9) that appears randomly within a number matrix composed of 59 rows of 35 single digits on two pages. Total time and errors of omission are recorded. The test-retest reliabilities of the DVT on a group of 40 healthy young adults for the total time score ($r = 0.91$) and error scores ($r = 0.66$), using a 1-week interval, were found to be high. The alternative form reliability for total time score ($r = 0.9$) was also found to be high (Kelland & Lewis, 1996).

Color Trails Test. The Color Trails Test (CTT) is an orthographic neuropsychological test used to measure sustained visual attention, visual scanning, and graphomotor skills (D’Elia, Satz, Uchiyama, & White, 1996). It consists of two parts. In Part A, the participants are required to make pencil line connections between 25 encircled numbers randomly arranged on a test sheet in proper numerical order. In Part B, the participants are required to make pencil line connections on another test sheet with 25 encircled numbers in an alternating color order. The times required for Part A and for Part B are recorded. Part A is a test of sustained attention involving perceptual tracking and simple sequencing, whilst Part B assesses frontal system functioning. The test-retest reliability on 27 healthy normal adults was fair to good ($r = 0.64$ for Part A and $r = 0.79$ for Part B) (D’Elia et al., 1996). Other studies have shown that the CTT is sensitive to age and educational level in a Chinese population (Lee & Chan, 2000a).

Chinese version of the Stroop Color-Word Test (Victoria version). The Chinese version of the Stroop Color-Word Test (Victoria version) (CST) is used to measure perceptual set shifting by conforming to changing demands and suppressing an habitual response in favor of an unusual one (Strauss et al., 2006). The CST originates from the Victoria version of the Stroop Word Test (Regard, 1981). Permission for translation was obtained from Dr. Regard (Lee & Chan, 2000b). The CST consists of three cards, each containing six rows of four items. The dot subtask consists of color dots, the word subtask consists of common words unrelated to the concept of colors, and the color-word subtask consists of words that are color names themselves. The four colors used are blue, green, red, and yellow. Each color is used six times and the four colors are arranged in a pseudorandom order within the array, each color appearing once in each row. The participants are required to name the colors in which the stimuli are printed and to disregard their verbal content. The times needed to complete the subtasks and the number of errors made with each card are then recorded (Lee et al., 2002). The interference score is calculated by subtracting the reaction time for the dot subtask from that of the color-word subtask (Lee, 2003). Working memory was found to contribute to Stroop interference. For instance, Kane and Engle (2003) found that individual differences in working memory capacity predict performance on the Stroop task, that is, the Stroop interference may reflect a failure to maintain the task goal of ignoring the word dimension or reflect the time-consuming process of resolving response competition in service of a successfully activated goal. The test-rest reliability of the CST, using a 1-month interval between test sessions, was found to be 0.89, 0.91, and 0.90, respectively, for the three parts of the test (Lee & Chan, 2000b).

Hooper Visual Organization Test. The Hooper Visual Organization Test (HVOT) is a test of visual-spatial ability (Strauss et al., 2006). It is designed to measure an individual's ability to integrate visual stimuli (Hooper, 1958). The HVOT consists of 30 drawings of common objects. Each object is cut into two or more parts and illogically arranged in the drawing. The participants are required to name each object verbally. The total number of correct responses is recorded, although a half-credit is given for some of the items for partially correct responses. The relationship between age and performance in the HVOT is a U-shape function, with scores improving during childhood and declining with advancing age (Strauss et al., 2006). The HVOT did not correlate significantly with gender or education but it had a moderate correlation with mental ability (Lezak et al., 2004; Strauss et al., 2006). Lezak et al. (2004) reported a coefficient of concordance (W) of 0.86, indicating good test-retest reliability after 6 months and again after 12 months.

Symbol Digit Modalities Test. The Symbol Digit Modalities Test (SDMT) is a test to assess complex scanning and visual tracking (Smith, 1991). This visual-scanning test is widely used as a test of divided attention (Ponsford & Kinsella, 1992), but requires complex visual scanning and tracking (Shum, McFarland, & Bain, 1990), and perceptual speed, motor speed, and memory (Lezak et al., 2004). The SDMT consists of both written and oral trials so that this test has the added advantage of providing a comparison between visuo-motor and oral responses. In accordance with the instructions, the written format is administered first before the oral format. For this test, the participants are required to examine a series of nine meaningless geometric designs and to search for a key for each symbol and substitute a digit for the symbol in the sequence within 90 seconds on each trial. The number of correct substitutions is recorded. The test-retest reliability on 80 normal adults was good (r =

0.80 for the written SDMT and r = 0.76 for the oral SDMT; Smith, 1991). The correlations between the written and oral versions of the SDMT were high for the administration to the normal adults (r = 0.78; Smith, 1991) and participants with head injuries (Ponsford & Kinsella, 1992). Some studies have shown that the SDMT is sensitive to age, gender, and educational level among normal adults and some clinical groups such as people with schizophrenia (Strauss et al., 2006; Chan, Yip, & Lee, 2004).

Judgment of Line Orientation. The Judgment of Line Orientation (JLO) is a test to measure spatial perception and orientation (Strauss et al., 2006). This test has been used for visual-spatial analysis at a basic level by estimating angular relationships between line segments (Benton, Varney, & Hamsher, 1978). The test consists of 5 practice items and 30 test items, each showing a different pair of angled lines. For each test item, the participants are presented with a semicircle divided into 11 numbered radii. The participants are presented with the test item on a stimulus card and asked to select the most appropriate radii in the semicircle that match the same angles as presented in the test item. The total number of correct responses is recorded. Benton, Sivan, Hamsher, Varney, and Spreen (1994) indicated that JLO scores declined slightly with advancing age in adults, beginning at about 50 years of age. In addition, Benton et al. (1994) noted that JLO is sensitive to gender, in that male participants tend to score higher than females, and to education, in that less well-educated participants tend to score lower than better-educated ones. The internal consistency by split-half reliability for the JLO is high when observed in children (r = 0.84) and in adults (r = 0.84 to 0.91; Benton et al., 1994; Strauss et al., 2006).

Chinese version of the Neurobehavioral Cognitive Status Examination. The Chinese version of the Neurobehavioral Cognitive Status Examination (*Cognistat*) is a short screening test to reflect the cognitive functioning of people in seven areas: orientation, attention, language, construction, memory, calculation, and reasoning. Language is further divided into comprehension, repetition, and naming subtests, while reasoning includes similarities and judgment (Chan, Lee, Fong, Lee, & Wong, 2002). The administration procedure of this test is modified, and is in contrast to the conventional method of administering the test, which requires the participants to perform it using screen and metric approaches. Our participants were only required to carry out the metric portion of the Cognistat in order to obtain an optimal performance from them and overcome the uncertainty associated with the sensitivity of single-screen items (Chan et al., 2002). The interrater reliability of the Chinese version of the Cognistat indicated good to excellent consistency among two raters (ICC ranged from 0.85 to 0.99). The sensitivity and specificity of the Chinese version of the Cognistat between normal elderly persons and patients who had suffered a stroke were 0.79 and 0.85, respectively (Chan et al., 2002). In the same study, the results revealed a two-factor structure: Factor 1: mental operations and visual spatial skills; and Factor 2: verbal reasoning, sequential data processing, and knowledge skills. Both sets of evidence supported the construct validity of the Chinese version of the Cognistat.

Sustained Attention to Response Task. The Sustained Attention to Response Task (SART) is a simple visual computerized task that is sensitive to anterior attention and sustained attention (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). The SART uses a continuous performance paradigm involving the pressing of keys in response to frequently presented nontargets, but with the requirement to withhold motor responses to occasional targets. The participants are presented with 225 single digits (25 of each of the nine digits) visually over a 4.3-minute period.

Each digit is presented for 250 ms, followed by a 900-ms mask. The participants respond using their preferred hand with a key press to each digit, except on 25 occasions when the digit 3 appears, when they have to withhold a response. The target digit is distributed throughout the 225 trials in a prefixed quasirandom fashion. The digits are also presented in one of five randomly allocated font sizes (48 point, 72 point, 94 point, 100 point, and 120 point) to enhance the demands for processing the numerical value. A circular mask 29 mm in diameter follows each digit, and both digits and mask are presented centrally on the computer screen. Each test is preceded by a practice period consisting of 18 presentations of digits, 2 of which are targets. The participants are asked to give equal importance to accuracy and speed in doing the test. The number of correct responses and commission errors made during the task performance, and the reaction times in the task, are recorded. The test-retest reliability of the error score in the SART is reported as 0.76 (Robertson et al., 1997).

Chinese Characters Test. The Chinese Characters Test (CCT) is a self-constructed test aimed to measure Chinese character recognition abilities. In the construction procedure, the raw Chinese characters were selected from those that appeared in the IE competence test. In order to increase the generalization of these characters, extra Chinese characters were added by controlling the number of strokes that were the same as that of characters in the IE competence test. In this way, the complexity of the characters would be attributable to the difficulty and frequency levels of the characters but not the number of strokes. The number of strokes, difficulty level, and frequency level of these Chinese characters were then found from the literature (Hou, 1979; Shen, 1996; Xiao, Fan, Li, & Li, 1986). The difficulty level and the frequency level of all Chinese characters were ranked from “1” to “10” indicating “the lowest difficulty” to “the highest difficulty,” and from “1” to “10” indicating “the highest frequency” to “the lowest frequency” respectively, resulting in the 10 x 10 Chinese character grids produced. Two characters from each of the grids were randomly selected; this constituted a total of 200 items as the test items in the pilot test. Pilot results indicated two points on which this test might be modified. First, the characters ranked from 6 to 10 on the scale of difficulty and ranked 6 to 10 on the scale of frequency were difficult for the participants with mental retardation to answer, and they considered that with these characters they had reached their ceiling level. Second, 200 characters as test items were deemed too many, and would tire the participants. As a result, new 5 x 5 Chinese character grids were produced (Table 3.1). Then two characters were randomly drawn from each of the grids; this constituted a total of 50 test items. For each of the test items, the participants were required to answer with the pronunciation of a character, to associate it with the word that corresponds to the character, and to express the meaning of the associated word. The numbers of pronunciations, word associations, and word expressions corrected were recorded.

McCarron Assessment of Neuromuscular Development. The McCarron Assessment of Neuromuscular Development (MAND) is designed as a standardized and quantitative procedure to measure fine and gross motor abilities (McCarron, 1997). The MAND consists of five fine and five gross motor tests, the scores of which are combined to form the total motor score. The fine motor tests include (1) beads in a box, (2) beads on a rod, (3) finger tapping, (4) nuts and bolts, and (5) rod slide subtests. The scores of these five fine motor tests are summated to form the total fine motor scores. The gross motor tests are classified under kinesthetic integration and muscle power. Tests to measure the kinesthetic integration function include (1) heel-toe walk, and (2) standing-on-one-foot subtests. Tests to measure muscle power include (1) hand strength, and (2) jumping. The scores of these four tests are summated to form the total gross motor scores. The MAND has good test-retest reliability (r = 0.99) for people with mental disability (McCarron, 1997; McCarron & Dial, 1986a, 1986b). It also shows good discriminant validity between people with and without brain damage with an accuracy of about 70% (Dial, Chan, & Norton, 1990). Significant correlation between the scores on the MAND and the subsequent work performance a year after the initial evaluation (r = 0.70) suggests a good predictive validity of the task performance of individuals (McCarron & Dial, 1986a).

Development Test of Visual-Motor Integration. The Development Test of Visual-Motor Integration (VMI) is designed to measure visuo-motor abilities (Beery, 1989). It is useful in evaluating test performances, in order of developmental sequence from ages 3 to 18, of accuracy in copying a set of 24 geometric figures. Since the development of copying accuracy levels off in the mid-teen years, this test would still applicable to adults, at least into the seventh decade (Lezak et al., 2004). The scoring followed the scoring criteria given in the manual. The agreement between raters on the VMI was found to be high, as reliability coefficients for two or more raters ranged from 0.58 to 0.99, with a median of 0.93 (Beery, 1989). The test-retest reliability of the VMI for a group of normal children was also found to be high, as reliability coefficients of this kind ranged from 0.63 (over a 7-month period) to 0.92 (over a 2-week period). In addition, the VMI was found to be sensitive to handicapping conditions, such as brain injuries or mental retardation, as sufferers performed less well on the VMI than their nonhandicapped counterparts (Beery, 1989).

Purdue Pegboard. The Purdue Pegboard is a test to measure unimanual and bimanual finger and hand dexterity (Tiffin, 1968). It consists of two parallel rows of 25 holes each. Pins are located at the extreme right-hand and left-hand cups at the top of the board, and collars and washers are placed in the two middle cups. This test consists of four subtests. In the first three subtests, the participants are required to place as many pins as possible in the holes, first with the preferred hand, then with the nonpreferred hand, and finally with both hands, within a 30-second time period. To test the right hand, the participants are required to insert as many pins as possible in the holes starting at the top of the right-hand row. The left-hand test uses the left rows. Both hands are used together to fill both rows top-down. In the fourth subtest, the participants are required to use both hands alternately to construct as many assemblies as possible within 1 minute. Examiners may choose a one-trial administration or a three-trial administration for each subtask. The scores for the first two subtests consist of the number of pins inserted within the time period for each hand, while the score for the third subtest consists of the total number of pairs of pins inserted. The score for the fourth subtest consists of the number of parts assembled. The correlation coefficients, using one-trial administration over intervals of 1 to 2 weeks, for normal people was found to range from 0.37 to 0.82, indicating fair to good interrater reliability. However, the reliability was better when three trials were given per subtest. Correlation coefficients for three-trial administration increased, ranging from 0.81 to 0.89 after retest intervals of 1 week (Strauss et al., 2006).

Table 3.1

<u>Chinese character grid for the selection of Chinese characters on the development of the Chinese Characters Test</u>

Increasing Difficulty →

Increasing Frequency ↑

大, **上**, 下, 小, 子, 一, 會, 出, 生, 去, 香, 美, 我, 見, 你, 來, **的**, 明, 和, 子, 裏, 很, 果, 尾,困, 不, 中,了, 二, 人, 們, 同, 國,地, 多, 學,成, 方, 有, 水	**電**, 過, 當, 要, 活, 是, 面, 前, 便, 港, 進, 表, 到, 長, 物, 事, 三, 工, 可, 本, 他, 四, 用, 正, **開**, 把, 每, 那, 作, 沒, 後, 都, 開	道, 意, 外, 平, 己, 等, 然, **發**, 間, 利, 但, 別, 求, 些, 兩, 點, 以, 公, **圖**	業, 為, 甚, 計, 相, 度, 最, 無, 就, 經, **新**, 想, 加, 由, 形, 法, 例, **定**, 所, 或, 使	**位**, 只, 重, 其, 直, 知, 目, 部, **關**
樂, 花, 金, 空, **愛**, 書, 海, 馬, 口, 山, 白, 信, 風, 界, 車, 走, 六, 父	東, 兒, 話, 熱, 寫, 笑, 員, **值**, **路**, 南, 品, 英, 神, 給	萬, 運, **近**, 放, 命, 真, 候, 賽, 主, 立, 市, 民, 共	容, **記**, **消**, 校, 影, 論, 門, 非, 息, 該, 怎, 保, 單	**始**, 根, 流, 更, 足, **名**, 份, 反, 商, 張, 科, 總, 鋼, 演, 覺
石, **台**, 孩, 紅, 服, 青, 朋, 早, 木, 班, 病, 衣, **讀**	司, 句, 軍, **音**, 飛, 農, 育, 林, 房, **溫**, 華, 答, 黑, 買, 陽, 請	皮, 包, 古, 右, 照, **號**, 談, **識**, 費, 鐘, 銀	失, 功, **喜**, 料, 味, 圓, 注, 燈, 落, **靜**	雖, 告, 步, 我, 牠, 低, 究, 價, 周, 帝, 官, 排, 深, 鐵, 院, **建**, **找**, 導, 思
媽, 牛, 巴, **課**, 沙, 里, 玩, 弟, 哥, 樹, 睡, 草, **語**	塊, 昨, 屋, 客, 怕, 油, **停**, 兵, 歌,**綠**, 練	**遊**, 午, 園, 禮, 舉, 左, 場, 洋, 趣, **送**, 雙	**群**, 室, 城, 祖, 急, **景**, 絲, 站, 旅, 粉, 植	**言**, 冷, 充,廠, 洲, 紀, 倒, 劇, **支**, 誰, 荷, 責, 奇
秋, 千, 布, 伯, 雨, 爸, 枝, 晴, **忙**, 蛋	春, **洗**, 飯, 怪, 筆, 街, 菜, 雲, 迷, **龍**	**戲**, 亮, **跳**, 楚, 永, 念, 浪, 血, 跑, 野	**封**, **頁**, 跌, 週, 童, 座, 針, 訓, 健, 壞, 粒	背, 判, 困, 批, 乾, 亡, 剛, 勞, 富, 訪, **護**, 銅, **顏**, 肯, 硬, 灣, 殺, 毛, 慣, 忽, 呼

<u>Note</u>. The **bold** characters were selected for the Chinese Characters Test

Data Collection Procedures

At the beginning of the test session, the participants were asked about their demographic characteristics. TONI-3 was then administered to the participants individually, which took about 5 to 10 minutes, followed by the IE competence test, which took approximately 1 hour to complete. The environment and the workstation setup for the IE competence test were the same as those in Phase 3 of Study 1. In addition, the evaluation procedure and the evaluation criteria of the IE competence test were the same.

After the IE competence test, a 30-minute break was given before the commencement of the tests of cognitive and motor functions. The tests of cognitive and motor functions were then performed in the same laboratory as the IE competence test, and the cognitive and motor tests were administered in a random order. The standardized instructions were given throughout the tests, and the time given to complete all tests was approximately 2 to 3 hours. During this period, each participant's performance was observed and breaks were given when Researcher A observed any sign of fatigue. In general, a 5- to 10-minute break was given after each 30-minute assessment session. All the tests were administered by Researcher A who was trained on the administration and scoring criteria of both tests by a certified neuropsychologist.

Data Analysis

Selection of participants for data analysis. People with a moderate grade of mental retardation may have such a low level of intellectual functioning that they are not able to perform the tests. For instance, they have been found not to be able to establish the baseline of Wechsler subtests (Vicari et al., 1992). To avoid this happening in the tests of their cognitive and motor functions, an additional criterion was used for selecting participants for entry into subsequent data analysis: those who managed to complete at least two thirds of the tests administered.

Demographic characteristics. Descriptive statistics on the participants' demographic data were reported. Using a TONI-3 score of 70 as the cut-off (Brown et al., 1997), the participants were further divided into "high" and "low" IQ groups. Independent-sample *t* tests were used to test whether or not the demographic characteristics of the participants between the high and low IQ groups differed significantly.

Individual abilities—overall IE performance. The participants' scores on the IE competence test were computed, and all computer task scores were then summated to derive the overall IE performance score. Possible overall scores ranged from a minimum of 0 to a maximum of 644, with higher scores reflecting higher overall performance in operating the computer-IE interface. Descriptive statistics on the participants' overall IE performance in the high and the low IQ groups were reported. The effects of the intellectual functioning of the participants (i.e., high versus low IQ) on their overall IE performance were tested using independent-sample *t* tests.

Individual abilities—cognitive and motor profiles. The tests of cognitive and motor functions were grouped according to their constructs.

1. Attention: Digit Span Forward (span and sequence scores), Part A of Color Trails Test (total time), Sustained Attention to Response Task (commission error), Digit Vigilance Test (omission error), and written version of Symbol Digit Modalities Test (total score).
2. Visual-Spatial Function: Judgment of Line Orientation (correct score), construction subtest of Cognistat (metric score), and Hooper Visual Organization Test (total score).

3. Language Function: comprehension, repetition, and naming subtests of Cognistat (metric scores), and Chinese Characters Test (total score).
4. Memory/Working Memory: Memory subtest of Cognistat (metric score), and Digit Span Backward (span and sequence scores).
5. Frontal Lobe/Executive Function: similarities and judgment subtests of Cognistat (metric score), Color Trails Test (interference score), and the Chinese version of the Stroop Color-Word Test (Victoria version; interference score).
6. Psychomotor Function: McCarron Assessment of Neuromuscular Development (fine motor and gross motor scores), Development Test of Visual-Motor Integration (total score), and Purdue Pegboard (dominant hand, nondominant hand, both hands, and assembly scores).

Descriptive statistics on the participants' scores on these tests were reported to establish the cognitive and motor profiles of the participants. Independent *t* tests were further conducted to compare the test scores between the "high" and "low" groups. All alpha levels were adjusted based on the number of between-group comparisons for each of the six cognitive domains so as to lower the possible Type I errors committed in the analyses.

Cognitive correlates of overall IE performance. Pearson's Product-Moment correlations between the overall IE performance score and the test scores on different cognitive and motor functions were computed. Similarly, the alpha level was adjusted to $p \leq 0.01$ to reduce the Type I errors committed in the analyses.

Predictor of overall IE performance by cognitive and motor functions. Stepwise multiple regression analyses were conducted to explore the extent to which the overall IE performance could be predicted by the participants' scores on the cognitive and motor functions. The predictors were the written version of the Symbol Digit

Modalities Test (total score), the Judgment of Line Orientation (correct score), the Chinese Characters Test (total score), Digit Span Backward (span score), the judgment subtest of the Cognistat (metric score), and the McCarron Assessment of Neuromuscular Development (fine motor total score) where the outcome variable was considered as the overall IE performance score. In addition, variance inflation factors were computed to examine the possible interrelationships (multi-collinearity) among the predictors.

Study Three

Mechanisms Underlying Poor Performance of People with Mental Retardation while Operating Internet Explorer

Objectives of Study 3

This study explored the possible mechanism that hindered the participants from operating Internet Explorer. The results obtained from Study 2 indicated that the visual search function was the best predictor of the participants' performances on the IE tasks. A conjunctive visual search paradigm was designed for studying how attention and working memory would influence the participants' visual search performances. Two variables were manipulated: distance and orientation of target stimuli. The visual lobes of the participants and the accuracy rates and response times of the participants' performances on the visual search tasks were also measured. Eye-tracking parameters, which included the overall number of fixations, scanpath duration (overall search time between two target stimuli), overall fixation duration, and fixation duration on area of interest (fixation duration on first and second targets), were also recorded.

Sampling

There were two groups of participants: people with mental retardation and people without mental retardation. The participants in the former group were people with a mild to moderate grade of mental retardation. The selection criteria for this group were similar to those in Study 2. On the other hand, the participants in the latter group were normal adults without mental retardation. They were undergraduate students recruited from The Hong Kong Polytechnic University. The reason for recruiting a normal group was to establish visual search and visual lobe baselines for a meaningful interpretation of the results obtained from the former group. The selection criteria used for the people in the group without mental retardation are as follows:

1. They are aged 18 or above;
2. They have normal or corrected-to-normal visual acuities and were not colorblind as reported in school or medical reports;
3. They have no history of psychiatric illnesses or organic etiology;
4. They have not displayed presence of any physical impairment; and
5. They have voluntarily consented to participate in the study.

Convenience sampling was used to recruit the potential participants (Portney & Watkins, 2000). To those participants who fulfilled the selection criteria, Researcher A presented and explained the Client Information Sheet and Consent Form (Appendix IX). All participants were given an incentive gift of HK$200 upon completion of the whole experiment.

The participants in Study 3 were required to complete two experimental tasks: visual search and visual lobe mapping. The visual search task was used to study how attention and working memory would affect the participants' visual search function by manipulating the distance and orientation between two target stimuli. The visual lobe task was to estimate the visual lobe areas and lobe shape of the participants.

Apparatus

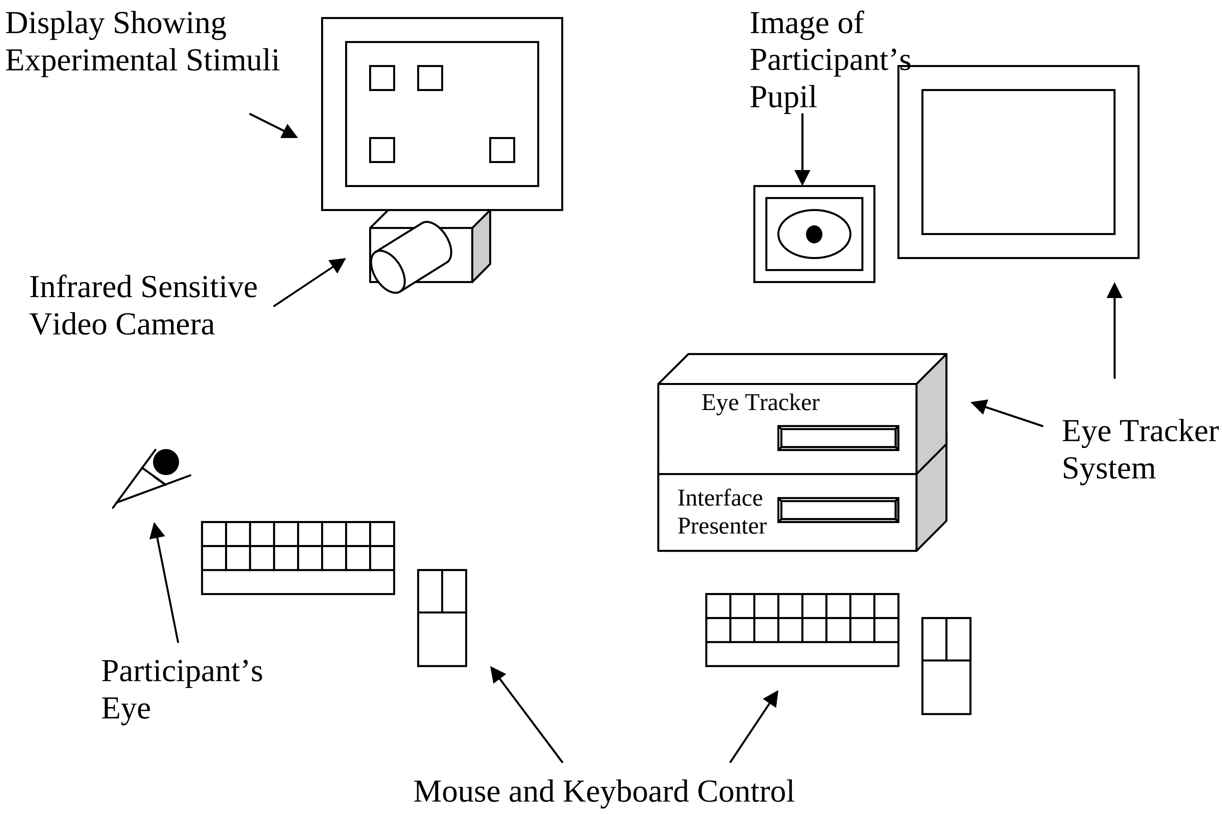
Visual search experiment. This experiment was hosted on a PC with a 17-inch monitor, a mouse, and a keyboard control. A second computer, remotely activated by the host computer, controlled the eye-tracking system, which was an Eye-gaze Response Interface Computer Aid (ERICA) Model 03.08.18 infrared corneal reflection system (Figure 3.4). An infrared-sensitive video camera was positioned just below the host computer’s monitor. The camera generated an illuminated pupil and the first Purkinje reflection on the participant’s cornea. The head posture and eye location were maintained with a head or chin rest, such that the eye was 500 mm from the screen and level with its center. At this distance, the screen subtended 39 x 31 degrees of the horizontal and vertical visual angles respectively. Every 30 pixels (horizontal) x 28 pixels (vertical) of a visual object in the interface screen subtend 1 cm, or 0.115 degrees of the visual angle. Video images of the pupil and the Purkinje reflection were captured at 30 Hz by the eye tracker. The eye-tracker software located the center of the pupil and calculated the vector from it to the corneal light glint. A calibration procedure related this vector with Cartesian coordinates on the interface screen, providing the participant’s eye-gaze location, or point of regard (POR). The calibration of the participant’s POR was approximately 5 minutes using the 16-point calibration routine built into the ERICA software. The POR coordinates were then collected and stored in a Microsoft Office Access datafile for later processing.

ILAB software - eye movement analysis software program. The eye movement data were displayed and analyzed using the ILAB 3.6.4 software (Gitelman, 2002) written in MATLAB program (Mathworks, Sherborn, MA). These data were filtered to remove blind artifacts. The spatial diameter of a fixation was set at 2 degrees of the visual angle, which was well beyond the amplitudes of microsaccades, microdrift, and microtremor (Robinson, 1979), and the minimum duration of visual fixations was set at 100 ms (Viviani, 1990).

The ILAB program was firstly developed and validated by Darren Gitelman of the Cognitive Neurology and Alzheimer's Disease Center, of the Northwestern University. This program uses a simple, menu-driven, graphical user interface that allows the researcher with higher flexibility in defining the parameters for analyzing and displaying the eye movement data. This program includes some basic eye movement analyses such as fixations, saccades, and region of interests, as well as some additional methods for conditioning the raw data, exporting data and results, and annotating the output display. In addition, this program uses the MATLAB environment which affords the researcher with easier and higher flexibility in reading and modifying the prepackaged algorithms and codes installed in the program (Gitelman, 2002). As this program consists of a series of open-source MATLAB functions and is distributed freely to the scientific community in early 2002, it has already been downloaded by over 100 laboratories. As a result, this program has been used for eye movement analysis and cited in some previous studies (Appendix X). Due to its widespread use, this program has also been used in the eye movement data analysis in our visual search experiment.

Figure 3.4

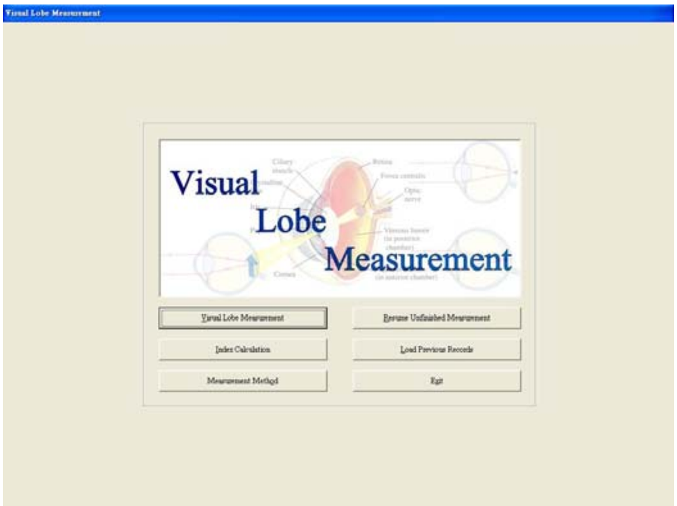
<u>Hardware setup in the visual search experiment</u>



Visual lobe-mapping experiment. The hardware setup which was used in the visual search experiment was adopted in this part of the experiment. A mechanical mouse was used by participants to control the stimulus presentation and make responses concerning estimated target positions. The head posture and eye location were also maintained with a head or chin rest to ensure that the eye was 500 mm from the screen and at the center level of the screen. The program, Visual Lobe Measurement System (VILOMS), developed and written in Visual Basic Language (Chan & So, 2006; So, 2003), was hosted on the computer for mapping the visual lobe areas and determining the visual lobe shape indexes of the participants. The front page of the VILOMS is shown in Figure 3.5.

Figure 3.5

Front page of the VILOMS (Chan & So, 2006; So, 2003).



Experimental Task

Visual search experiment. The templates of the stimuli used in this visual search task were developed using CorelDRAW (version 12). They were imported into a self-constructed experimental program written in Visual Basic Language. The basic design of a stimulus displayed a total of 16 color squares organized in a preset pattern within a 7 x 8 imaginary rectangular grid. The 16 squares could either be small (8 mm x 8 mm) or large (10 mm x 10 mm) in size, and lime green (RGB color as R: 0 G: 102 B: 51) or dark green (RGB color as R: 153 G: 255 B: 0) in color. The target stimuli had two squares that had a different size and color from the other 14 squares, while the control stimuli had only one square instead of two squares. All squares were randomly placed at an intersection of the imaginary 7 x 8 grids, such that they were aligned horizontally and vertically. The horizontal and vertical lengths of each of the imagined grids were 1 radius of the visual lobe size used in another study (So, 2003), which was 5.509 cm (horizontal) x 3.416 cm (vertical) respectively. Examples of the target stimulus and control stimulus are shown in Figure 3.6.

The 2 size x 2 color combinations gave four sets of stimuli.

Set 1 consists of a large and dark green square target, a small and dark green square distractor (A), and a large and lime green square distractor (B) (Figure 3.7a).

Set 2 consists of a large and lime green square target, a small and lime green square distractor (A), and a large and dark green square distractor (B) (Figure 3.7b).

Set 3 consists of a small and dark green square target, a large and dark green square distractor (A), and a small and lime green square distractor (B) (Figure 3.7c).

Set 4 consists of a small and lime green square target, a large and lime green square distractor (A), and a small and dark green square distractor (B) (Figure 3.7d).

The numbers of the two types of distractors (A and B) within a screen were made as nearly equal as possible. This meant that all target stimuli (100%) were composed of seven distractors (A) and seven distractors (B), together with two target squares. However, half of the control stimuli (50%) were composed of seven distractors (A) and eight distractors (B) together with one target square, while the other half of the control stimuli (50%) was composed of eight distractors (A) and seven distractors (B) together with one target square. In these displays, neither color nor size was sufficient in itself to identify the target, making this a conjunctive search task (Treisman & Gelade, 1980).

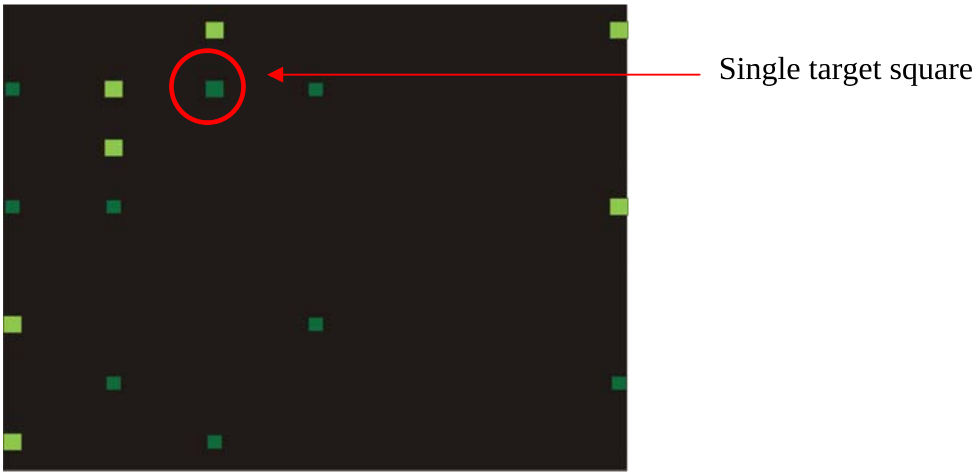
The variables manipulated in the task were the distance (close: 1 visual lobe, medium: 1.5 visual lobes, and far: 2 visual lobes) and the orientation (horizontal, vertical, and oblique) of the two target squares. The manipulation of these two variables was meant to test the extent to which attention and working memory would affect the visual search performances of the participants. Examples of visual presentations from these nine conditions are shown in Figure 3.8. The participants were required to attend to the stimulus and to visually search for the target square(s) (one or two) on the screen and indicate as quickly as possible the number of target square(s) that they found. In doing this, the participants would be required to scan through each of the target and distractor squares before they would indicate the number of target square(s). The eye-tracking parameters, accuracy rate, and response time would reflect the ways in which the visual search was conducted and the stimuli were processed.

A total of 432 trials (24 blocks of 18) were administered. The occurrence of each of the two responses (one-target square and two-target squares) was equal, with no more than three consecutive identical responses. The order of trials per block was pseudorandomized, and the order of the blocks of stimuli sets was counterbalanced between participants.

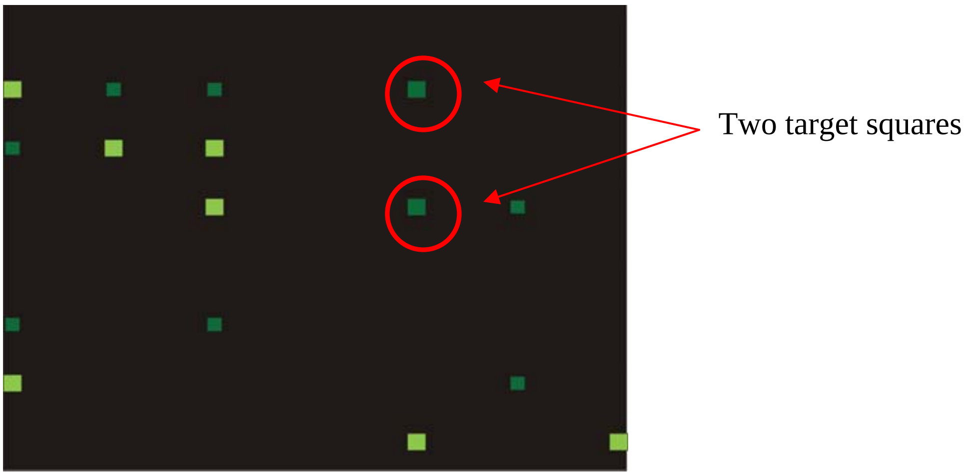
Figure 3.6

<u>Examples of control stimulus and target stimulus in the visual search experiment</u>

<u>Control stimulus: Visual stimulus with one-target square</u>



<u>Target stimulus: Visual stimulus with two-target squares</u>

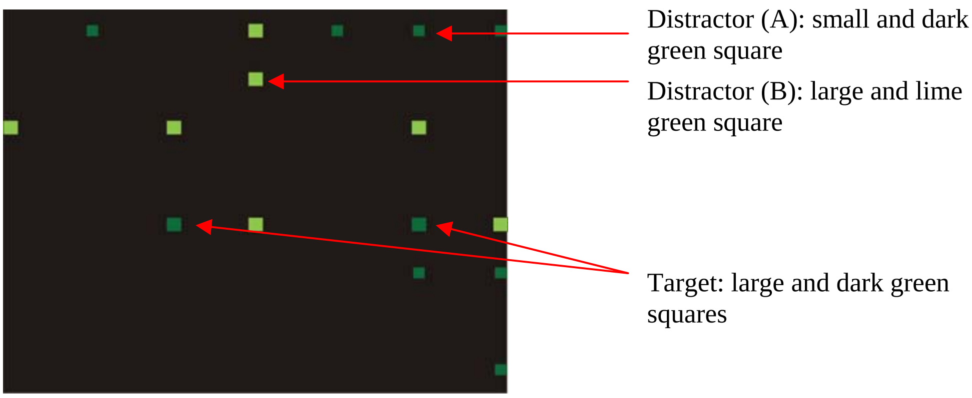


<u>Note:</u> Target: Large and dark green square(s); Distractor (A): Small and dark green squares; Distractor (B): Large and lime green squares.

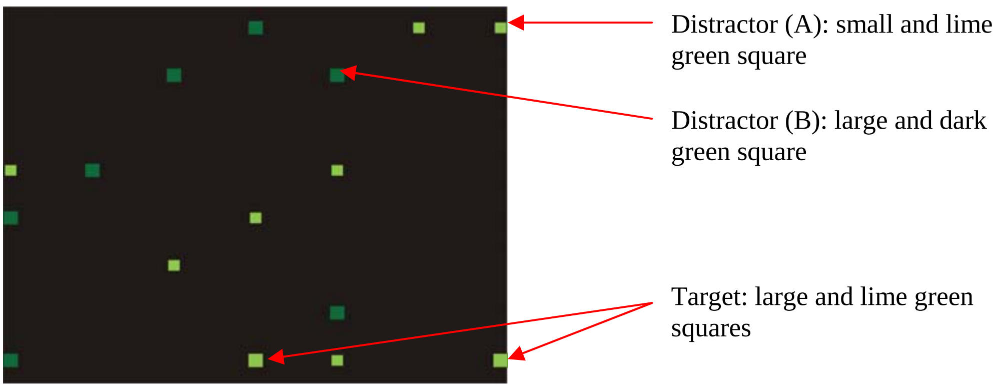
Figure 3.7

<u>Examples of four sets of visual stimuli used in the visual search experiment</u>

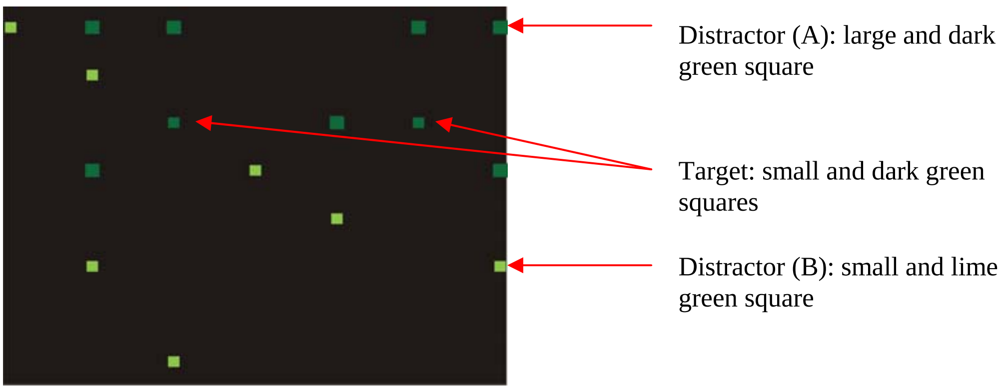
(a). Set 1



(b). Set 2



(c). Set 3



(d). Set 4

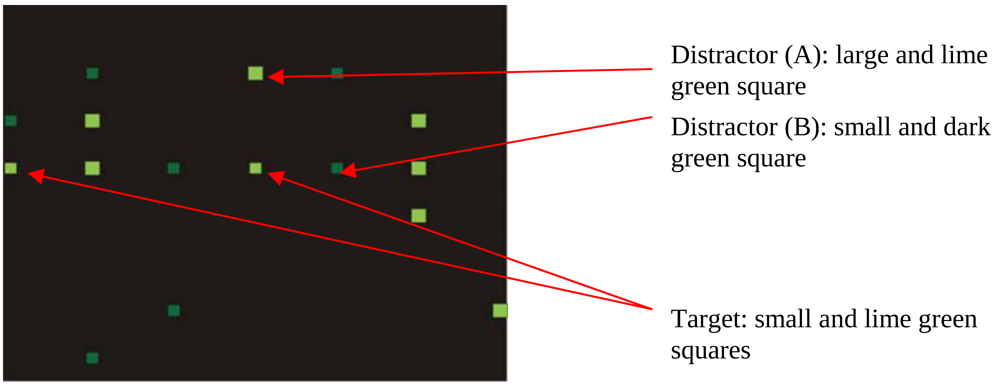
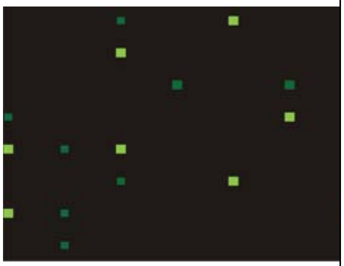
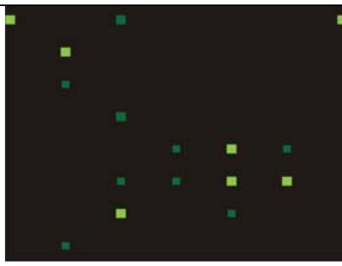
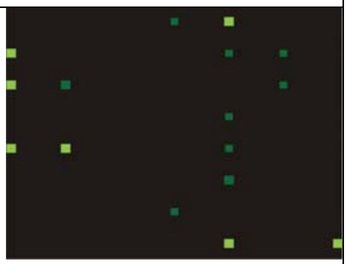
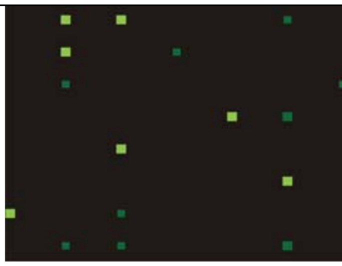


Figure 3.8

<u>Examples of the visual stimuli (two target-squares) occurring in the 3 (distance) x 3 (orientation) conditions in the visual search experiment</u>

	Horizontal	Vertical	Oblique
Close			
Medium			
Far			

<u>Note:</u> Close: 1 visual lobe; Medium: 1.5 visual lobes; Far: 2 visual lobes;

Target: Large and dark green squares; Distractor (A): Small and dark green squares;

Distractor (B): Large and lime green squares.

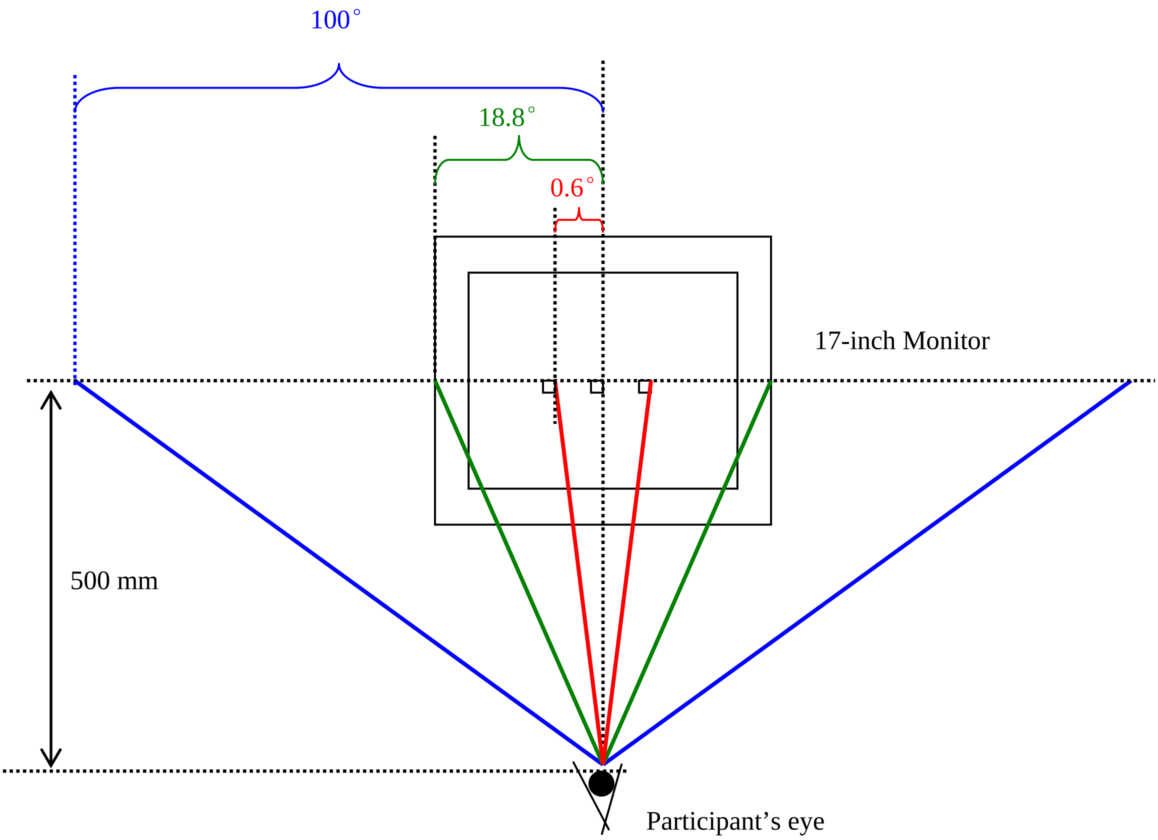
Visual lobe and visual field are important concepts that modulate visual search performance in this study. Visual field is defined as the space in which stimuli are visible to an eye in a given position (Millodot, 2004). The determination of its boundary is simply to bring an object around from behind the head of an individual who is looking straight ahead and asking when the object first becomes visible from the periphery (Anderson & Patella, 1999). In contrast, the visual lobe is defined as the space where the retinal sensitivity is good enough to extract, recognize, and identify the properties of the stimulus, such as shape and color, rather than detect their presence (Ball et al., 1988; Kraiss & Knaeuper, 1982). Obviously, the boundaries of the visual lobe are considerably smaller than that of the visual field. According to previous studies on Chinese subjects, the mean radius of the visual lobe was 5.51 cm/ 0.6 degrees (horizontal) x 3.42 cm/ 0.4 degrees (vertical) (Chan & So, 2006; So, 2003). The boundaries of the visual field measured from the point of fixation are around 60 degrees superiorly (above), 75 degrees inferiorly (below), 100 degrees temporally (to the right for the right eye, to the left for the left eye), and 60 degrees nasally (to the left for the right eye, to the right for the left eye) (Anderson & Patella, 1999).

Both the visual field and visual lobe of the participants were considered when the visual search experiment was designed (Figures 3.9 & 3.10). In our experimental set-up, participants were seated in front of the 17-inch monitor (240mm horizontal x 270mm vertical), with the viewing distance of 500mm, to perform the visual search task. Under these dimensions, the horizontal (100 degrees) and vertical (60 degrees) visual angles of the monocular visual field of participants were much larger than the horizontal (18.8 degrees) and vertical (15.1 degrees) visual angles of the monitor, respectively. Therefore, whenever we manipulated the sizes of monitor and the properties of the stimuli in this set-up, such as the sizes and colors of stimuli as well as the distances and orientations of two target items, the modulating effects on visual field of the participants to the visual search performance became small.

Nevertheless, as our visual search task required the participants to focus their spotlight attention to locate and identify the target item one by one, their visual lobe could possibly influence the visual search performance of our participants. Thus, in this study, we controlled the minimum distance between target and/ or distractor based on the boundaries of the visual lobe; that was 1 visual lobe radius of normal young adults, which was 5.51 mm (horizontal) x 3.42mm (vertical). This manipulation ensured that the horizontal (0.6 degrees) and vertical (0.4 degrees) visual angles of each participant's eye were able to subtend a single target item only. Therefore, eye movement would be required when the participants scanned from one target item (first target) to another (second target) in the monitor.

Figure 3.9

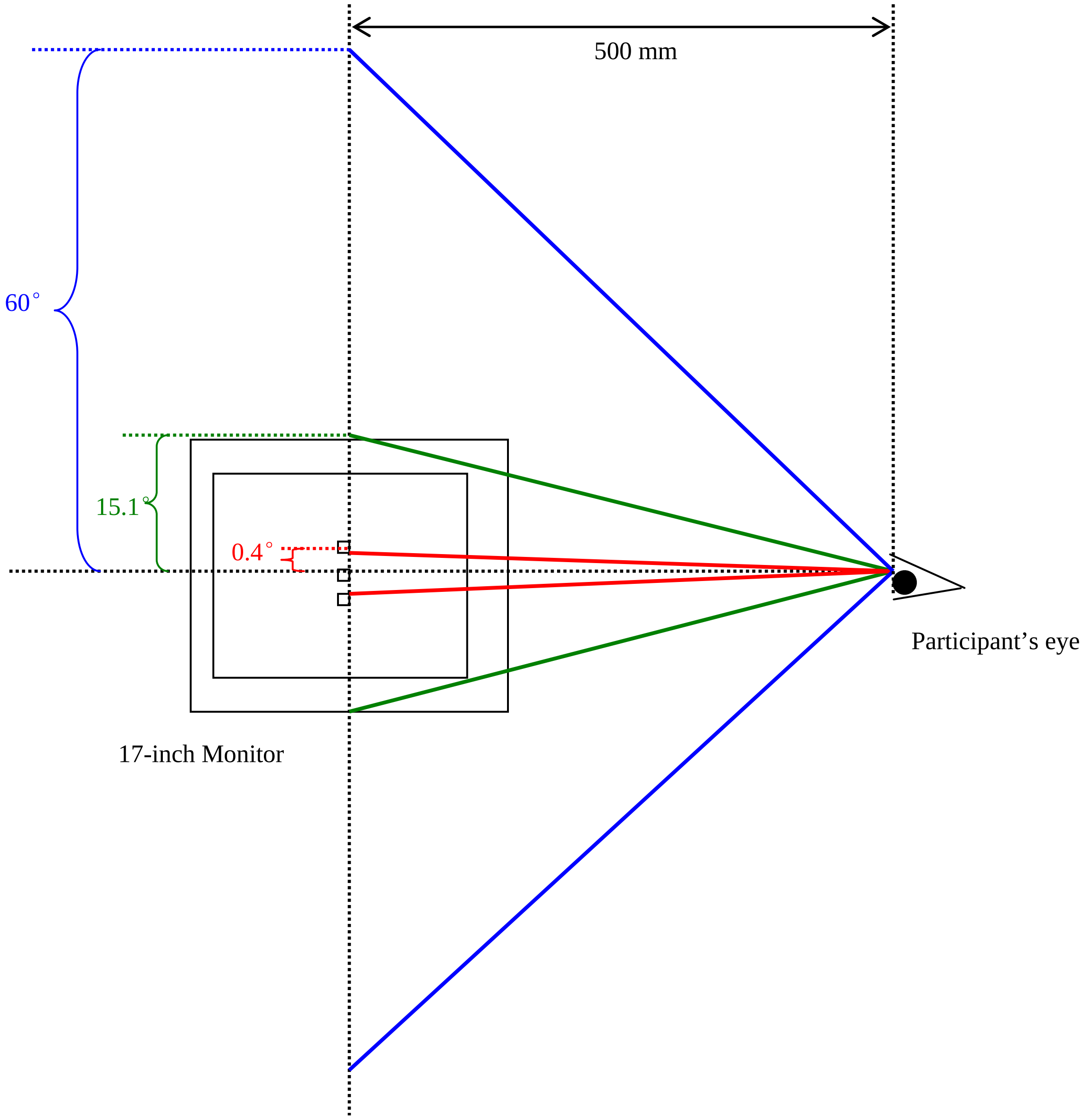
Horizontal dimensions of the visual field and visual lobe of participants in the visual search experiment



Note:
Blue line represents the horizontal visual angle of the visual field of normal participants
Red line represents the horizontal visual angle of the visual lobe of normal participants
Green line represents the horizontal visual angle of the monitor width

Figure 3.10

Vertical dimensions of the visual field and visual lobe of participants in the visual search experiment



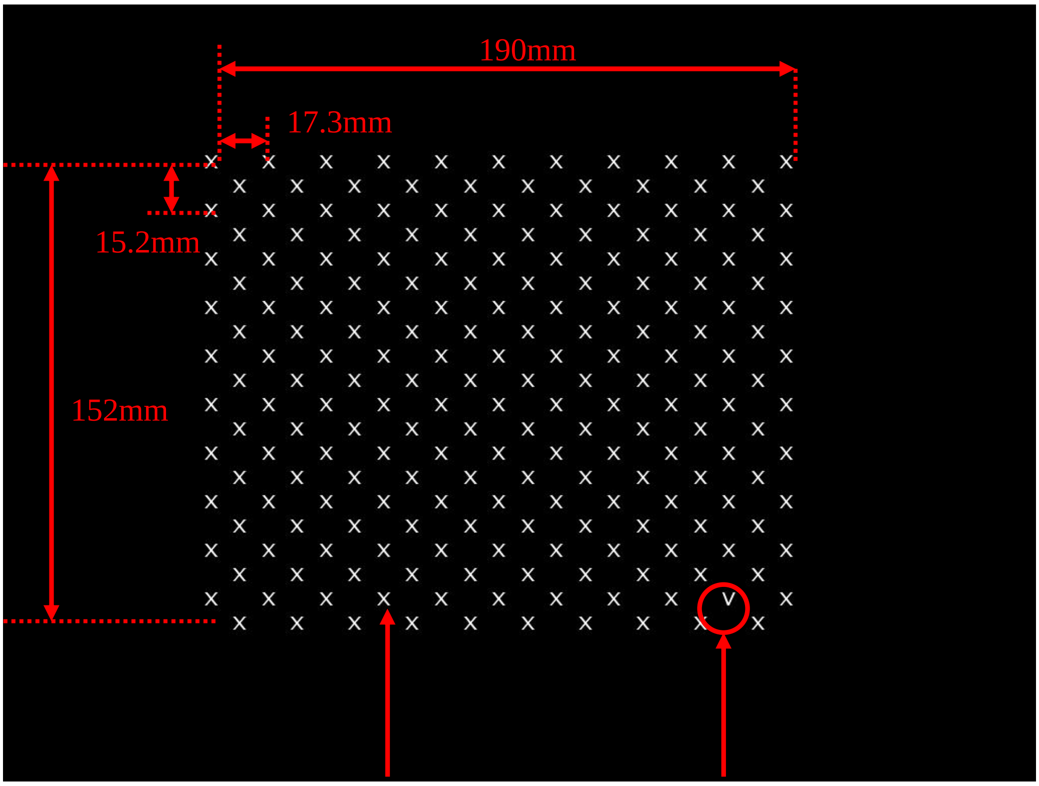
Note:
Blue line represents thte vertical visual angle of the visual field of normal participants
Red line represents the vertical visual angle of the visual lobe of normal participants
Green line represents the vertical visual angle of the monitor length

Visual Lobe-Mapping Experiment. The stimuli used in the visual lobe mapping were generated with the Visual Lobe Measurement System (VILOMS), and each of the stimuli contained one target character “V” with a homogeneous background of regularly spaced nontarget characters “Xs” (Figure 3.11). A review of the literature on the visual lobe-mapping methods indicated that full-field mapping is very time consuming; many researchers have mapped visual lobes on eight axes, four axes, two axes, and even one axis (Chan & So, 2006; Courtney & Chan, 1985). In order to accurately estimate the lobe shape characteristics, a sufficient number of meridians needed to be used. Hence, VILOMS used 24 imaginary and regularly spaced meridians radiating from the center of a fixation point in order to provide a reasonable full-field lobe map for this experiment. In each stimulus presentation, a target “V” appeared randomly at one of the locations along these 24 meridians, while 209 nontargets “X” filled up all other positions forming a uniform two-dimensional test field of 21.77 degrees (width) x 17.42 degrees (height). The visual stimuli were presented on the screen at a distance of 500 mm from the participant’s eyes such that the farthest eccentricity tested at 14.55 degrees on the diagonal meridians. Each of the visual stimuli was 3.85 mm x 3.85 mm, subtending a 26.47-minute arc both horizontally and vertically with its center, separated by 17.27 mm (118.75-minute arc) horizontally x 15.20 mm (104.52-minute arc) vertically.

The target appeared four times randomly at each of the 210 target locations along the 24 meridians. The method of limits was used on each meridian for the determination of sensitivity limits, and the threshold for target detection was set at 0.5. Therefore, for each of the possible target locations, the target appeared randomly four times. If the participant was able to detect the target twice at a particular location, the measurement system recognized this particular location. This location represented the eccentricity from the fixation point at which the target could be detected and covered by the visual lobe. The target detection process continued until the maximum eccentricity of all 24 meridians was decided. A correct response was defined as a cursor position click within one character-space of the actual target location. Depending on the individual's ability, the number of trials for the participants ranged from 350 to 600 for a complete 24-meridian mapping (Chan & So, 2006). The shape characteristics of the lobes measured were then quantified with the geometric methods in VILOMS for shape features, as described in Appendix I.

Figure 3.11

A typical stimulus used in the visual lobe-mapping experiment



Non-target: 3.85mm x3.85mm

Target: 3.85mm x3.85mm

Procedures

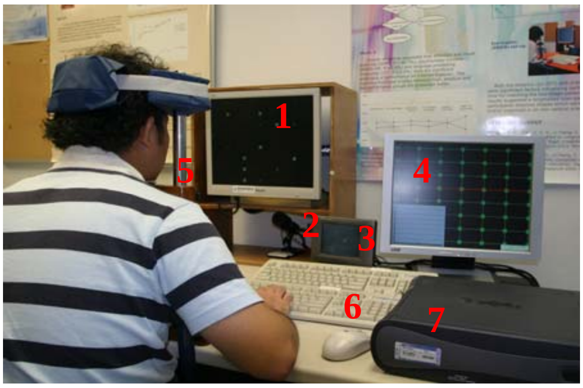
Visual search experiment. Each participant was seated 500 mm away from the computer screen, with the keyboard placed within arm's reach. The experimenter sat to his or her right, also within arm's reach of the keyboard. Prior to the introduction of the formal test trials, the chin rest and workstation were adjusted so that the participant's eye position was maintained approximately level with the center of the screen (Figure 3.12). In addition, the eye-tracker software was able to locate the center of the pupil and the corneal reflection. The calibration routine was then conducted to match the participant's eye gaze with the corresponding locations on the screen (Figure 3.13). The calibration procedure required the participant to fixate on each of a total of 16 fixed points, in a given order of succession, located on different parts of the screen, with the fixation time at each stimulus location set to at least 3 seconds. This procedure was aimed to ensure that the minimum-variance criterion at each location was satisfied. The minimum-variance criterion for a successful calibration equated to residuals that were less than 0.5 visual angles from the actual target location. Calibration was repeated prior to each block.

Training sessions were provided for each participant prior to the experiment. This was done to ensure that the participant was familiarized with the task and his or her performance had reached a stable level. Training sessions involved the participants familiarizing themselves with the features of stimuli and the step work in the experimental tasks. During the familiarization sessions, we presented each of the four sets of stimuli on index cards. When the cards were shown, Researcher A highlighted the features of the stimuli and explained the differences between the target and the two types of distractors (A and B). After the participant was able to identify the differences of stimuli on the index cards, the stimuli were then in view during the computerized trials as well. After the participant was familiarized with the features of the stimuli, he or she was trained to differentiate the visual stimuli of the trials with one- or two-target squares. Again, the participant was presented with index cards; the researcher then labeled the targets and explained the stimuli with one- or two-target squares used in the trial. The stimuli were then again in view during the computerized trials, in which the participant had to try to decide the correct response. After the familiarization, the participant was presented with at least five practice trials on each of the four sets and asked to start working on the task. The training session continued until the participant had achieved an accuracy of above 70%. The stimuli used in the practice trials were not repeated in the test trials, and there was no time limit for these training sessions. In general, the overall duration ranged from 30 to 120 minutes for the participants with mental retardation and around 15 minutes for their normal counterparts.

During the experimental trial, a trial was initiated only when the participant has made a key press on the valid character during the Fovea Fixation Mechanism (FFM). FFM is designed to ensure the foveal fixation of participants during target exposure and employs three null foveal characters and one valid character, both of which are displayed randomly at the fixation point. A sequence of foveal characters during FFM is shown in Figure 3.14. The participant was required to judge whether the displayed foveal character was the valid one and respond with a “2” key press when the valid character was shown. As the fovea character kept changing randomly, the chance of making a correct hit without fixating at the central point was low. Therefore, the trial was initiated after the participant detected the valid foveal character, that is, when a triangle was displayed in an upright position, the participant pressed the “2” key to initiate the trial. The purpose of the fovea fixation mechanism test was to ensure that the participant fixated at the center of the screen when the trial began. This would maximize the eye gaze’s tendency to fixate at the center. The visual stimulus was presented immediately following the depression of the “2” key. The participant was directed to scan the stimulus and then press the “1” key when just one target was detected, and press the “2” key when two targets were detected. The participants were reminded to put equal emphasis on response time and accuracy when performing in each trial. The task was completed in around 2 to 3 hours for the people without mental retardation and in around 3 to 5 hours for the participants with mental retardation. All 24 blocks were administered on the same day to people without mental retardation, while the individuals with mental retardation only received 12 blocks per day, with all 24 blocks completed within two consecutive days.

Figure 3.12

The hardware setup for the visual search experiment



Note:
1: Display showing experimental stimuli.
2: Infrared-sensitive video camera.
3: Display showing the image of the participant’s pupil and corneal reflection.
4. Online display showing the participant’s visual search performance.
5: Chinrest or headrest to restrain head movement.
6: Mouse and keyboard control.
7: Eye-tracker system and interface presenter.

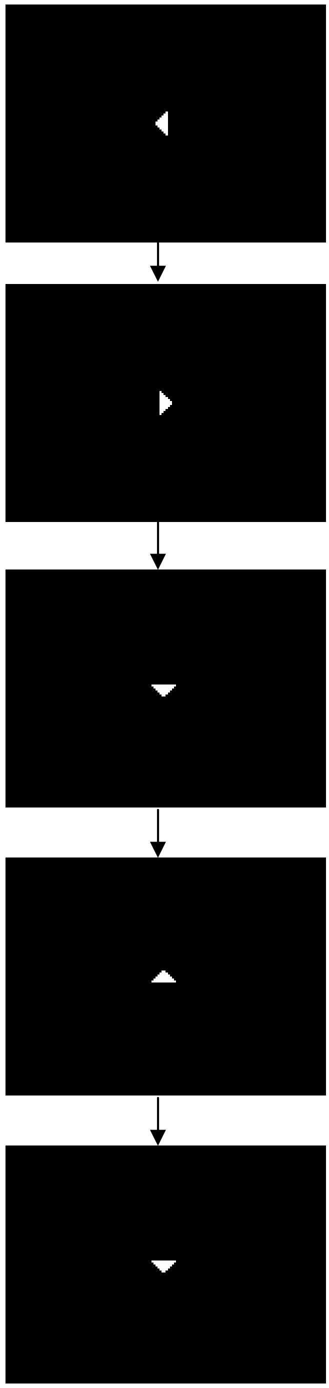
Figure 3.13

Calibration conducted by the ERICA software in the visual search experiment

Note:
1: Check video: to check the image of the participant’s pupil center and corneal reflection.
2: Calibration: to match the participant’s eye gaze with the corresponding screen locations.
3: Check results: to give the score that indicates the level of successful calibration.

Figure 3.14

A sequence of foveal characters during the Fovea Fixation Mechanism



Null foveal character

Null foveal character

Null foveal character

Valid foveal character: Participant has made a mouse click at this time to initiate the stimulus presentation.

Null foveal character

Note: The foveal characters are not to scale when compared with the size of the screen; they are magnified here for illustration purposes. The actual size of characters is 5.6 mm.

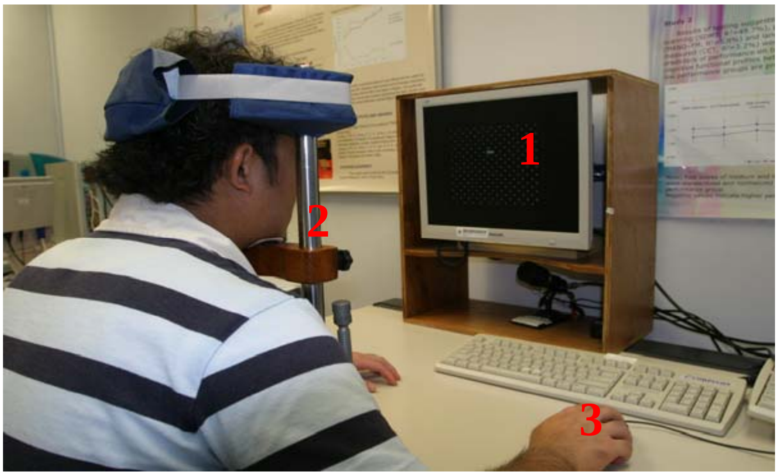
Visual lobe-mapping experiment. Each of the participants was seated 500 mm from the computer screen, with the mouse placed within arm's reach. The experimenter sat to his or her right also within arm's reach of the mouse. The participant's head position and eye location were maintained on the head or chin rest so that the participant's eye position remained about level with the center of the screen (Figure 3.15). Before the introduction of the test trials, a written instruction was presented and the experimenter showed some trials in the computer and labeled different types of visual characters. After they had understood the task procedures, each participant attended a 5-minute practice session to allow them to familiarize themselves with the task.

For each experimental trial, stimulus presentation was initiated by the participant when he or she made a mouse click on the valid character during the FFM. FFM was used to ensure the participant's foveal fixation during target exposure. The FFM used in this research was similar to the FFM used in the visual search experiment except for one difference: the participant responded with a mouse click instead of a key press when the valid character was shown. That is, when a triangle was displayed in an upright position, the participant clicked the mouse to initiate the trial. After a confirmation mouse click for the valid character had been made, the measurement system ensured that the participant's eyes fixated at the center of the display. Then, the visual stimulus was instantly initiated and lasted for 400 ms. When the stimulus was presented, the participant was required to detect the target "V" and was required to hold the target's position for a few seconds until the postexposure masking stimulus was presented. The postexposure masking "+" character appeared immediately and masked the original positions of all background nontarget "Xs" and the target "V." When the postexposure stimulus was displayed, the participant retrieved the original position of the target and then indicated the estimated target position by mouse clicking on a "+" position. A visual presentation of a typical trial procedure on the visual lobe-mapping experiment is shown in Figure 3.16. Even if the target could not be detected, an estimate of the location by mouse clicking on any "+" position was still required.

A 5-minute break was given to the participants for every 15 minutes of measurement, which comprised about 200 stimulus presentations depending on the participant's pace. The total duration of the measurement varied with the individual participants. In general, the measurement could be completed within 30 to 45 minutes for people without mental retardation and in 60 to 90 minutes for people with mental retardation.

Figure 3.15

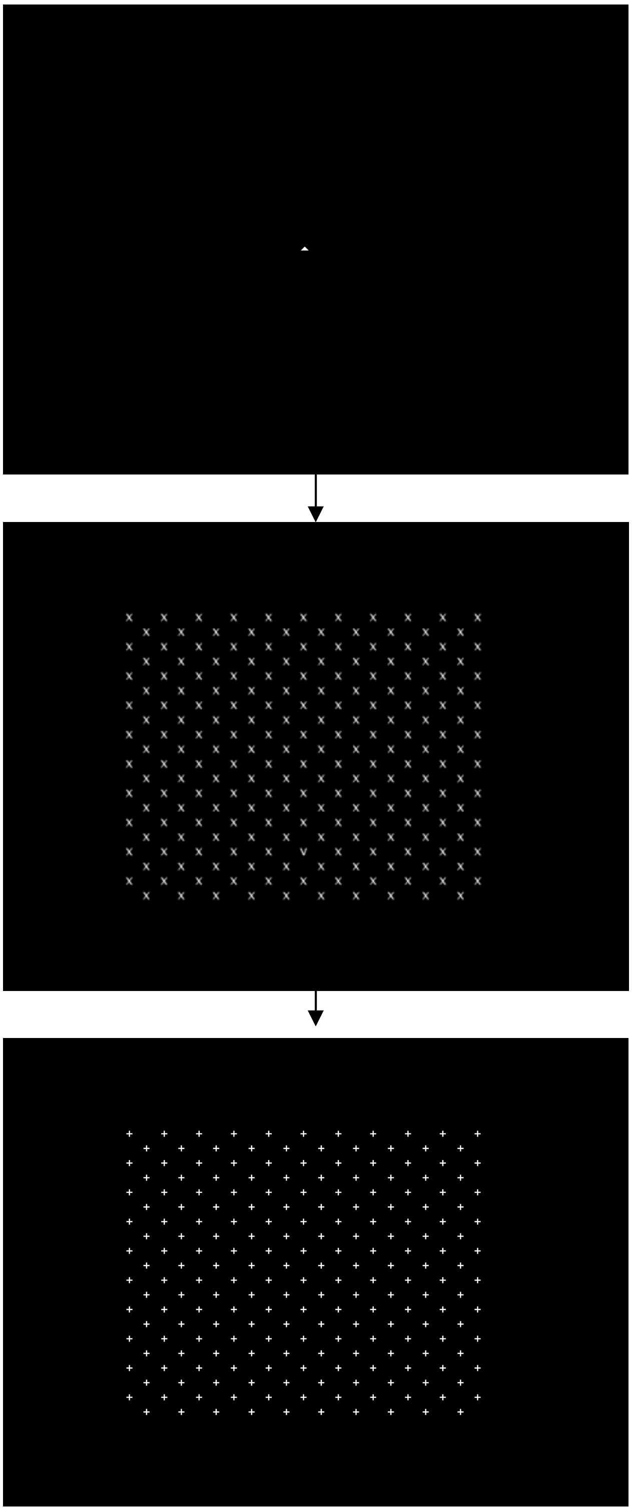
<u>Hardware setup of VILOMS in the visual lobe-mapping experiment</u>



Note:
1: Display: to show visual stimuli.
2: Chin or head rest: to retrain head movement.
3: Mouse control: to input the response signal.

Figure 3.16

Typical trial procedure on the visual lobe-mapping experiment



Participant has made a mouse click when the valid character (upward pointing triangle) has appeared during FFM to initiate the stimulus presentation.

Participant has detected the target "V" and held its position until the postexposure masking stimulus was presented.

The postexposure-marking "+" character has appeared which masks the original positions of all background nontargets "Xs" and target "V." Participant has retrieved the original position of the target and has indicated its estimated position by mouse clicking on a "+" position.

Data Analysis: Visual Search Experiment

Attention correlates with visual search performance. The results from Study 2 indicated that attention and visual search were the most significant cognitive abilities that contributed to the performance on the IE tasks. In order to have a better understanding of these two aspects, we intentionally adopted an attention network model proposed by Posner and Petersen (1990) to investigate how the attention networks related to the visual search performance of the participants with mental retardation. Based on a previous neuropsychological study that investigated the attention networks of persons with acquired brain injury after attention process training (Sohlberg, McLaughlin, Pavese, Heidrich, & Posner, 2000), the tests that measure the corresponding attention networks were selected. The score on the SART, which was a continuous performance test, was used as measure of a vigilance network. The time score of Part A of the Color Trails Test (CTT), which was a modified nonalphabetical parallel version of the Trail Making Test, was used as measure of an orienting network. The interference score of the CTT was used as a measure of an executive attention network. Due to the fact that performances in working memory tasks are frequently related to executive control measures (Sohlberg et al., 2000; Kinsella, 1998), the test scores of Digit Span Backward (DSB) were further selected as a measure of the supervisory attentional control components of working memory. Pearson's Product-Moment Correlations between the test scores of attention networks and the eye-tracking parameters, including overall number of fixations, scanpath duration, overall fixation duration, and fixation duration on areas of interest (fixation duration on the first target and fixation duration on the second target), in the visual search tasks were computed to explore the relationship between the attention functions and the visual search performance of the participants with mental retardation. Moroever, the alpha level was adjusted to $p<0.05/5= 0.01$ to lower the Type I errors committed in the analyses. For details of the descriptions of these eye-tracking parameters, we suggest the readers to refer to the literature review chapter of this thesis.

Search strategies used by people with and without mental retardation. The aim of this part of the analysis is to identify the search strategies employed by the participants with and without mental retardation engaged in the visual search task and compare them in order to establish any similarities if there are any. A search strategy is defined as a cognitive control process which guides the visual focus to the target stimulus (Hu, Ge, & Xu, 2005). The characteristics of the search strategies were analyzed by automated analysis procedures written in the MATLAB program (Mathworks, Sherborn, MA) which analyzed the oculomotor scanpath of each correct trial. The oculomotor scanpath was defined as the spatially and temporally structured sequences of fixations and saccades in accordance with the spatial configuration of a stimulus or scene (Zihl & Hebel, 1997). For the definitions of fixations and saccades, the reader can refer to the literature review chapter. Inspection of the oculomotor scanpath was found to be useful in understanding the search styles employed by our participants. If the participant used systematic search strategies, they should adapt their oculomotor scanning pattern so that it closely resembled the spatial configuration of the stimulus display (Zihl & Hebel, 1997). The participant was therefore expected to start the saccade from the central point to the nearby square, and fixate on this square to decide whether it is a target or not, and then start another saccade to find another nearby square. This saccade-fixate-saccade sequence was repeated, and made to follow the spatial configuration of the stimulus until the participant discovered two identical targets. Furthermore, the systematic search strategies should adapt their oculomotor scanning pattern with fewer numbers of fixations for retracing their previous locations (Hodgson et al., 2002). On the other hand, the oculomotor scanpath for the disordered or nonconsistent search strategy was found to cause an increased rate of ocular refixation during visual search. This oculomotor scanning pattern not reflecting the spatial configuration of the stimulus would, in turn, increase the fixations and lengthen the scanpath duration and fixation duration.

The possible systematic search strategies were identified and categorized first by looking at the saccade-fixate-saccade sequence based on these two criteria: (1) the oculomotor scanpath resembling the spatial configurations of stimulus display; and (2) the eye movement scanpath not returning to previous fixated items. In this thesis, the trial with the scanpath in which there was only one backtracking saccade to the previous fixated first target (backtrack 1) was still defined as the one using a systematic search strategy. Such backtracking during a visual search task has been noted previously (Findlay & Brown, 2006; Peterson, Kramer, Wang, Irwin, & McCarley, 2001). Findlay and Brown (2006) compared the error rates between the trials with one backtrack and the trials with backtracking saccades on more than one occasion. Their results indicated that the cases with one backtrack were not associated with the significantly increased errors caused by the previously scanned item being “forgotten.” They suggested that such backtracking was a fairly normal pattern in a scanning sequence and was often adopted and appeared as a preplanned sequence. Peterson et al. (2001) used the conjunctive search task and asked the participants to determine which target was present on the display while the participants’ eye movements were simultaneously recorded. Their results indicated that a larger proportion of the revisitations were directed to the target, suggesting that the revisits to the first target were not due to the participants' forgetting which items had already been examined, but instead were due to their returning to the first target that had been inadequately processed on first examination. For data analysis, the independent-sample *t* test was used to compare the difference between the percentages of trials, in which the systematic search strategy was employed by the participants with and without mental retardation.

Furthermore, the mean ratio which reflected the participants' likelihood of forming additional fixations before they made the response was reported, and an independent-sample *t* test was used to compare the difference on this mean ratio between these two groups. The calculation method for this ratio is reported in the results section.

Visual search performance among people with and without mental retardation. The aim of this part of the analysis is to compare the visual search performance among people with and without mental retardation. Independent-sample *t* tests were used to compare the behavioral measures and the eye-tracking parameters derived from the visual search task among people with and without mental retardation. The alpha level was adjusted to $p \leq 0.05/5 = 0.01$ to lower the Type I errors committed in the analyses. The behavioral measures included error rates and response time. The eye-tracking parameters included total number of fixations, scanpath duration, and total fixation duration. The descriptive statistics of these dependent variables were also reported. (For details of the descriptions of these eye-tracking parameters, we suggest the reader refers to the literature review chapter of this thesis. Furthermore, we have not selected all the data from these dependent variables for subsequent data analysis, thus we suggest the reader refers to the results and discussion chapters for the selection criteria for these dependent variables.)

Efficiency of search across distance and orientation of two target stimuli for people with and without mental retardation. The core aim of this part of the analysis is to compare the efficiency on various distances and orientations of two target stimuli. The manipulation of these two factors was meant to measure the attention and working memory functions. The results established would formulate the guidelines for the design of a human-machine interface for people with mental retardation.

With the aim of providing the general profiles of this search task as a reference, a series of repeated measure ANOVAs was firstly used to compare the efficiency of search across distance and orientation of two target stimuli for people without mental retardation. The posthoc analyses followed, in which all alpha levels were adjusted for Bonferroni's correction. Afterwards, another separate series of repeated measure ANOVAs was used to compare the efficiency of search across distance and orientation of two target stimuli for people with mental retardation. A 3 (*distance:* close, medium, far) x 3 (*orientation:* horizontal, vertical, oblique) factorial design was employed, with both variables manipulated for the participants. The primary analysis was a 3 x 3 factorial ANOVA performed using the SPSS 12.0 statistical package. In this part of the analysis, we did not enter the Group factor (people with mental retardation, people without mental retardation) into the overall statistical model, because previous results indicated that the search strategies employed by people with and without mental retardation were different. The descriptive statistics of the eye-tracking parameters, including the scanpath duration and overall fixation durations for people with and without mental retardation as dependent measures, were depicted.

To examine whether the visual lobe in designing the study confounded the results from the effect of distance and orientation of two target stimuli on modulating visual search performance of the participants with and without mental retardation, we used the factor of speed (taking into account distance traveled) rather than time to conduct another 3 (*distance:* close, medium, far) x 3 (*orientation:* horizontal, vertical, oblique) factorial ANOVA data analysis. The posthoc analyses then followed, in which all alpha levels were adjusted for Bonferroni's correction.

Data Analysis: Visual Lobe-Mapping Experiment

For a 24-axis lobe shape mapping, the target appeared randomly at one of the 210 target locations along the 24 meridians. The method of limits was used to determine the sensitivity limits. A correct response was defined as a cursor position click within one character space of the actual target location. The lobe area, perimeter, and a total of 16 lobe shape characteristics for shape features like sphericity, boundary smoothness, symmetry, elongation, and regularity were then quantified with the geometric methods in VILOMS (Chan & So, 2006; So, 2003). The indices on sphericity included in this study were *form factor, perimeter-area ratio, perimeter-area ratio of convex hull, area-maximum area ratio,* and *ratio of radii,* while the indices on boundary smoothness included in this study were *global convex deficiency, rugosity,* and *spike parameter*. The indices on symmetry included in this study were *vertical vertices symmetry, horizontal vertices symmetry, top-bottom area symmetry, left-right area symmetry, vertical symmetry of convex hull,* and *horizontal symmetry of convex hull*. The index on elongation included in this study was *length-width ratio* and the index on regularity included was the *Boyce-Clark index*. The definitions and quantification methods used for each of these lobe shape characteristic indices were discussed in detail in the literature review chapter.

Since the cognitive and motor requirements of the mapping task overwhelmed the abilities of some of the participants with mental retardation, we restricted the lower limit of the percentage of correct responses. An independent-sample *t* test was performed to test for any statistical difference on the percentage of correct responses on the mapping task between people with and without mental retardation. It was retained for subsequent data analysis of the lobe shape indices.

The first aim of this part of the thesis is to describe and quantify the visual lobe areas and lobe shape characteristics of people with and without mental retardation. Therefore, some samples with and without mental retardation on the visual lobes mapped on 24 meridians and the corresponding 16 shape indices on sphericity, boundary smoothness, symmetry, elongation, and regularity were reported. Subsequently, the descriptive statistics of these 16 shape indices were also reported to describe the characteristics of the lobe shape of people with and without mental retardation. Finally, several independent-sample *t* tests were used to compare each of these lobe shape indices in people with and without mental retardation.

CHAPTER IV

RESULTS

Introduction

This chapter presents the results of the three studies. It begins with the results obtained from the development of the computer competence tasks. The data on the cognitive and motor profiles of the participants and then the prediction of the performances on the IE competence task are presented. This is followed by an analysis of the comparisons on the visual lobe area and its shapes among the participants with and without mental retardation. Lastly, the results on testing the effects of visual search experiments in the eye-tracking parameters are presented.

Study One

Small-Scale Survey on Computer Utilization

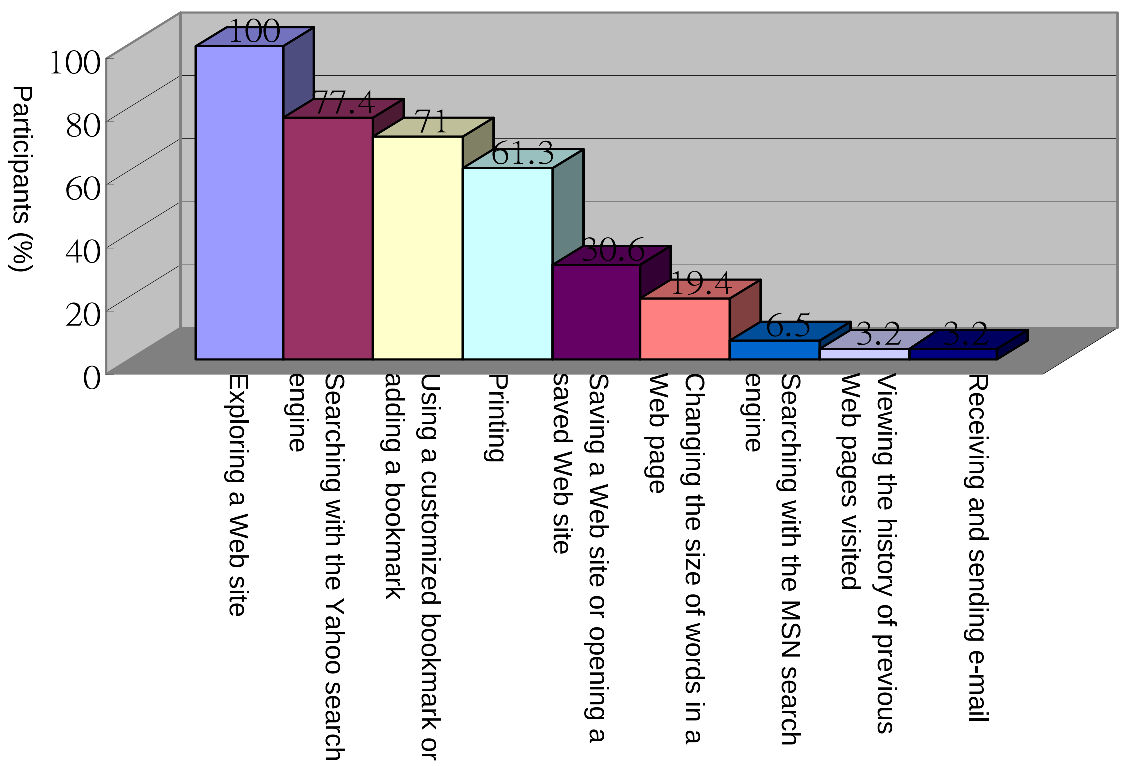
Characteristics of the participants. A total of 62 mentally retarded participants who had previous experience in using a computer were recruited to provide information on the utilization of computers. Their mean age was 18.3 (SD = 7.7). Forty-two were male (67.7%), while 20 were female (32.3%). All were known cases of mental retardation with 47 (75.8%) of them diagnosed with a mild grade and 15 (24.2%) with a moderate grade mental retardation. Majority of them or 66.1% had received secondary education or above in a special school program, 25.8% had received at least primary education in a special school program, and 8.1% had received vocational training.

Results from the questionnaire. Majority of the participants indicated that they had experience in using a computer for “accessing the Web” (98.4%), “playing games" (82.3%), and "painting" (80.6%). All of them had Microsoft's Internet Explorer (IE) installed in the computer that they used for accessing the Web. Because of this, IE was selected as the Web browser for the task analysis and testing in the rest of the study.

In the same survey, the participants were also asked to list the activities for which they used the Web browser (IE) (Figure 4.1). The five most frequent activities listed were *exploring Web sites* (100%), *searching with the* Yahoo *search engine* (77.4%), *using a customized bookmark or adding a bookmark* (71%), *printing* (61.3%), and *saving a Web site* or *opening a saved Web site* (30.6%). These activities were considered in the development of the computer competence test used in the study.

Figure 4.1

Web browsing activities commonly used by people with mental retardation



Expert Panel Review

Characteristics of the panel. Ten panel members consisting of five men (50.0%) and five women (50.0%) were recruited. The expert panel consisted of six occupational therapists, one psychologist, and three social workers. Their mean experience of working with people with mental retardation was 7.1 years (SD = 4.4).

Qualitative review—computer tasks and subtasks. The panel members were gathered together and were shown videos on the operations of the computer hardware and software involved in each of the five Web-browsing activities selected based on the survey results. The panel members divided the browsing activities into 16 IE tasks. They further classified these 16 IE tasks into three categories: general (3 tasks), hardware related (2 tasks), and software related (11 tasks; Table 4.1). Using the comments and consensus of the panel members, these 16 IE tasks were further divided into a total of 161 subtasks (Appendix XI). All of these subtasks became the sequential steps that were required for performing the IE tasks.

Table 4.1

The 16 IE tasks as identified by the expert panel

Task Categories	IE Tasks (N = 16)
General	(1) General orientation and recognition, (2) General motor functions, (3) General language functions.
Hardware related	(1) Powering on the computer, (2) Powering off the computer.
Software related	(1) Start Web browser, (2) Close Web browser, (3) Explore Web site, (4) Respond to the dialogue box, (5) Use customized bookmark, (6) Add bookmark, (7) Direct print, (8) Indirect print, (9) Save Web site, (10) Open saved Web site, (11) Use search engine.

Qualitative review—ability demand for IE task performance. The panel members were asked to rate each subtask in terms of its physical and mental functions as required for its successful performance. Through the review process, the panel members further added visual scanning and left-right discrimination onto the original list of mental abilities (Appendix IV). The review process involved the panel members evaluating all the ability items for each of the 161 subtasks. A check mark was made when the ability was required to accomplish a particular subtask. The percentage of the ability items involved in performing the 161 subtasks was calculated (refer to the Method section for the method used to calculate the percentage of the ability items). Table 4.2 shows a list of the physical and mental abilities which gained an overall score of at least 40% on the percentage of the ability items involved in performing the 161 subtasks. Both sensory-motor and cognitive abilities were required for performing the IE tasks. In the list of ability items, orientation and visual acuity had the highest frequency count. They were followed by word recognition, stabilization, eye-hand coordination, positioning, vigilance, hand dexterity, calibration, working memory, selective attention, visual scanning, and proprioception. These abilities will be used as the guidelines for selecting the cognitive and motor tests which are relevant for computer performance by people with mental retardation in Study 2.

Further analysis of these selected motor and cognitive abilities required for performing each of the 16 IE tasks was conducted. The cut-off value to decide the abilities which were said to be required to perform a particular IE task was based on the mean value of agreement of the subtasks grouped under each of the IE tasks, which is equal to or greater than 50%. Because of limited space, we did not print out this part of the results. In general, the results revealed that orientation, visual acuity, and attention were loaded on almost all of the 16 tasks (14 tasks for orientation and visual acuity, and 9 tasks for attention), indicating that these three abilities are the basic abilities needed for computer performance. The results further revealed that Chinese word recognition and working memory were mainly loaded on the more difficult tasks. Particularly, Chinese word recognition ability was involved in IE tasks including *use customized bookmark*, *add bookmark*, *use search engine*, *indirect print*, *save Web site*, *open Web site*, *explore Web site*, and *general language function*. Meanwhile, the working memory was mainly loaded on the tasks *save Web site*, *open Web site*, and *explore Web site*.

Table 4.2

The identified physical and mental abilities required to perform IE tasks

Ability items [a]	No. of subtasks [b]	Percentage of the ability item involved in performing the 161 subtasks (%)
Orientation	147	91.3
Visual acuity	133	82.6
Chinese word recognition	98	60.9
Stabilizes	98	60.9
Eye-hand coordination	97	60.2
Positions	95	59.0
Sustained attention/vigilance	91	56.5
Manipulates (dexterity)	91	56.5
Calibrates	82	50.9
Working memory	80	49.7
Selective attention	79	49.1
Visual scanning	76	47.2
Proprioception	76	47.2

Note. [a] Only the ability items which scored at least 40% for the percentage of the ability item involved in performing the 161 subtasks are reported.
[b] The figures inside the grid are the summated number of subtasks; each of these subtasks has a percentage of agreement among 10 panel members equal to or above 0.5. The maximum number of subtasks is 161.

Field Test—IE Competence Test

Interrater reliability of the IE competence test. The interrater reliability of the test items was estimated by recruiting two raters to conduct the IE competence test on 10 participants. For each of the two raters, the mean item score on the subtask was computed for each of the 16 IE tasks. Intraclass correlation coefficients (ICC) using a two-way mixed model (absolute agreement) for each IE task were computed (Table 4.3). The ICC obtained for the 16 IE task items ranged from 0.69 to 0.99 ($p < 0.05$). Among all the participants, 14 out of the 16 IE tasks (87.5%) had an ICC above 0.75, indicating moderate to good interrater reliability of the task items for the IE competence test.

Table 4.3

Interrater reliability of test items in the IE competence test—ICC (3, 1)

	Rater 1 Mean (SD)	Rater 2 Mean (SD)	ICC [a]	95% C.I.
Close Web browser	3.20(0.88)	3.27(0.78)	0.75	0.27 - 0.93
Shut down the computer	3.17(0.69)	3.22(0.63)	0.95	0.83 - 0.99
Turn on the computer	3.33(0.55)	3.25(0.88)	0.69	0.12 - 0.91
General motor functions	3.14(0.56)	3.20(0.51)	0.93	0.75 - 0.98
Direct print	3.17(0.76)	3.23(0.82)	0.78	0.33 - 0.94
Response to the dialogue box	3.23(0.59)	3.23(0.50)	0.96	0.86 - 0.99
Start Web browser software	2.80(0.91)	2.97(0.73)	0.88	0.60 - 0.97
Use customized bookmark	2.93(0.75)	3.01(0.65)	0.72	0.19- 0.92
General orientation and recognition	3.00(0.58)	3.08(0.52)	0.93	0.77 - 0.98
Add bookmark	2.95(0.76)	3.05(0.73)	0.77	0.32 - 0.94
Use search engine	2.86(0.63)	2.92(0.55)	0.92	0.73 - 0.98
Indirect print	2.79(0.60)	2.84(0.55)	0.94	0.78 - 0.98
Save Web site	2.85(0.59)	2.90(0.54)	0.92	0.73 - 0.98
Open saved Web site	2.49(0.74)	2.64(0.68)	0.86	0.55 - 0.96
Explore Web site	2.21(0.51)	2.38(0.65)	0.82	0.43 - 0.95
General language functions	2.23(0.92)	2.28(0.98)	0.99	0.97 - 0.99

Note. The two-way mixed model (Absolute Agreement Definition) was used; [a] $p \leq 0.05$.

Demographic characteristics of the participants. A total of 57 participants was recruited to complete the IE competence test. All of them were people with mild- or moderate-grade mental retardation. Majority of the participants (74.4%) were between 14 and 17 years old. Their mean age was 17.2 (SD = 3.3), and their mean number of years of special education was 6.9 (SD = 2.7). Moreover, their average time spent (in the past three months) on the computer per week was 4.0 hours (SD = 2.9). The participants were further divided into high (n = 30) and low IQ (n = 27) groups (based on TONI-3 score = 70 as the cut-off; Brown et al., 1997); their demographic characteristics are summarized in Table 4.4, from which it is indicated that there were no significant differences in gender composition, age, education, and computer usage between the two groups.

Table 4.4

Demographic characteristics of the participants in the high and low IQ groups

	High IQ Group (n = 30) Mean (SD)	Low IQ Group (n = 27) Mean (SD)	F [a] or χ^2 [b]	df	p
Age (years)	16.80 (3.34)	17.56 (3.29)	0.394 [a]	55	0.39
Education (years)	7.10 (1.71)	6.70 (3.48)	0.582 [a]	55	0.58
Computer usage (hrs/week)	4.62 (3.15)	3.37 (2.36)	0.099 [a]	55	0.10
Gender					
Male	21	18	0.073 [b]	1	0.99
Female	9	9			

IE task performance. There were variations in the scores of the participants on the IE competence test. The highest scores were on *close Web browser* (mean = 3.74), whereas the lowest scores were on *general language functions* (mean = 2.78) (Table 4.5). Logistic regression (forward stepwise) was then used to provide information on the possible reduction in the number of IE tasks for the next stage of analysis. All the 16 IE tasks were the predictor variables, and the participants' group membership was the dependent variable. Group membership was determined according to the high or low IQ category using the TONI-3 score of 70 as the cut-off. The overall model was significant, with one constant and two task predictors (χ^2 = 38.35, df = 2, p < 0.001). The two significant tasks for predicting the memberships of the participants were "General motor functions" (b = -3.43, SE = 1.59) and "use customized bookmark" (b = -3.54, SE = 1.06). The accuracy of the prediction model was 80.7%, yielding a sensitivity of 0.81 and a specificity of 0.80 (Table 4.6). As a result, these two tasks were used to further explore the participants' performance level in carrying out the IE tasks. The Hosmer-Lemeshow statistic was then used to formally evaluate the goodness of fit for the logistic regression model. The result of this test did not reject the goodness of fit (χ^2 = 4.44, df = 7, p = 0.728), indicating that our observed distribution of categorical variables fits the theoretical distribution predicted in our logistic regression model.

Table 4.5

Participants' mean scores on the IE competence test

IE tasks	Mean	SD
Close Web browser	3.74	0.50
Shut down the computer	3.67	0.46
Turn on the computer	3.66	0.33
General motor functions	3.66	0.45
Direct print	3.61	0.48
Respond to the dialogue box	3.61	0.45
Start Web browser	3.54	0.69
Use customized bookmark	3.40	0.57
General orientation and recognition	3.38	0.51
Add bookmark	3.35	0.52
Use search engine	3.25	0.53
Indirect print	3.24	0.43
Save Web site	3.23	0.44
Open saved Web site	2.96	0.64
Explore Web site	2.82	0.76
General language functions	2.78	0.94

Table 4.6

Logistic regression analysis on IE task performance

	Variables in the equation				
Variables	b	SE	df	p	Exp(b)
General motor functions	-3.432	1.587	1	0.031	0.032
Use customized bookmark	-3.542	1.061	1	0.001	0.029
Constant	24.955	7.324	1	0.001	

Classification:

	Predicted	
Observed	High IQ group	Low IQ group
High IQ group	24	6
Low IQ group	5	22

Dependent variable: Group membership using TONI-3 cut-off score = 70

Clustering based on IE task performance. Hierarchical cluster analysis and decision-tree classification were used to investigate to what extent the participants performed differently on the IE tasks. The results of the previous analysis suggested that "general motor functions" and "use customized bookmark" were the two tasks that were significantly associated with the intellectual functions of the participants. Therefore, only these two tasks were entered into the next stage of the statistical analysis. Hierarchical cluster analysis was used to classify the IE performance of the participants based on the two predicted tasks model. The hierarchical agglomerative procedure, using Ward's method (Ward, 1963), was chosen for clustering; this optimized the minimum variance within clusters. The determination of the number of cluster solutions was based on the visual inspection of the dendrogram, and then this was confirmed by a more formal approach, that is, the examination of the pattern of changes in the plot of the number of clusters versus the fusion coefficient (Aldenderfer & Blashfield, 1987).

Upon visual inspection of the dendrogram tree, two major clusters at one level could be recognized, and there could possibly be three if different levels of the tree are considered. To decide whether the two- or three-cluster solution was more appropriate, the graph of the number of clusters against the fusion coefficient was investigated by using the method which is analogous to the "screen test" of factor analysis. A marked "flattening" observed in the three-cluster solution suggested that three clusters are present in the data. The three clusters included the high ($\underline{n}$ = 30), medium ($\underline{n}$ = 16), and low ($\underline{n}$ = 11) cluster groups. External validation of this three-cluster solution was performed using one-way MANOVA, in which the variables used for the external validation were the remaining 14 IE tasks in the IE competence test that were not included in the cluster procedure. MANOVA revealed a statistically significant group effect on the performances of the participants on the 14 IE tasks (Pillai's trace: $F(28, 84) = 3.62$, $p < 0.001$). Moreover, univariate F tests and pairwise comparisons further indicated statistically significant differences among these three clusters ($F(2, 54) = 12.93$- 45.80, $p < 0.001$) in all 14 IE tasks (Table 4.7).

Table 4.7

Comparison of the 14 IE tasks among three clusters

	Low Cluster (L) (n = 11) Mean (SD)	Medium Cluster (M) (n = 16) Mean (SD)	High Cluster (H) (n = 30) Mean (SD)	F [a]	Pairwise [b]
General orientation and recognition	2.79(0.52)	3.30(0.47)	3.64(0.29)	18.88	LxM*, LxH**, MxH*
General language functions	1.68(0.57)	2.50(0.92)	3.33(0.59)	24.45	LxM*, LxH**, MxH**
Shut down the computer	2.99(0.58)	3.73(0.23)	3.89(0.16)	35.50	LxM**, LxH**
Turn on the computer	3.30(0.47)	3.63(0.18)	3.81(0.16)	14.23	LxM*, LxH**
Start Web browser	2.52(0.72)	3.67(0.49)	3.84(0.32)	33.39	LxM**, LxH**
Close Web browser	3.03(0.74)	3.85(0.30)	3.94(0.13)	26.17	LxM**, LxH**
Add bookmark	2.61(0.56)	3.35(0.25)	3.61(0.31)	31.27	LxM**, LxH**
Explore Web site	1.96(0.32)	2.59(0.57)	3.27(0.64)	22.80	LxM*, LxH**, MxH**
Direct print	3.00(0.58)	3.56(0.29)	3.86(0.27)	23.73	LxM**, LxH**, MxH*
Indirect print	2.72(0.55)	3.23(0.24)	3.45(0.29)	18.50	LxM**, LxH**
Save Web site	2.67(0.48)	3.16(0.18)	3.47(0.30)	26.85	LxM**, LxH**, MxH*
Open saved Web site	2.14(0.58)	2.90(0.45)	3.30(0.43)	24.69	LxM**, LxH**, MxH*
Use search engine	2.49(0.42)	3.17(0.22)	3.58(0.33)	45.80	LxM**, LxH**, MxH**
Response to the dialogue box	3.09(0.56)	3.67(0.38)	3.77(0.29)	12.93	LxM**, LxH**

[a] $p \leq 0.001$

[b] Pairwise adjusted Bonferroni p-level: * $p \leq 0.05$, ** $p \leq 0.001$

The decision-tree method was used to further verify the results obtained from the cluster analysis. The cut-off score used for the general motor function task was 25 (out of 32), and for the use customized bookmark task, it was 24 (out of 28; Figure 4.2). The general motor function task was useful for separating participants into low- (n = 11) and medium-performance (n = 18) groups. In contrast, the use customized bookmark task was useful for separating participants into medium- and high-performance (n = 28) groups. The consistency of the classifications from the cluster analysis and decision-tree methods using κ-coefficient was 0.91, which was excellent (Table 4.8).

Figure 4.2

Decision-tree method for the classification of IE performance groups

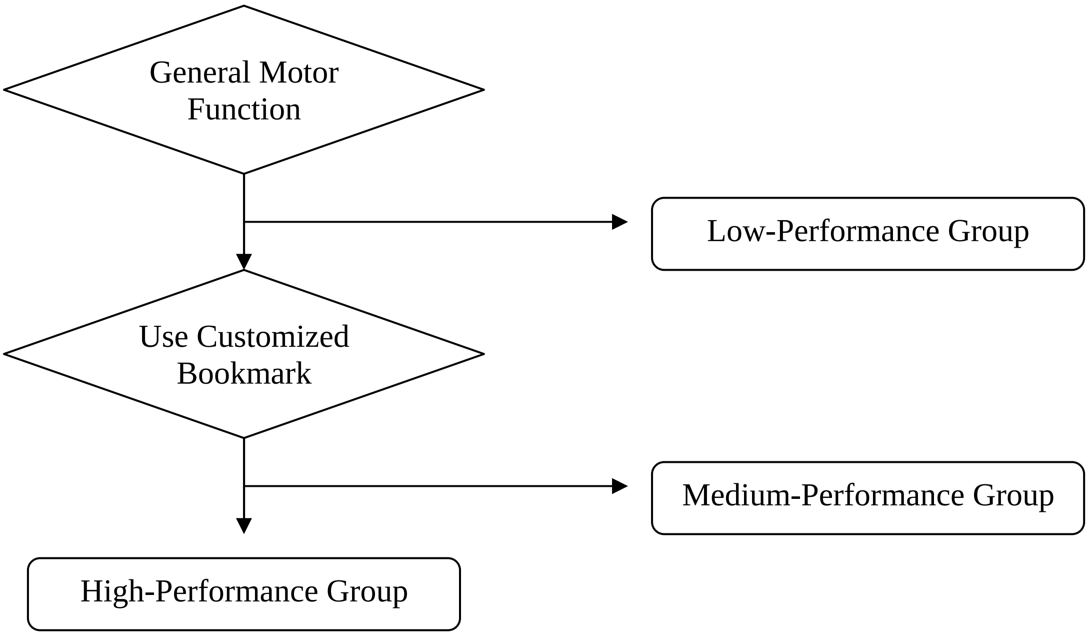


Table 4.8

Classification between cluster analysis and decision-tree classification

Decision-Tree Classification	Cluster Analysis		
	Low Cluster	Medium Cluster	High Cluster
Low-Performance Group	10		1
Medium-Performance Group	1	16	1
High-Performance Group			28

Note: κ-coefficient = 0.914

There were significant differences in the mean intellectual functioning measured by TONI-3 among the three groups ($F(2,54) = 23.54$, $p < 0.001$). The high-performance group (mean = 76.61; SD = 4.98) had a significantly higher intellectual functioning than the medium-performance group (mean = 70.50; SD = 4.60) and the low-performance group (mean = 66.27; SD = 2.83; ps < 0.001). Particularly, the intellectual functioning of the medium-performance group was marginally more significant than that of the low-performance group ($p = 0.055$).

The mean scores of the three groups on the general motor functions and use customized bookmark tasks were tested with two separate one-way ANOVAs. The results indicated significant differences among the three groups both in the general motor functions ($F(2,54) = 89.54$, $p < 0.001$) and use customized bookmark tasks ($F(2,54) = 57.02$, $p < 0.001$). Furthermore, posthoc comparisons indicated that the low-performance group (mean = 2.88 on the general motor function task; mean = 2.74 on the customized bookmark function task) scored significantly lower on both of these two tasks than the medium group (mean = 3.76 on the general motor function task; mean = 3.10 on the customized bookmark function task) and the high group (mean = 3.90 on the general motor function task; mean = 3.86 on the customized bookmark function task). The high group scored significantly higher than the medium group in the use customized bookmark task but not in the general motor function task (Table 4.9).

Table 4.9

Comparisons of IE task performance among the low-, medium-, and high-performance groups

IE Task	Low (L) (n = 11) Mean (SD)	Medium (M) (n = 18) Mean (SD)	High (H) (n = 28) Mean (SD)	F [a]	Pairwise[b]
General motor function	2.88(0.29)	3.76(0.24)	3.90(0.17)	89.54	LxM**, LxH**
Use customized bookmark	2.74(0.65)	3.10(0.22)	3.86(0.16)	57.02	LxM*, LxH**, MxH**

Note. [a] $p < 0.001$; [b] Pairwise adjusted Bonferroni values: * $p \leq 0.05$, ** $p \leq 0.001$

Conclusion

There are several observations derived from the survey, the expert panel review, and the field test. First, the operation of IE was found to be the common computer utilization of people with mental retardation. Second, the operation of IE can be broken down into at least 16 tasks, in which people with mental retardation would have varied performance levels when carrying out these tasks. Third, the performance of these 16 IE tasks required various levels of physical and mental abilities, though it required fewer motor abilities than cognitive abilities. Among all participants, it was found that orientation, visual acuity, and attention abilities were required most for all the tasks, followed by word recognition and working memory. Fourth, the general motor function and use customized bookmark tasks were found to be the two tasks that were critical for classifying participants into different group memberships for operating IE.

Study Two

Selection of Participants for the Analysis

The purpose of the analysis was to identify the core cognitive abilities predictive of the level of performance of participants in operating IE. Of the original 70 participants, 2 were unable to perform in at least two thirds of the 13 tests. These 2 participants were excluded from the subsequent data analysis. The 68 remaining participants were divided into high and low IQ groups (using TONI-3 score = 70 as the cut-off; Brown et al., 1997). The 35 participants in the low IQ group were found to be significantly older than those in the high IQ group (mean age = 16.3 (SD = 5.38) for high IQ group versus 20.9 (SD = 8.6) for low IQ group). To eliminate the potential confounding effect of age, we removed 6 participants who had the oldest age from the low IQ group. The demographic data on the revised group memberships are summarized in Table 4.10. There were 33 participants in the high IQ group and 29 participants in the low IQ group. Forty were male and 22 were female. Their mean age was 17.4 (SD = 6.0), and the mean number of hours spent (in the past 3 months) on the computer per week was 4.1 (SD = 2.8). All remaining 62 participants had successfully completed all cognitive and motor tests.

Table 4.10

Demographic characteristics of the participants in the revised high and low IQ groups

Tests	High IQ Group (n = 33) M (SD)	Low IQ Group (n = 29) M (SD)	t [a] or χ^2 [b]	df	p
Age (years)	16.27 (5.38)	18.62 (6.46)	-1.56 [a]	60	0.12
Education (years)	7.12 (1.78)	7.79 (1.74)	-1.5 [a]	60	0.14
Computer use (hrs/week) [c]	4.45 (3.05)	3.69 (2.54)	1.06 [a]	60	0.29
Gender					
Male	22	18	0.14 [b]	1	0.79
Female	11	11			

Note. [c] In the past three months.

Individual Abilities— Overall IE Performance

The IE competence test was conducted, and all participants performed the 16 IE tasks. On the average, the test took about 1 hour to complete. The overall IE performance score was then computed. The results indicated that the participants in the high IQ group (mean = 571.0; SD = 43.8) performed significantly better in the test than those in the low IQ group (mean = 496.2; SD = 72.0) ($t(60) = 5.006$, $p < 0.001$).

Individual Abilities—Cognitive and Motor Profiles

A total of 13 common clinical tests were used to establish the cognitive and motor profiles of the participants with mental retardation. These test results were used to predict the participants' performance level in operating IE. The descriptive statistics on the scores of the participants in these tests are grouped according to the predominant cognitive domains (Table 4.11). The results from several independent-sample *t* tests indicated that the performances in almost all cognitive and motor tests of people in the high IQ group were significantly better than those of people in the low IQ group ($t(60) = -5.44$ to 6.32, $ps \leq 0.017$).

Table 4.11

Participants' scores in the cognitive and motor test

Tests [a]	Total (n = 62) Mean (SD)	High IQ Group (n =33) Mean (SD)	Low IQ Group (n =29) Mean (SD)	t
Attention				
DSF— Span	5.40(2.05)	6.30 (1.67)	4.38 (1.99)	4.14 [d]
DSF—Seq	5.29 (1.99)	6.18 (1.59)	4.28 (1.94)	4.24 [d]
CTT—A	143.03 (84.76)	96.64 (47.03)	195.83 (87.75)	-5.44 [d]
SART	14.95 (5.81)	14.70 (5.74)	15.24 (5.97)	-0.37
SDMT	18.34 (9.79)	24.09 (8.54)	11.79 (6.48)	6.32 [d]
DVT	40.69 (36.57)	29.06 (25.89)	53.93 (42.50)	-2..74 [d]
Visual-spatial				
JLO	25.21 (13.24)	31.39 (11.58)	18.17 (11.49)	4.50 [b]
Cognistat—C	1.48 (1.60)	2.09 (1.67)	0.79 (1.21)	4.51 [b]
HVOT	12.44 (4.72)	14.03 (4.43)	12.55 (2.49)	3.02 [b]
Language				
Cognistat—Comp	3.69 (1.52)	4.39 (1.52)	2.90 (1.08)	4.51 [c]
Cognistat—R	2.48 (1.91)	3.24 (1.84)	1.62 (1.61)	3.67 [c]
Cognistat—N	3.94 (1.07)	4.15 (0.91)	3.69 (1.20)	1.69
CCT	63.98 (40.85)	79.70 (38.58)	46.09 (36.23)	3.52 [c]
Memory				
Cognistat—M	5.98 (3.93)	7.24 (3.86)	4.55 (3.55)	2.84 [b]
DSB—Span	2.37 (1.86)	3.21 (1.69)	1.41 (1.57)	4.32 [b]
DSB—Seq	1.98 (1.67)	2.79 (1.58)	1.07 (1.28)	4.67 [b]
Executive Function				
Cognistat—S	1.87 (1.90)	2.70 (1.94)	0.93 (1.36)	4.18 [c]
Cognistat—J	1.29 (1.45)	1.85 (1.46)	0.66 (1.17)	3.51 [c]
CTT—B-A	87.32 (55.30)	78.64 (49.19)	97.21 (60.88)	-1.33
CST	20.76 (28.07)	18.76 (17.66)	23.03 (36.75)	-0.60
Psychomotor				
MAND—FM	269.44 (65.05)	294.58 (59.89)	240.83 (59.39)	3.54 [e]
MAND—GM	196.18 (56.68)	210.94 (49.23)	179.38 (60.68)	2.26
VMI	13.63 (3.11)	14.58 (3.33)	12.55 (2.49)	2.68
PP—DH	8.19 (2.33)	9.12 (2.41)	7.14 (1.75)	3.67 [e]
PP—NH	8.21 (2.66)	9.06 (2.68)	7.24 (2.31)	2.84
PP—BH	6.18 (2.06)	7.06 (1.78)	5.17 (1.91)	4.02 [e]
PP—A	14.95 (5.38)	16.70 (5.83)	12.97 (4.07)	2.88

Note: [a] DSF—Span = Digit Span Forward (span score); DSF—Seq = Digit Span Forward (sequence score); CTT—A = Part A of Color Trails Test (total time); SART = Sustained Attention to Response Task (commission error); SDMT = Symbol Digital Modalities Test Written Version (total score); DVT = Digit Vigilance Test (omission error); JLO = Judgment of Line Orientation (correct score); Cognistat—C = Cognistat—Construction subtest (metric score); HVOT = Hooper Visual Organization Test (total score); Cognistat —Comp = Cognistat—Comprehension subtest (metric score); Cognistat—R = Cognistat —Repetition subtest (metric score); Cognistat—N = Cognistat—Naming subtest (metric score); CCT = Chinese Characters Test (total score); Cognistat—M = Cognistat—Memory subtest (metric score); DSB—Span = Digit Span Backward (span score); DSB—Seq = Digit Span Backward (sequence score); Cognistat—S = Cognistat—Similarities subtest (metric score); Cognistat—J = Cognistat—Judgment subtest (metric score); CTT—B-A = Part B minus Part A of Color Trails Test (interference time score); CST = Chinese version (CST) of the Stroop Color-Word Test Victoria Version (interference time score); MAND—FM = McCarron Assessment of Neuromuscular Development—Fine Motor total score; MAND—GM = McCarron Assessment of Neuromuscular Development—Gross Motor total score; VMI = Development Test of Visual-Motor Integration (total score); PP—NH = Purdue Pegboard (nondominant hand score); PP—DH = Purdue Pegboard (dominant hand score); PP—BH = Purdue Pegboard (both hands score); and PP—A = Purdue Pegboard (assembly task score).

[b] $p \leq 0.05/3 = 0.017$ (The alpha levels were adjusted in the visual-spatial and memory domains.)

[c] $p \leq 0.05/4 = 0.013$ (The alpha levels were adjusted in the language and executive function domains.)

[d] $p \leq 0.05/6 = 0.008$ (The alpha level was adjusted in the attention domain.)

[e] $p \leq 0.05/7 = 0.007$ (The alpha level was adjusted in the psychomotor domain.)

Cognitive Correlates of Overall IE Performance

The relationships between the cognitive and motor abilities and overall IE performance of people with mental retardation are presented as Pearson's correlation coefficient (r) (Table 4.12). In the attention domain, all test scores entered were significantly correlated with the overall IE performance score (r = 0.471 to 0.705, $ps \leq 0.001$) except the SART (commission error; r = -0.200, $p \geq 0.01$). Among the visual-spatial function domain, all variables were significantly correlated with the overall IE performance score (r = 0.407 to 0.520, $ps \leq 0.001$). For the language or word recognition domain, all test scores entered were significantly correlated with the overall IE performance score (r = 0.363 to 0.597, $ps \leq 0.01$). In the memory domain, all test scores entered were significantly correlated with the overall IE performance score (r = 0.429 to 0.551, $ps \leq 0.001$). In the executive function domain, the similarities and judgment subtests of the Cognistat were significantly correlated with the overall IE performance score (r = 0.439 to 0.453, $ps \leq 0.001$), but the interference time scores of the CTT and the CST were not significantly correlated ($\underline{r}$ = -0.068-0.018, $\underline{p}$s > 0.01). In the psychomotor function domain, all test scores were significantly associated with the overall IE performance score ($\underline{r}$ = 0.429 to 0.611, $\underline{p}$s $\leq$ 0.001).

Table 4.12

Relationships between cognitive and motor functions and overall IE performance

Tests [a]	Overall IE Performance Score Pearson's r
Attention	
DSF—Span	0.534 [c]
DSF—Seq	0.524 [c]
CTT—A	-0.553 [c]
SART	-0.200
SDMT	0.705 [c]
DVT	-0.471 [c]
Visual-spatial	
JLO	0.520 [c]
Cognistat—C	0.407 [c]
HVOT	0.422 [c]
Language	
Cognistat—Comp	0.558 [c]
Cognistat—R	0.478 [c]
Cognistat—N	0.363 [b]
CCT	0.597 [c]
Memory	
Cognistat—M	0.429 [c]
DSB—Span	0.551 [c]
DSB—Seq	0.549 [c]
Executive Function	
Cognistat—S	0.439 [c]
Cognistat—J	0.453 [c]
CTT—B-A	-0.068
CST	0.018
Psychomotor	
MAND—FM	0.611 [c]
MAND—GM	0.585 [c]
VMI	0.455 [c]
PP—DH	0.476 [c]
PP—NH	0.429 [c]
PP—BH	0.554 [c]
PP—A	0.458 [c]

Note: [a] DSF—Span = Digit Span Forward (span score); DSF—Seq = Digit Span Forward (sequence score); CTT—A = Part A of Color Trails Test (total time); SART = Sustained Attention to Response Task (commission error); SDMT = Symbol Digital Modalities Test Written Version (total score); DVT = Digit Vigilance Test (omission error); JLO = Judgment of Line Orientation (correct score); Cognistat—C = Cognistat—Construction subtest (metric score); HVOT = Hooper Visual Organization Test (total score); Cognistat – Comp = Cognistat—Comprehension subtest (metric score); Cognistat—R = Cognistat— Repetition subtest (metric score); Cognistat—N = Cognistat—Naming subtest (metric score); CCT = Chinese Characters Test (total score); Cognistat—M = Cognistat—Memory subtest (metric score); DSB—Span = Digit Span Backward (span score); DSB—Seq = Digit Span Backward (sequence

score); Cognistat—S = Cognistat—Similarities subtest (metric score); Cognistat—J = Cognistat—Judgment subtest (metric score); CTT—B-A = Part B minus Part A of Color Trails Test (interference time score); CST = Chinese version (CST) of the Stroop Color-Word Test Victoria Version (interference time score); MAND—FM = McCarron Assessment of Neuromuscular Development—Fine Motor total score; MAND—GM = McCarron Assessment of Neuromuscular Development—Gross Motor total score; VMI = Development Test of Visual-Motor Integration (total score); PP—NH = Purdue Pegboard (nondominant hand score); PP—DH = Purdue Pegboard (dominant hand score); P —BH = Purdue Pegboard (both hands score); and PP—A = Purdue Pegboard (assembly task score).
[b] $p \leq 0.01$
[c] $p \leq 0.001$

Cognitive Functions Predictive of Overall IE Performance

To determine the relative importance of different cognitive functions in predicting the performances of the participants with mental retardation when operating Internet Explorer, separate multiple regression analyses were conducted for each of the six cognitive domains on the overall IE performance score. The six domains were attention, visual-spatial, language or word recognition, memory, executive function, and psychomotor. For the attention domain, the SDMT was entered in the first step. This was followed by the DSF-Span, the SART, and then the DVT. All the predictors in the regression equation were significant ($R^2 = 0.609$, Model $F(4, 57) = 22.196$, $p < 0.001$), but the SDMT test score was found to have contributed most (49.7%) to the total variance. For the visual-spatial domain, the JLO test score was the only significant predictor for the overall IE performance score ($R^2 = 0.27$, Model $F(1, 60) = 22.213$, $p < 0.001$). For the language or word recognition domain, the CCT test score was entered first, followed by the Cognistat-Comp test score. Two predictors in the regression equation were significant ($R^2 = 0.461$, Model $F(2, 59) = 25.183$, $p < 0.001$], in which the CCT score alone accounted for 35.7% of the total variance. For the memory domain, the DSB-Span test score was found to be the only significant predictor ($R^2 = 0.304$, Model $F(1, 60) = 26.150$, $p < 0.001$). For the executive function domain, the Cognistat—J test score was the only significant predictor (R^2 = 0.205, Model $F(1, 60) = 15.454$, $p < 0.001$). For the psychomotor domain, the MAND—FM test score was entered into the regression equation first, followed by the MAND—GM test score. All the predictors in the equation were significant (R^2 = 0.416, Model $F(2, 59) = 20.977$, $p < 0.001$), while the MAND—FM test score alone contributed most (37.4%) to the total variance. In each of the above six prediction equations, the largest value of the variance inflation factors was <7, indicating that multi-collinearity among the predictors did not unduly affect the regression estimates (Neter, Kutner, Nachtsheim, & Wasserman, 1996).

Based on the strongest predictors in each of the six cognitive domains, an overall regression analysis was conducted for predicting the overall performance score. The strongest predictors (with the highest R^2 value) in each of these six cognitive domains were the predictors entered into the overall regression equation. Entering these six predicted task scores in a stepwise fashion, the overall model was significant (R^2 = 0.586, Model $F(3, 58) = 27.399$, $p < 0.001$) in which three test scores, SDMT (R^2 = 0.497), MAND—FM (R^2 = 0.058), and CCT (R^2 = 0.032), were found to be the significant predictors of the overall IE performance score (Table 4.13). Based on the predictors in the final regression equation, we found that SDMT contributed most (49.7%) to the total variance. Again, the largest value of the variance inflation factors in the overall regression equation was <7, indicating that multi-collinearity among the predictors did not influence the regression estimates (Neter et al., 1996). The SDMT is a test to measure complex visual scanning ability (Smith, 1991). This visual scanning ability was considered the best cognitive function to predict performance in the operation of IE among people with mental retardation. This result suggests that further investigation on visual search ability should be conducted in a later part of this dissertation.

Table 4.13

Multiple regression analysis on overall IE performance by the strongest predictors in each of the six cognitive domains

Variables [b]	Variables in the equation [a]				
	B	SE	Beta	t	p
Constant	380.908	25.294		15.059	< .001
SDMT	2.843	.854	.402	3.328	.002
MAND—FM	.290	.113	.272	2.576	.013
CCT	.389	.184	.229	2.12	.038

Note: [a] Dependent variables: Overall IE Performance Score; [b] SDMT = Symbol Digital Modalities Test Written Version (total score); MAND—FM = McCarron Assessment of Neuromuscular Development—Fine Motor total score; CCT = Chinese Characters Test (total score).

Conclusion

The cognitive and motor profiles relevant for computer use were developed for the participants. The results revealed that different cognitive and motor abilities were significantly correlated with the performance of the participants in the IE competence test. There are several observations to be made from these results. First, almost all test scores in these six cognitive domains, including attention, visual-spatial, language or word recognition, memory, executive function, and psychomotor function, were found to be significantly correlated with the performances in operating IE. Second, among all the tests included in these six cognitive domains, the visual search function measured by SDMT, the word recognition ability measured by CCT, and the fine-motor ability measured by MAND were found to be the three strongest cognitive functions in predicting the IE operations of the participants. Among these three strongest predictors, the visual search function measured by SDMT was found to be the best predictor of the participants' performances. This cognitive ability was selected for in-depth study in the last part of the dissertation.

Study Three

Demographic Characteristics of the Participants

Twenty-four people with mental retardation (male = 16 and female = 8) participated in this study. Of this number, 21 had already participated in Study 2. Thirty people without mental retardation (male = 16 and female = 14), who served as controls, were also recruited. All participants were invited to participate in two laboratory-based experiments: visual search and visual lobe mapping.

All the participants with mental retardation had a mild or moderate grade of retardation. They were recruited through the computer training program serving people with mental retardation, which is offered by a colleague of the author at The Hong Kong Polytechnic University. The mean age of the participants was 19.0 (SD = 5.4,) and their mean intelligence score was 74.4 (SD = 5.9) as measured by TONI-3. All participants without mental retardation were undergraduate students of The Hong Kong Polytechnic University. Their mean age was 20.8 years (SD = 1.9), and their mean intelligence score was 123.0 (SD = 12.3), which is the average standard score from TONI-3. All participants had normal or corrected-to-normal visual acuity, and none were colorblind.

Visual Search Task

Attention correlates of visual search performance. Attention is viewed as involving specialized networks (attention networks) to carry out specific functions. These networks include a vigilance network for achieving and maintaining the alert state, an orienting network for familiarizing with sensory events, and an executive network for controlling brain areas to perform complex cognitive tasks. The cognitive tests from these networks were used to correlate with the test scores of the eye-tracking parameters by the Pearson product-moment correlation. The test scores of the SART (measure of vigilance network), the time score of Part A of the CTT (orienting network), the interference score of the CTT (executive attention network), the test scores of the DSB (supervisory attentional control of working memory), and the eye movement parameters yielded by the visual search task were used for analysis. The participants' scores in Part A of the CTT (orienting network) were found to be significantly correlated with the overall number of fixations, the scanpath duration, and the overall fixation duration (r = 0.590-0.661, ps < 0.01; Table 4.14). In addition, the CTT (executive network) interference score was also significantly correlated with the scanpath duration, the overall fixation duration, and the fixation duration of the first target (r = 0.605-0.652, ps < 0.01). The span and sequence scores of the DSB were significantly correlated with the scanpath duration, the overall fixation duration, the fixation duration of the first target, and the fixation duration of the second target (r = -0.568- -0.736, ps < 0.01 for span score; r = -0.645- -0.726, ps < 0.01 for sequence score).

Table 4.14

Correlation of various measures of the attention network and eye movement parameters

Eye movement variables	Measures of attention network [a]				
	SART	CTT-A	CTT-B-A	DSB-Span	DSB-Seq
Overall number of fixations [b]	0.078	0.661 [f]	0.207	-0.325	-0.343
Scanpath duration [c]	-0.100	0.615 [g]	0.652 [f]	-0.736 [f]	-0.724 [f]
Overall fixation duration [d]	-0.080	0.590 [g]	0.639 [g]	-0.719 [f]	-0.712 [g]
Fixation duration on first target [e]	-0.364	0.421	0.605 [g]	-0.568 [g]	-0.645 [g]
Fixation duration on second target [e]	-0.388	0.437	0.452	-0.683 [f]	-0.726 [f]

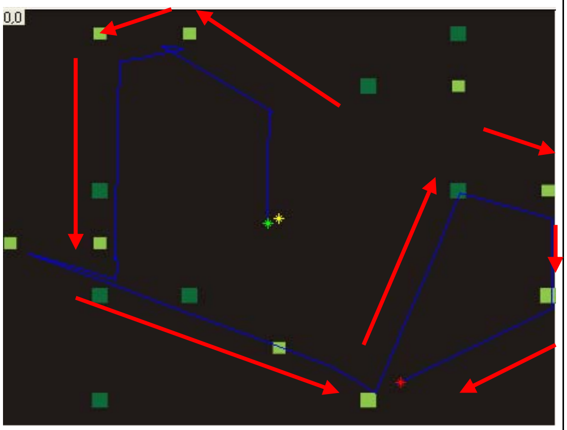
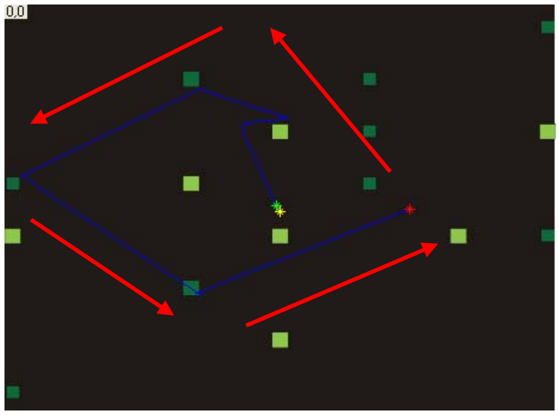
Note:
[a] SART = Sustained Attention to Response Task (commission error); CTT—A = Part A of Color Trails Test (total time); CTT—B-A = Part B minus Part A of Color Trails Test (interference time score); DSB—Span = Digit Span Backward (span score); DSB—Seq = Digit Span Backward (sequence score).
[b] An indicator of search efficiency. The greater the number of fixations reflected, the more objects the participant is required to sample before discovering both target stimuli.
[c] An indicator of the complexity of both the search and processing components. A longer scanpath duration indicated that the participant had more difficulty in searching and extracting/interpreting information from the spatial configuration of the display, which in turn reflected a higher working memory required for searching and processing the information.
[d] An indicator of the complexity of processing. A larger overall fixation duration signified that the participant had greater difficulty in extracting and interpreting items (including targets and nontargets) from the display, which in turn reflected a higher working memory required for processing the information.
[e] An indicator of the complexity of processing in the designated area of interest. A longer fixation duration on the first and second targets signified that the participant had greater difficulty in extracting and interpreting the first and second targets, respectively.
[f] $p < 0.001$
[g] $p \leq 0.01$

Search strategy of participants with and without mental retardation. The oculomotor scanpath of the participants without mental retardation was analyzed first. This involved the development of an initial categorization of the search strategies employed for performing the conjunctive search stipulated in the visual search task.

The results seemed to indicate that the participants without mental retardation tended to adopt a “circular” search to identify the target (Figure 4.3). Once the first target had been identified, the participants tended to identify the second target using at least four search strategies (85.6% of all the correct trials). In Strategy 1, the participants did not seem to form additional fixations on the nontarget area before they identified the second target and made the response. This search strategy follows the pattern Target A to Target B and was named the *AB strategy;* it comprised 27.6% of all the correct trials (Figure 4.4a). In Strategy 2, the participants appeared to form additional fixations on the nontarget area before identifying the second target and making the response. This search strategy follows the pattern Target A to Nontarget N to Target B, and was named the *ANB strategy;* it comprised 30.1% of all the correct trials (Figure 4.4b). In Strategy 3, the participants did not form additional fixations on nontarget areas before fixating on the second target, but they returned and formed fixations on the first target that they had previously inspected before making the response. This search strategy follows the pattern Target A to Target B to Target A, and was named the *ABA strategy;* it comprised 10.9% of all the correct trials (Figure 4.4c). In Strategy 4, the participants formed additional fixations on the nontarget area before they identified the second target, and they then returned and formed a fixation on the previously inspected first target before making the response. This search strategy follows the pattern Target A to Nontarget N to Target B to Target A, and it was named the *ANBA strategy;* it comprised 14.4% of all the correct trials (Figure 4.4d).

Figure 4.3

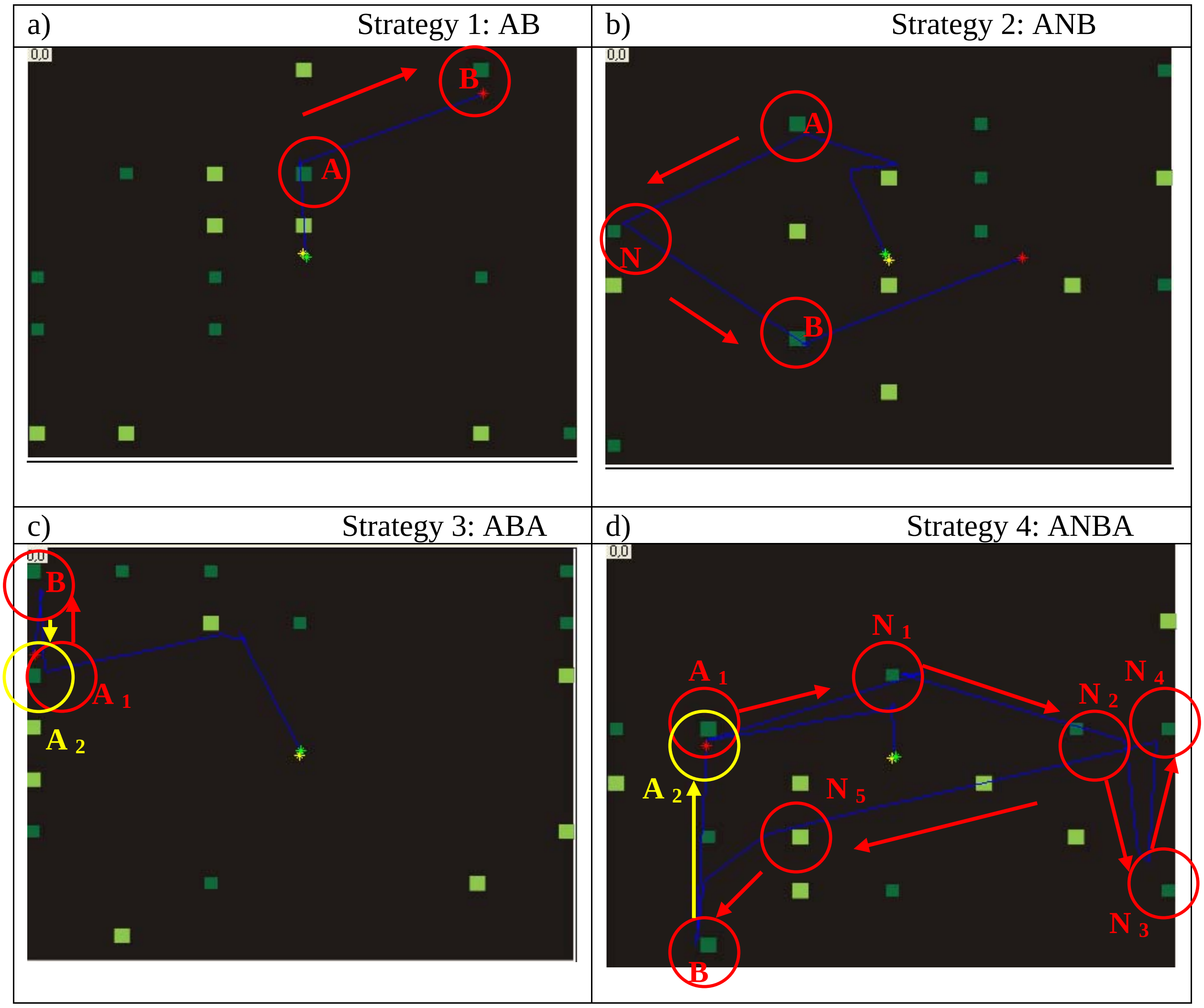
<u>Examples of the "circular" search strategy used by the participants without mental retardation</u>

Example 1	Example 2
	

<u>Note:</u>
The blue line represents the oculomotor scanpath traces; the green star represents the start of the trial; the red star represents the end of the trial; and the yellow star represents the center point.
The target stimuli are two "large and lime green" squares in Example 1, while the target stimuli are two "large and dark green" squares in Example 2.
The red arrows represent the direction of eye movement.

Figure 4.4

<u>Examples of typical search strategies for identifying the second target used by the participants without mental retardation</u>



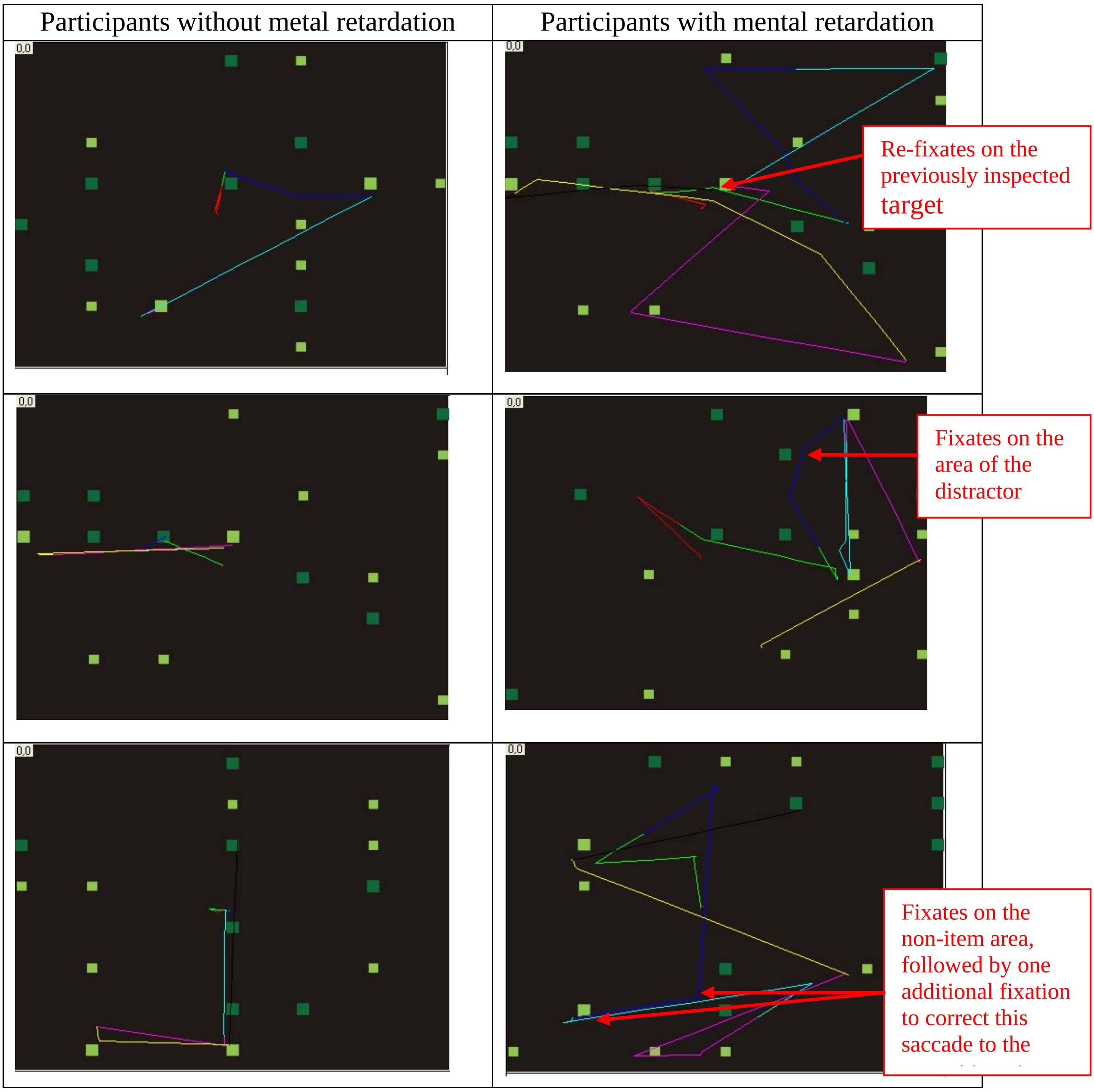
<u>Note:</u>
The target stimuli are two "large and dark green" squares; the blue line represents the eye movement traces; the green star represents the start of the trial; the red star represents the end of the trial; and the yellow star represents the center point.
The red arrows represent the direction of eye movement before fixating on the second target, while the yellow arrows represent the direction of eye movement for returning to the first target.
Red circles represent the fixation area, while yellow circles represent the refixation area.

The oculomotor paths of the participants with mental retardation were analyzed, and attempts were made to categorize their search strategies with reference to those identified for their normal counterparts. The results indicated that the participants with mental retardation (mean = 54.48%; SD = 19.09) were less likely to use the four typical search strategies than the participants without mental retardation (mean = 85.65%; SD = 8.40; $t(30.1) = 7.44$. $p < 0.001$). The participants with mental retardation were identified as having 11.36%, 21.90%, 6.84%, and 14.38% of all the correct trials using the AB, ABA, ANB, and ANBA search strategies, respectively. In addition, the participants with mental retardation tended to use more nonconsistent search strategies than their normal counterparts (Figure 4.5).

Visual inspection of the oculomotor scanpath suggested nonconsistent search strategies employed by these participants, in which they made additional fixations before identifying the second target and making the response. The additional fixations included the area of the previously inspected target, the location of distractors, and some blank areas that did not contain any targets or distractors (which demanded at least one corrective fixation(s) followed by this inaccurate fixation on this non-item area). The participants who employed the nonconsistent search strategies were described as using more ANB and ANBA strategies. The ratio of *trials requiring additional fixations* (ANB + ANBA) to *trials requiring no additional fixations* (AB + ABA) might shed light on this likelihood. The result from the independent-sample *t* test indicated that the participants with mental retardation (mean = 2.21; SD = 0.89) were significantly more likely to use nonconsistent search strategies ($t(27.7) = -4.96$, $p < 0.001$) than their normal counterparts (mean = 1.26; SD = 0.32).

Figure 4.5

<u>Examples of oculomotor paths from three randomly selected trials of the participants with and without mental retardation</u>



<u>Note:</u> The target stimuli are two "large and lime green" squares; the oculomotor scanpath follows the following color sequence: red→ green→ blue→ light blue→ pink→ yellow→ black.

Visual search performance among people with and without mental retardation. The visual search parameters included in the analysis were error rates, response time, overall number of fixations, scanpath duration between the two target stimuli, and overall fixation duration between the two target stimuli. For the analyses of error rates, all 432 trials were included. The results from the independent-sample *t* tests revealed that the participants with mental retardation had significantly higher error rates on the visual search task than those without mental retardation ($t(24.83) = -6.47$, $p < 0.001$; Table 4.15). For the analyses of response time, correct trials were used, but those with a response time greater than 2.5 times the mean of the remaining correct trials were excluded from the analysis (see Mast, Ganis, Christie, & Kosslyn, 2003). Moreover, the participants with mental retardation had significantly slower response times on the visual search task than those without mental retardation ($t(25.02) = -8.19$, $p < 0.001$). For the analyses of the overall number of fixations, the scanpath duration, and the overall fixation duration, only the correct trials with outliers excluded were entered into the analysis. The participants with mental retardation had a significantly longer scanpath duration ($t(26.29) = -8.66$, $p < 0.001$) and a longer overall fixation duration ($t(26.02) = -8.55$, $p < 0.001$) than their normal counterparts.

Table 4.15

Descriptive statistics of parameters for the participants with and without mental retardation

Tests	Participants with MR (n = 30) Mean (SD)	Participants without MR (n = 24) Mean (SD)	t
Error rates	0.15 (0.09)	0.04 (0.02)	-6.47 [a]
Response time (ms)	5004.44 (1306.15)	2774.10 (305.50)	-8.19 [a]
Overall number of fixations	22.49 (26.16)	9.86 (9.12)	-2.257
Scanpath duration (ms)	2181.08 (530.40)	1211.20 (158.38)	-8.66 [a]
Overall fixation duration (ms)	1846.92 (463.80)	1011.08 (132.63)	-8.55 [a]

Note: [a] $p \leq 0.001$

Efficiency of search across distances and orientations of the two target stimuli. A 3 (*distance:* close, medium, far) x 3 (*orientation:* horizontal, vertical, oblique) factorial ANOVA was conducted using SPSS 12.0. Among the participants without mental retardation, the main effect of *distance* was significant on the scanpath duration (Pillai's Trace: $F(2,28) = 43.69$, $p < 0.001$). Similarly, the effect of *orientation* was found to be significant on the scanpath duration (Pillai's Trace: $F(2,28) = 54.15$, $p < 0.001$).

The main effect of *distance* with Bonferroni's correction indicated that the participants without mental retardation had significantly longer scanpath durations in the far-distance condition (estimated mean = 1356.65; SE= 30.66) than in the close-distance condition (estimated mean= 1079.19; SE = 25.94) ($p<0.001$), in the far-distance condition than in the medium-distance condition (estimated mean = 1209.43; SE = 30.66) ($p<0.001$), and in the medium-distance condition than in the close-distance condition ($p<0.001$).

The main effect of *orientation* with Bonferroni's correction indicated that oblique (estimated mean = 1365.77; SE = 37.16; $p < 0.001$) and horizontal orientations (estimated mean = 1215.79; SE = 31.47; $p < 0.001$) had longer scanpath durations than their vertical counterparts (estimated mean = 1063.70; SE = 25.94). Furthermore, the oblique orientation had a longer scanpath duration than the horizontal one.

The interaction between the *distance* and *orientation* effects was also significant (Pillai's Trace: $F(4,26) = 4.85$, $p = 0.005$). Posthoc analyses with Bonferroni's correction indicated that the participants had significantly longer scanpath durations in the far-distance condition (mean = 1166.07; SD = 226.32 for vertical orientation, and mean = 1578.11; SD = 266.67 for oblique orientation) than in the close-distance condition (mean = 892.40; SD = 139.24 for vertical orientation, and mean = 1204.66; SD = 215.64 for oblique orientation) when the targets were arranged in vertical and oblique orientations ($ps < 0.001$), and in the medium-distance condition (mean = 1132.64; SD = 190.67) than in the close-distance condition (mean = 892.40; SD = 139.24) when the targets were arranged in vertical orientation ($ps < 0.001$). In the close-distance condition, oblique (mean = 1204.66; SD = 215.64) and horizontal (mean = 1140.50; SD = 230.65) orientations had significantly longer scanpath durations than their vertical counterparts (mean = 892.40; SD = 139.24; $ps \leq 0.001$). The far-distance and oblique-orientation condition (mean = 1578.11; SD = 266.67) had the longest scanpath duration of all nine conditions ($ps < 0.001$; Figure 4.6).

For the overall fixation duration, the main effects of *distance* (Pillai's Trace: $F(2,28) = 33.18$, $p < 0.001$) and *orientation* (Pillai's Trace: $F(2,28) = 41.38$, $p < 0.001$) were significant. The main effect of *distance* with Bonferroni's correction indicated that the participants without mental retardation had significantly longer fixation durations in the far-distance condition (estimated mean = 1107.38; SE = 31.38) than in the close-distance condition (estimated mean = 916.46; SE = 20.45; $p < 0.001$), in the far-distance condition than in the medium-distance condition (estimated mean =

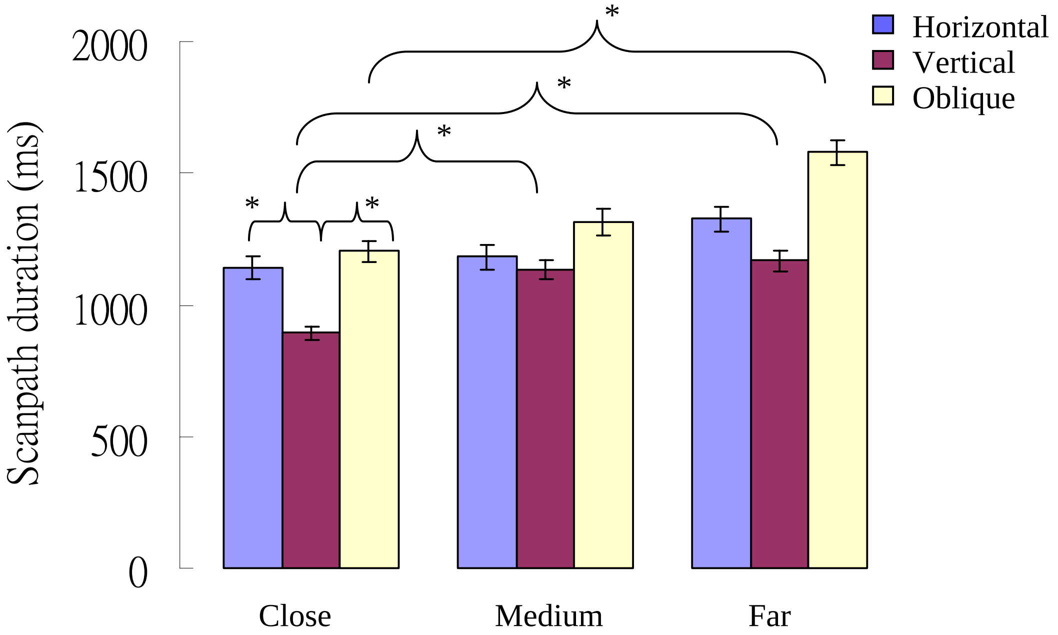
1015.87; SE = 26.33; $p < 0.001$), and in the medium-distance fixation durations than in the close-distance condition. Meanwhile, the main effect of *orientation* with Bonferroni's correction indicated that oblique (estimated mean = 1116.95; SE = 29.96; $p < 0.001$) and horizontal orientations (estimated mean = 1012.08; SE = 27.73; $p < 0.001$) had longer fixation durations than their vertical counterparts (estimated mean = 910.68; SE = 21.28). The oblique orientation had longer fixation durations than the horizontal one. The interaction between the effects of *distance* and *orientation* was also significant (Pillai's Trace: $F(4,26) = 4.65$, $p = 0.006$). Posthoc analyses with Bonferroni's correction indicated that the participants had significantly longer overall fixation durations in the far-distance condition (mean = 976.96; SD = 183.01 for vertical orientation, and mean = 1269.86; SD = 213.21 for oblique orientation) than in the close-distance condition (mean =784.95; SD = 118.82 for vertical orientation, and mean = 998.09; SD = 163.52 for oblique orientation) when the targets were arranged in vertical and oblique orientations ($ps < 0.001$), and longer durations in the medium-distance condition (mean = 970.13; SD = 157.86) than in the close-distance condition (mean = 784.95; SD = 118.82) when the targets were arranged in vertical orientation ($p < 0.001$). In the close-distance condition, oblique (mean = 998.09; SD = 163.52) and horizontal (mean = 966.35; SD = 188.35) orientations had significantly longer overall fixation durations than their vertical counterparts (mean = 784.95; SD = 118.82; $ps \leq 0.001$). The far-distance and oblique-orientation condition (mean = 1269.86; SD = 213.21) had the longest overall fixation duration of all the nine conditions ($ps < 0.001$; Figure 4.7).

To investigate whether or not the effect of the visual lobe in designing the study confounded the results, we used speed (taking into account the distance traveled) rather than time to repeat the 3 (*distance:* close, medium, far) x 3 (*orientation:*

horizontal, vertical, oblique) factorial ANOVA data analysis. Among the participants without mental retardation, the results on scanpath duration (after allowing for the distance traveled) were similar to the previous results. The main effect of *distance* was significant on scanpath duration (Pillai's Trace: $F(2,28) = 166.38$, $p < 0.001$). Similarly, the effect of *orientation* was found to be significant on scanpath duration (Pillai's Trace: $F(2,28) = 131.45$, $p < 0.001$). The interaction between the effects of *distance* and *orientation* was also significant (Pillai's Trace: $F(4,26) = 7.98$, $p < 0.001$). For the overall fixation duration (after taking into account the distance traveled), the results were similar to previous results. The main effects of *distance* (Pillai's Trace: $F(2,28) = 187.89$, $p < 0.001$) and *orientation* (Pillai's Trace: $F(2,28) = 176.01$, $p < 0.001$) were also significant. The interaction between the effects of *distance* and *orientation* was also significant (Pillai's Trace: $F(4,26) = 8.97$, $p < 0.001$). After taking into account the distance traveled, we found that the results on the main distance and orientation effects, as well as the distance x orientation interaction effect for the participants without mental retardation, were similar to previous ones. Therefore, the visual lobe in designing the study was not found to confound the effects of the distance and orientation of two target stimuli on modulating the visual search performances of the participants without mental retardation.

Figure 4.6

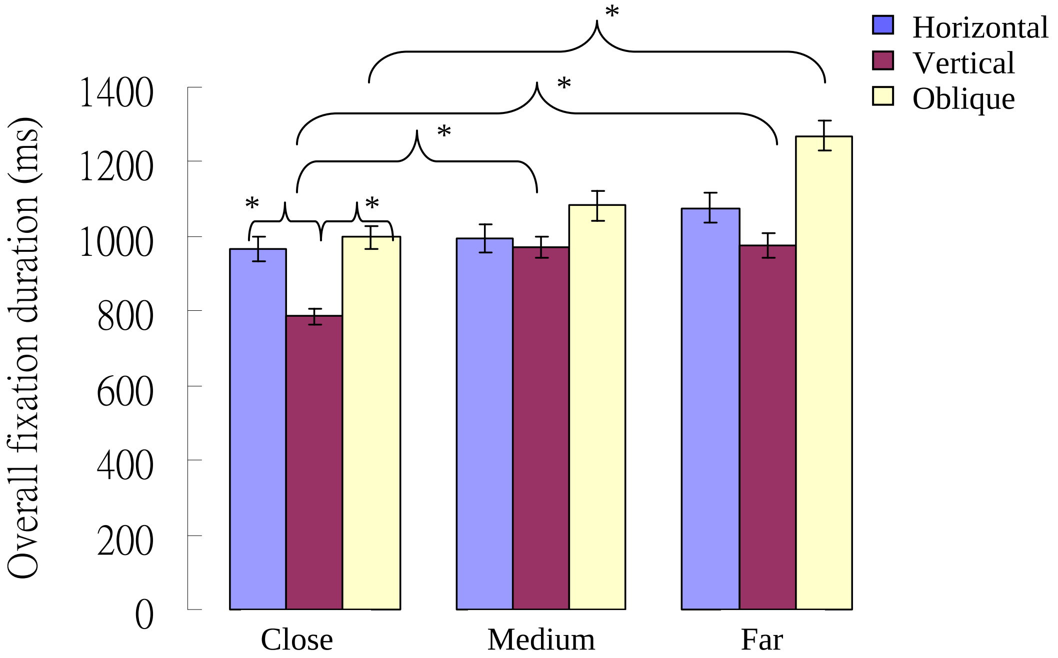
Mean scanpath duration of participants without mental retardation



Note: The error bars indicate the standard errors.
* The alpha level was adjusted for Bonferroni's correction.

Figure 4.7

Mean overall fixation duration of participants without mental retardation



Note: The error bars indicate the standard errors.
* Alpha level was adjusted for Bonferroni's correction.

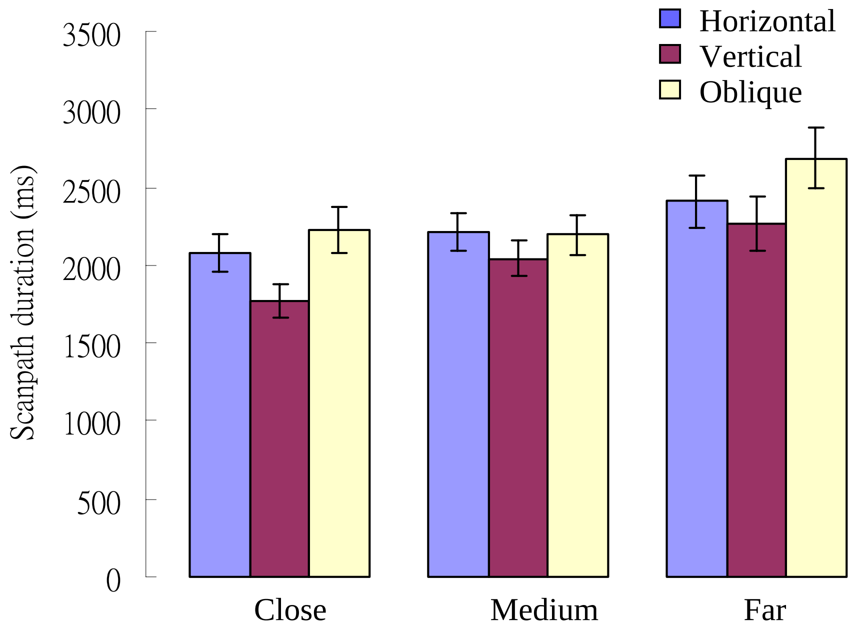
For the participants with mental retardation, the main effect of *distance* was significant on scanpath duration (Pillai's Trace: F(2,22) = 11.81, p < 0.001). Similarly, the effect of *orientation* was found to be significant on scanpath duration (Pillai's Trace: F(2,22) = 5.97, p = 0.008). The interaction between the effects of *distance* and *orientation* was, however, not statistically significant (Pillai's Trace: F(4,20) = 1.70, p = 0.189). The main effect of *distance* with Bonferroni's correction indicated that the participants with mental retardation had significantly longer scanpath durations in the far-distance condition (estimated mean = 2454.58; SE = 155.05) than in the close-distance condition (estimated mean = 2025.58; SE = 102.32; p ≤ 0.001), and in the far-distance condition (estimated mean = 2454.58; SE = 155.05) than in the medium-distance condition (estimated mean = 2147.81; SE = 104.23; p = 0.013). The main effect of *orientation* with Bonferroni's correction indicated that oblique (estimated mean = 2368.63; SE = 138.38; p = 0.008) and horizontal orientations (estimated mean = 2231.56; SE = 112.25; p = 0.034) had longer scanpath durations than their vertical counterparts (estimated mean = 2027.77; SE = 119.09; Figure 4.8).

For the overall fixation duration, the main effects of *distance* (Pillai's Trace: F(2,22) = 7.71, p = 0.003) and *orientation* (Pillai's Trace: F(2,22) = 4.91, p = 0.017) were significant. However, the interaction between the effects of *distance* and *orientation* was not statistically significant (Pillai's Trace: F(4,20) = 1.65, p = 0.200). The main effect of *distance* with Bonferroni's correction indicated that the participants with mental retardation had significantly longer scanpath durations in the far-distance condition (estimated mean = 2037.51; SE = 131.85) than in the close-distance condition (estimated mean = 1739.94; SE = 89.10; p = 0.002), and in the far-distance condition (estimated mean = 2037.51; SE = 131.85) than in the medium-distance condition (estimated mean = 1820.53; SE = 92.16; p = 0.038). The main effect of *orientation* with Bonferroni's correction indicated that oblique (estimated mean = 2368.63; SE = 138.38; $p = 0.026$) and horizontal orientations (estimated mean = 2231.56; SE = 112.25; $p = 0.03$) had longer scanpath durations than their vertical counterparts (estimated mean = 2027.77; SE = 119.09; Figure 4.9).

To investigate whether or not the effect of the visual lobe in designing the study confounded the results for the participants with mental retardation, we used speed (taking into account the distance traveled) rather than time to conduct another 3 (*distance:* close, medium, far) x 3 (*orientation:* horizontal, vertical, oblique) factorial ANOVA data analysis. The main effect of *distance* was significant on scanpath duration (Pillai's Trace: $F(2,22) = 92.23$, $p < 0.001$). Similarly, the effect of *orientation* was found to be significant on scanpath duration (Pillai's Trace: $F(2,22) = 57.86$, $p < 0.001$). The interaction between the effects of *distance* and *orientation* was not statistically significant (Pillai's Trace: $F(4,20) = 2.69$, $p = 0.061$). For the overall fixation duration, the main effects of *distance* (Pillai's Trace: $F(2,22) = 83.54$, $p < 0.001$) and *orientation* (Pillai's Trace: $F(2,22) = 71.01$, $p < 0.001$) were significant. The interaction between the effects of *distance* and *orientation* was statistically significant (Pillai's Trace: $F(4,20) = 5.16$, $p = 0.005$). Again, after taking into account the distance traveled, we found that the results for the participants with mental retardation were quite similar to previous ones. Therefore, the visual lobe in designing the study did not confound the effects of the distance and orientation of two target stimuli on modulating the visual search performances of the participants with mental retardation.

Figure 4.8

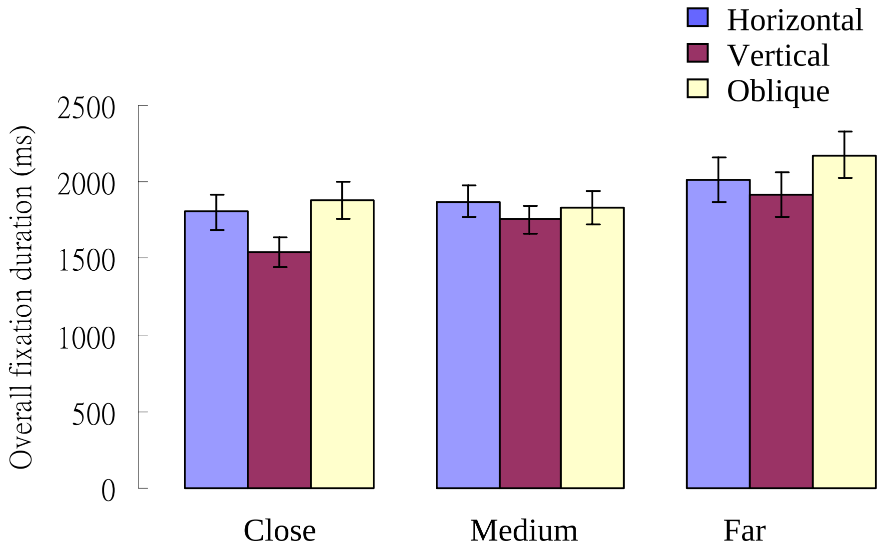
Mean scanpath duration of participants with mental retardation



Note: The error bars indicate the standard errors.

Figure 4.9

Mean overall fixation duration of participants with mental retardation



Note: The error bars indicate the standard errors

Visual Lobe-Mapping Experiment

Characteristics of the participants. In order to produce a correct response on the visual lobe-mapping task, the participants were not only required to detect the visual targets within the limits of their attentional fields, but they also needed to retain the target image on screen for at least a few seconds while moving the mouse to the designated location and clicking on it. This was not easy to achieve for the participants with mental retardation, particularly those with lower motor and working memory abilities. It was decided to exclude those participants with mental retardation who failed to achieve an accuracy rate lower than two standard deviations from the mean of the participants without mental retardation. There were a total of 30 participants without mental retardation, and 10 participants with mental retardation whose results on the visual lobe-mapping task were included in the analysis.

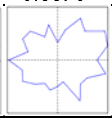
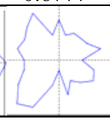
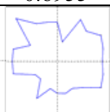
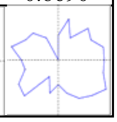
Comparison of the visual lobe area and shape indices between participants with and without mental retardation. The visual lobe shapes of the participants with and without mental retardation, mapped on 24 meridians, were randomly selected and are shown in Figures 4.10 and 4.11, respectively. The results revealed that the visual lobes of both groups were irregularly shaped. There were quite large individual differences within each group, and most of the lobes were not strictly ovaloid or circular in shape. The descriptive statistics of the lobe shape indices of the participants with and without mental retardation are summarized in Table 4.16.

For the participants without mental retardation, the mean values of the shape indices on sphericity (form factor, perimeter-area ratio, perimeter-area ratio of the convex hull, area-maximum area ratio, and ratio of the radii) showed a medium level of sphericity. The boundaries of the visual lobes were of a low level of roughness as depicted by the shape indices on boundary smoothness (global convex deficiency, rugosity, and spike parameter). A slight level of irregularity for the lobe shapes was shown by the Boyce-Clark index, but generally, the shapes were elongated and horizontally oriented as shown by the length-width ratio. The symmetry indices were slightly asymmetric along the vertical and horizontal axes. The differences in corresponding mean lengths were about 35% in terms of vertical vertices symmetry and 13% in terms of horizontal vertices symmetry. The differences in corresponding mean areas were about 23% in terms of top-bottom and about 11% in terms of left-right area symmetry. The vertical and horizontal symmetry of the convex hull showed that the lobes of the participants without mental retardation had bottom and right lobe lengths which are a little greater than the top and left lobe lengths, respectively.

The independent-sample *t* tests indicated that the participants with mental retardation showed a significantly smaller visual lobe area than those without mental retardation ($t(38) = 4.125$, $p < 0.001$). In addition, the participants with mental retardation showed a less circular-shaped visual lobe as depicted by the shape indices on sphericity (form factor, perimeter-area ratio, and area-maximum area ratio; $t(38) = 2.28\text{-}2.74$, $ps < 0.05$), a rougher boundary as depicted by the shape indices on boundary smoothness (rugosity and spike parameter; $t(38) = -2.46\text{-}2.86$, $ps < 0.05$), a similar level of asymmetry along the vertical and horizontal axes as depicted by almost all shape indices on symmetry ($ps > 0.05$), a similar level of horizontal elongation ($p > 0.05$), and a lower level of regularity as depicted by the Boyce-Clark index ($t(38) = 2.12$, $p = 0.04$) than the participants without mental retardation.

Figure 4.10

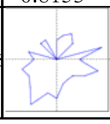
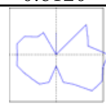
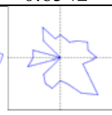
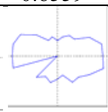
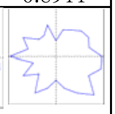
Visual lobes of six randomly selected participants without mental retardation mapped on 24 meridians and their shape indices

		Participants					
		A	B	C	D	E	F
	Perimeter (arc rad.)	1.2851	1.3105	1.1160	1.1812	1.4717	1.5097
	Area (rad. sq.)	0.0650	0.0595	0.0426	0.0426	0.0820	0.0698
Sphericity	Form Factor	0.4944	0.4353	0.4303	0.3834	0.4759	0.3847
	Perimeter-Area Ratio	0.7034	0.6600	0.6562	0.6194	0.6901	0.6205
	Perimeter-Area Ratio of Convex Hull	0.8274	0.8912	0.8661	0.8374	0.8746	0.8864
	Area-Maximum Area Ratio	0.5375	0.5193	0.5053	0.4657	0.5450	0.5028
	Ratio of Radii	0.7332	0.7206	0.7108	0.6824	0.7383	0.7091
Boundary Smoothness	Global Convex Deficiency	0.2026	0.2352	0.2622	0.2283	0.1915	0.226
	Rugosity	1.1551	1.2513	1.2186	1.2982	1.2190	1.3353
	Spike Parameter	0.2140	0.2453	0.1669	0.2099	0.2247	0.2594
Symmetry	Vertical Vertices Symmetry	0.3250	0.2261	0.3151	0.2096	0.2745	0.3480
	Horizontal Vertices Symmetry	0.1348	0.1395	0.1753	0.1462	0.1208	0.0951
	Top-Bottom Area Symmetry	0.1574	0.0874	0.0711	0.0005	0.1358	0.1362
	Left-Right Area Symmetry	0.0347	0.1450	0.2136	0.2791	0.0504	0.2048
	Vertical Symmetry of Convex Hull	1.2777	0.9746	1.1561	1.0000	0.8589	0.9400
	Horizontal Symmetry of Convex Hull	0.9825	0.9825	0.7837	1.0084	0.9825	0.9801
Elongation	Length-Width Ratio	1.3671	1.2650	1.1005	0.9215	1.1843	1.2655
Regularity	Boyce-Clark Index	0.8712	0.8890	0.8825	0.8777	0.8955	0.8690
Plot of visual lobe shape mapped on the 24-meridians							

Note: The boundary of the plot of the visual lobe shape (in blue) represents the maximum eccentricity from the fixation point in which the target could be detected and covered by the visual lobe.

Figure 4.11

Visual lobes of six randomly selected participants with mental retardation mapped on 24 meridians and their shape indices

		Participants					
		A	B	C	D	E	F
	Perimeter (arc rad.)	1.2731	1.0673	1.0177	1.3810	1.2461	1.3706
	Area (rad. sq.)	0.0241	0.0548	0.0285	0.0376	0.0515	0.0597
Sphericity	Form Factor	0.1871	0.6048	0.3464	0.2480	0.4171	0.3993
	Perimeter-Area Ratio	0.4327	0.7779	0.5887	0.4982	0.6461	0.6321
	Perimeter-Area Ratio of Convex Hull	0.8462	0.9190	0.8679	0.8243	0.7873	0.8910
	Area-Maximum Area Ratio	0.3348	0.6199	0.4935	0.2534	0.3857	0.5059
	Ratio of Radii	0.5786	0.7874	0.7025	0.5034	0.6211	0.7112
Boundary Smoothness	Global Convex Deficiency	0.3923	0.1552	0.2348	0.3275	0.1509	0.2383
	Rugosity	1.6577	1.1330	1.3846	1.4951	1.2660	1.3037
	Spike Parameter	0.1388	0.2290	0.2321	0.1398	0.1804	0.1812
Symmetry	Vertical Vertices Symmetry	0.5031	0.2835	0.3700	0.3435	0.2546	0.2677
	Horizontal Vertices Symmetry	0.1494	0.0588	0.1408	0.2718	0.0981	0.1119
	Top-Bottom Area Symmetry	0.5255	0.1666	0.3134	0.2216	0.0628	0.1595
	Left-Right Area Symmetry	0.0760	0.0342	0.1448	0.2870	0.1027	0.2033
	Vertical Symmetry of Convex Hull	1.7448	1.3546	1.1974	1.2158	1.2274	1.2139
	Horizontal Symmetry of Convex Hull	0.7647	1.2189	0.7546	0.8726	0.9825	1.0000
Elongation	Length-Width Ratio	1.1295	1.3026	1.3793	1.0275	1.9132	1.3245
Regularity	Boyce-Clark Index	0.8153	0.9175	0.8120	0.8542	0.8339	0.8911
Plot of visual lobe shape mapped on the 24-meridians							

Note: The boundary of the plot of the visual lobe shape (in blue) represents the maximum eccentricity from the fixation point in which the target can be detected and covered by the visual lobe.

Table 4.16

Descriptive statistics of shape indices of the participants with and without mental retardation

Shape index	Participants without MR (n = 30) Mean (SD)	Participants with MR (n = 10) Mean (SD)	t
Perimeter (rad.)	1.315 (0.141)	1.300 (0.205)	0.27
Area (rad. sq.)	0.059 (0.015)	0.036 (0.017)	4.13 [a]
Form Factor	0.438 (0.128)	0.299 (0.170)	2.74 [b]
Perimeter/Area Ratio	0.655 (0.100)	0.520 (0.178)	2.28 [c]
P/A Ratio of the Convex Hull	0.868 (0.036)	0.850 (0.056)	1.14
Area-Max. Area Ratio	0.533 (0.110)	0.418 (0.173)	2.48 [c]
Ratio of the Radii Ratio	0.726 (0.076)	0.628 (0.161)	1.86
Global Convex Deficiency	0.222 (0.075)	0.331 (0.213)	-1.59
Rugosity	1.275 (0.146)	1.513 (0.294)	-2.46 [c]
Spike Parameter	0.215 (0.044)	0.166 (0.058)	2.86 [b]
Vertical Vertices Symmetry	0.348 (0.097)	0.381 (0.105)	-0.91
Horizontal Vertices Symmetry	0.130 (0.060)	0.166 (0.090)	-1.44
Top-Bottom Area Symmetry	0.233 (0.186)	0.327 (0.243)	-1.29
Left-Right Area Symmetry	0.111 (0.078)	0.216 (0.165)	-1.95
Vertical Symmetry of the Convex Hull	1.049 (0.283)	1.373 (0.220)	-3.30 [b]
Horizontal Symmetry of the Convex Hull	0.999 (0.172)	0.945 (0.162)	0.89
Length/Width Ratio	1.313 (0.208)	1.264 (0.260)	0.60
Boyce Clark Index	0.861 (0.044)	0.814 (0.097)	2.12 [c]

Note: [a] $p \leq 0.001$
[b] $p \leq 0.01$
[c] $p \leq 0.05$

CHAPTER V

DISCUSSION

General Introduction

This chapter begins with a discussion of the performance of the Internet Explorer (IE) task by the participants with mental retardation. The cognitive and motor functions that are important for operating these tasks are also examined. In particular, the discussion focuses on how cognitive and motor deficiencies hinder competence in operating IE, as well as what general design principles can be followed in order to compensate for mental deficiencies when dealing with a computer interface.

A large part of this chapter is devoted to the theoretical model of visual search. This model begins with a discussion of the visual lobe area and shape characteristics of the subjects and how visual lobe modulates the visual search performance in this project. Subsequently, the theoretical effects of attention function and working memory function on the visual search tasks are elaborated.

Also, the visual search strategies and the oculomotor behaviors employed by the subjects with and without mental retardation in the visual search experiment, and the mechanism that explains the deficiencies in the visual search performance for the participants with mental retardation are discussed.

In addition, a discussion is devoted to explaining the effect of the manipulation of visual elements in the human-computer interface, including the distances and orientations of the two target stimuli in the visual display, on modulating the visual search performances of these people. The implications of these findings for the design of a human-computer interface are further explored.

Finally, the limitations of this project as well as possibilities for future research are discussed.

IE Performance and Its Relationships with Cognitive and Motor Abilities

IE Task Performance of People with Mental Retardation

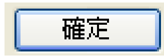
Our first study aimed to examine the extent to which the participants with mental retardation managed to use the computer program. The survey results indicated that the IE Web-browsing task was the most common human-computer interaction task performed by people with mental retardation. The results further indicated that the operation of IE can be broken down into 16 tasks. These tasks were found to demand different cognitive and motor functions from the users. The IE competence test results obtained from the participants with mental retardation revealed that the performance of the participants varied across the 16 tasks. Some tasks were found to be more difficult than others. Further task analyses suggested that almost all the IE tasks required visual acuity, attention, and orientation abilities. Moreover, the difficulty level of tasks was related to the participants' ability in working memory and recognition of Chinese words.

Of the 16 IE tasks, the participants managed to perform seven. These seven tasks were *close Web browser*, *shut down the computer, turn on the computer, general motor functions, direct print, respond to the dialogue box,* and *start Web browser*. The other nine tasks were found to be more difficult to perform. They were *use customized bookmark, general orientation and recognition, add bookmark, use search engine, indirect print, save Web site, open saved Web site, explore Web site,* and *general language functions tasks*. In general, the easier tasks tended to involve fewer steps (mostly three to four steps) and demanded less of the cognitive functions, in particular, word recognition and working memory, than the difficult tasks.

The performance of the 16 IE tasks required the participants to (1) identify the displayed information (stimulus identification), (2) select the response based on the displayed information (response selection), and (3) execute the responses (response execution; Proctor & Vu, 2003; Sanders, 1998). The difference in the difficulty level among the IE tasks could be explained with reference to these three stages of human information processing.

First, visual acuity, orientation, and attention were the prerequisite perceptual-cognitive abilities for performing all the IE tasks. These abilities appear to be critical for identifying any displayed information presented on a computer screen. For instance, the participants would need to have sufficient visual acuity to view the icons appearing in the IE environment. In identifying the display information, the participants were also required to give attention to specific locations in the display and hence increase this type of attentiveness that is called orientation (Posner & Raichle, 1997). For instance, in the close Web browser task, the participants were required to disengage from the current focus (such as the text on the Web page) and instead dwell on the  icon (appearing at the top right-hand corner of the screen), in order to proceed with exiting from the IE program (Kinsella, 1998; Posner & Petersen, 1990). This deployment of attention on the  icon was a prerequisite for the later location of the icon and for the extraction of the information contained in it. Attention is analogous to vigilance in the attention model proposed by Posner and Raichle (1997). Vigilance is defined as the ability to maintain an attentional capacity over a period of time (Lezak et al., 2004). This ability is important for almost all IE tasks because this process helps maintain the alert state to complete the IE task. For instance, in the shut down the computer task, the participants were required to maintain a sustained state of alertness across all three stages of information processing for completing this task. They started to identify a target 

icon and execute the motor response by clicking on this icon. After this, they still maintained their alertness and continued to identify and click on another 

icon. These processes were repeated until all subsequent icons, such as 

, were identified and clicked. This maintenance of a sustained state of alertness along the course of identifying and clicking icons is important throughout the whole process of powering off the computer.

The similarities between the easier and difficult tasks were that both types of task required the participants to engage in the three stages of information processing. The differences between these two types of task were probably that the performance of the difficult tasks would involve intense and diverse cognitive functions (Paap, Noel, & McDonald, 1987) and would demand higher cognitive resources for operation (Proctor & Vu, 2003; Sanders, 1998). As mentioned earlier in this section, the more difficult tasks involved a higher level of word recognition and working memory. For instance, in performing the use search engine task, the participants had to recognize and process the Chinese words appearing on the toolbar menu and Web hyperlinks, for example, 

(*address of Web site*) appearing in the toolbar menu, and 

(*entertainment*) appearing in the Web hyperlinks. As using the search engine was a multistep task, the participants were required to keep track of the paths to avoid becoming lost and also to work out what step to choose next (Zhang & Salvendy, 2001). For example, on the first page of the Yahoo! Web site's search engine, different categories of information, such as 娛樂 hyperlink (means *entertainment*) and 教育 hyperlink (means *education*), are printed at the same first level. If the participants were looking for information regarding the topic of education, then they were required to identify and click this 教育 hyperlink (*education*; first level) and continue to search the subheadings, such as 特殊教育 (*special education*; second level), underneath the 教育 hyperlink (means *education*). If the participants suddenly changed their interest and shifted to information regarding the topic of entertainment, then they had to know where they were, for example, the second level of the Yahoo! Web page. They also needed to work out what was the next step to be carried out, for example, how many "clicks" were required in order to return to the first level of the Yahoo! Web page for identifying the intended 娛樂 hyperlink (*entertainment*). Previous studies have revealed that working memory is the most important cognitive function which enables individuals to remember the search paths and the locations previously fixated in order to avoid repeated browsing and to enable them to move ahead to the next stage of browsing (Beck et al., 2006b; Findlay & Brown, 2006; Klein & MacInnes, 1999; McCarley et al., 2003). Most of our participants appeared to have problems in performing the IE tasks, particularly the difficult ones. These difficult tasks involved searching and retrieving information on the Web page or on a menu with a hierarchical structure. Retrieving information in a multilayer menu or Web page design makes heavy demands on both perceptual ability (visual search ability including visual acuity, orientation, and attention) and high-level cognitive function (working memory). Furthermore, the breadth and depth of the menu system is constrained by visual search and working memory limitations (Larson & Czerwinsky, 1998; Miller, 1981; Zhang & Salvendy, 2001). In relation to this, Zhang and Salvendy (2001) indicated that accommodating low visual search ability and reducing the working memory load might be effective ways of improving the performance of participants in a Web-based environment.

The results also indicated that performing the IE tasks involved a certain level of functions, particularly in the stage of response execution. These motor functions include stabilization, which refers to stabilizing the body parts for precise movement or balance; eye-hand coordination, which refers to coordinating the interaction of information from the eyes with body movement; and dexterity, which refers to the control of precise hand movements to manipulate the task objects (Fisher, 2003; Watson, 1997). Almost all IE tasks, except general language function, would require the participants holding the mouse to move the cursor to the location of the icons, and then to use the mouse to click on the icons. Holding the mouse required the participants to have a good stabilization function because this part of the action required them to stabilize the wrist and finger joints to securely hold the mouse. Meanwhile, moving the cursor to the location of the target icon required the participants to have good eye-hand coordination because this part of the action necessitated the coordination of information interaction between the eye and the upper limb to prevent the cursor from overshooting or undershooting the location of the target icon. Pressing the mouse button to click on the target icon required the participants to have a good dexterity function because this part of the action required them to have a precise “finger-pressing” action for clicking the icon on the screen. As our participants were people with mental retardation, they had lower high-level cognitive functions such as working memory and Chinese word recognition and language processing compared with their normal counterparts (e.g. Henry & MacLean, 2002; McCauley, 2001). The implications are that people with mental retardation are likely to have problems with performing Web-browsing tasks, particularly difficult ones. One way to address this problem is to make changes to the existing user interface by reducing the demands on cognitive functions. In other words, the information processing required for browsing IE should involve a lower level of cognitive function in terms of communicating cognitive resources. As previously mentioned, performing Web-browsing tasks makes heavy demands on both perceptual ability (visual search ability including visual acuity, orientation, and attention) and high-level cognitive function (working memory). In order to enhance the performance of these tasks, the changes to the existing user interface should place an emphasis on lowering the demands on these two functions. For example, manipulation of the visual information displayed on the computer screen and improved arrangement of the locations of icons on the menu toolbar or hyperlinks on the Web page could both reduce the visual search and working memory demands for performing Web-browsing tasks. In order to improve performance, such as information retrieval along the hierarchical structure, some studies have suggested that a modified design that emphasizes the accommodation of visual search (perceptual process) could better reduce the mental workload of participants and hence greatly improve their performance. For example, Lohse (1997) concluded that a color graph design could reduce cognitive overload by shifting some of the information-processing burden to the visual perceptual system, which in turn would free more working memory resources for other steps in the problem-solving task. All of these analyses suggest that the interface design should help the participants in reducing their workloads by emphasizing the change in visual search ability (perceptual process). Those participants who were clustered in the low-performance group were likely to have been limited by both functions in the perceptual system (visual search process) and the high-level cognitive system (working memory). Thus, a modification of the design which placed emphasis on the visual search process should ultimately enhance their performance in the IE tasks. Based on the principles of universal design, if the lower performance of some participants could be improved by a modified design that emphasized the visual search process, the participants with higher performance could then benefit as well. Therefore, in our study, the modification of design should focus on the visual search process in information search and retrieval in Web-browsing tasks. A manipulation of the structure display of the Web site and the arrangement of the icon locations in the menu that reduced the efforts of the participants in searching for information from the display could greatly reduce their workload in identifying the target items, as well as increase the usability of the Web browser program or other types of human-computer interface.

Cognitive and Motor Predictors of IE Performance among People with Mental Retardation

After controlling their demographic characteristics, for example age, level of education, and previous computer exposure, it was found that the participants' intellectual functioning was found to significantly affect their performance of the IE tasks. Our finding was consistent with those revealed in Rozell and Gardner's (2000) study. This study used path analysis to test the model of cognitive, motivational, and affective processes influencing computer-related performances. On the contrary, Rozell and Gardner concluded that computer performance differences were affected by individual differences in hereditary traits, for example IQ. They believed that these innate abilities are key determinants of computer achievement. We thus attempted to control the demographic characteristics of participants before their performances were entered into the regression model because most previous studies did not do this, and then the findings were that their personal characteristics (e.g., age and previous computer experience) were the common significant variables influencing the use of technologies (e.g. Mazer et al., 2003; Rozell & Gardner, 2000). These previous studies concluded that such demographic characteristics appeared to covariate with the cognitive functions to account for the ability to operate the computer. To identify clearly to what extent the cognitive and motor abilities of individuals with mental retardation affected their computer performances, their demographic characteristics would be controlled before running the regression model for predicting the participants' performance of IE tasks.

Intellectual functioning was found to only partially explain their performance of IE tasks. The results obtained in Study 2 indicated that their IE task performances were also significantly correlated with their cognitive and motor functions. These findings were consistent with previous studies that the cognitive and motor functions of individuals were the prerequisites for access to the computer interface or other information technologies (Cress, 1993; Cress et al., 1991; Gattiker, 1992; Petrie, 2001; Rozell & Gardner, 2000). Our major findings were that among the different cognitive and motor functions, attention and visual search function as measured by the Symbol Digit Modalities Test (SDMT), language function as measured by the Chinese Characters Test (CCT), and psychomotor function as measured by the fine-motor tests in the McCarron Assessment of Neuromuscular Development (MAND-FM), were the three most significant predictors of participants' overall performance of IE tasks. Among these three functions, the attention and visual search measures accounted for the greatest variance and hence most influenced the performance of the participants.

These three functions further illustrate the relevance of adopting human information processing: stimulus identification, response selection, and response execution (Proctor & Vu, 2003; Sanders, 1998). The attention and visual search functions play important roles in the stimulus identification stage that enables the participants to scan the icons and orient their attention to the appropriate icons displayed at a particular location on the screen for subsequent processing. Meanwhile, the language function is essential in the response selection stage because it enables the participants to recognize the semantic meanings of the words printed in the toolbar menu or the Web page, and make appropriate decisions on the responses. The motor function is important in the response execution stage in which the participants select the target icons on screen by moving the cursor on the screen with the mouse, and pressing the button on the mouse, or the key on the keyboard, or both. These findings also concur with those revealed in Study 1 and their basic perceptual-cognitive skills, that is, attention and orientation were regarded as the most useful function for dealing with the IE interface.

Preliminary implications for the design of a human-computer interface for people with mild and moderate grades of mental retardation are suggested. Analysis on the task requirements of the Symbol Digit Modalities Test (SDMT), the Chinese Characters Test (CCT), and the McCarron Assessment of Neuromuscular Development (MAND-FM) might shed light on the task demands when the participants engaged in performing the IE tasks. The SDMT measures visual attention that involves participants engaging in visual scanning and tracking, perceptual and motor speed, and memory tests (Strauss et al., 2006). The participants were to sustain the attention and remain alert on geometric design and digits in their memory, and simultaneously, visually search for a series of meaningless geometric designs. The task content of the SDMT appears to be similar to that of the IE tasks, in that the participants sustain their attention to keep the theme or keyboards in mind, and simultaneously, visually search for target icons or hyperlinks appearing on the same screen or subsequent screens.

The MAND-FM is a test that measures the fine-motor physical function of participants. The task content involves coordination and movement (McCarron, 1997). The participants performed the IE tasks that involved reaching for and grasping the mouse, clicking on the left and right mouse buttons, and moving the mouse to locate the cursor on the icon. The manipulation of the input devices for executing the response in a human-computer interface demanded complex visual-motor coordination and motor control (Lane & Ziviani, 1999, 2002).

The CCT is a measure of the ability of participants to recognize Chinese characters and comprehend their meanings. The relevant IE tasks mostly required recognition by the participants of words displayed on icons, menu options, and the Web page.

In the field of human-computer interaction, different guidelines on the accessibility for the human-computer interface for people with disabilities have been developed. Of all these guidelines, the inclusive design guidelines have received the greatest attention from HCI designers. The philosophy behind the "design for all" principles is that the design of products should take into account the needs of everyone, including those with restricted functions due to age or disability, as well as those with average abilities (Buhler, 2001). Based on these principles, the modification of the human-computer interface should accommodate a wide range of users. In order to enhance Web access or other activities at the human-computer interface for participants with mental retardation, the design of the interface should be modified to fit their attention and visual search, language processing, and psychomotor functions. Some literature on interface design for people with attention and visual search difficulties suggests that a universal design should limit the target items or make the icons free from distraction, hence minimizing the needs for visual tracking of target items in a screen cluster. This is because excessive information (e.g., button and menu options displayed in the interface) would reduce the user's cognitive resources for processing the target information and would thus lead to cognitive overload and disorientation (Dalal, Quible, & Wyatt, 2000; Davies et al., 2001). The modification of the interface should therefore explicitly consider the arrangement of the target items in the screen layout and the icons in the menu structure. Some studies suggest but do not limit themselves to the following: reducing the visual and auditory complexity of the output display (Cress & Goltz, 1989); making the target items salient or making them appear to be the absolutely essential set of functions or the only commands (Sutcliffe, Fickas, Sohlberg, & Ehlhardt, 2003); displaying the important information in a prominent place (Preece, Rogers, Benyon, Holland, & Carey, 1994); and providing continuous feedback about the user's position within the system in order to focus his or her attention (Petrie, 2001).

As far as the language-processing function is concerned, some solutions suggested from previous literature on user interface design for people with limited language abilities would provide simple language (Petrie, 2001; Singh, 2000); eliminate dense text in the interface (Sutcliffe et al., 2003); use concept-based visual icons to enhance the lexical retrieval (Singh, 2000); match the instructions to the linguistic levels of users; and provide voice output cues to reduce reliance on the amount of reading (Cress & Goltz, 1989; Singh, 2000).

Concerning the motor function, some guidelines on the accessibility of the human-computer interface for people with disabilities suggest that psychomotor impairments would be minimized by providing some alternative actions or enlarging the buttons for pressing so that the demands on the fine-motor control were not as critical (Petrie, 2001).

Theoretical Models of Visual Search

Visual Lobe Comparisons of Participants with and without Mental Retardation

The first objective of our visual lobe-mapping experiment aimed to examine the general distribution and descriptive statistics of the various lobe shape indices of our participants with and without mental retardation. The second objective was to compare the visual lobe indices between people with and without mental retardation. The results from the visual lobe-mapping experiment indicated that the 24-meridian binocular visual lobes for the participants with and without mental retardation were irregular. The individual differences were quite large within each of the two groups, indicating that individual visual lobes were distinct in terms of sphericity, boundary smoothness, symmetry, elongation, and regularity.

Furthermore, the findings indicated some general patterns for the lobes of the participants without mental retardation (i.e., normal counterparts). Their lobes were slightly irregular, with a medium level of sphericity and a low level of roughness, horizontally elongated, and slightly asymmetric along both vertical and horizontal axes. The vertical and horizontal symmetry indexes of the convex hull showed that the lobes of normal counterparts had bottom and right lobe lengths a little greater compared with the top and left lobe lengths, respectively. These findings are consistent with those reported from previous studies which also used the VILOMS program for mapping the visual lobe shape indices for a normal population (e.g. Chan & So, 2006; So, 2003). Despite the fact that we changed a few of the parameters used in the visual lobe experiment in order to accommodate the lower abilities of the participants with mental retardation, the validity of our findings was therefore retained.

The visual lobe area and shape characteristics of the participants were computed. The results indicated that the participants with mental retardation tended to have smaller lobe areas than those without mental retardation. Moreover, the participants with mental retardation showed a less circular-shaped lobe with a rougher boundary and a lower level of regularity than those without mental retardation. The lobe shapes of both groups were horizontally elongated and had similar levels of asymmetry along the vertical and horizontal axes. These results suggest a similarity in the binocular visual lobes between the participants with and without mental retardation despite the fact that these two groups have slight differences in their visual lobes' sphericity, boundary smoothness, and regularity. Nevertheless, it is not known whether these differences are inborn or attributable to limited exposure to the forms throughout life. Further studies should therefore be conducted to verify this.

A smaller visual lobe could have resulted in a lower visual search performance among the participants with mental retardation. Furthermore, a smaller visual lobe could limit the size or width of the visual attentional field (Kraiss & Knaeuper, 1982; So, 2003). With a smaller visual lobe, there would be occasions on which the target fell outside the visual field during a search task. It would then have been essential to use more eye movements to bring the target within the conspicuity area. As a result, the participants with mental retardation would have needed to shift their attention from one location to another more often than their normal counterparts. In other words, more fixations would have resulted (Findlay & Gilchrist, 1998). Our eye-tracking results also confirmed this hypothesis that the participants with mental retardation required more fixations to search for the second targets in the visual search task than their normal counterparts.

Courtney and Chan (1985) indicated that the shape of the visual lobe was irregular and contained areas of insensitivity such that it may be necessary to consider shape and area in order to understand the effects of the visual lobe on visual search performance. In comparison, this study's results indicated that both groups of participants had irregular visual lobes. Furthermore, apart from a smaller visual lobe area, the lobes of the participants with mental retardation showed a less circular shape, a rougher boundary, and a lower level of regularity compared with those of their normal counterparts. The higher "irregularity" of the visual lobe could have been a contributing factor to the lower visual search performance of the participants with mental retardation. When searching for the target, people who have a higher irregularity of the visual lobe may experience difficulty in finding the target when the targets fall onto the irregular edges of the visual lobe. Moreover, the results also revealed that the participants with mental retardation tended to adopt search styles that were not commonly used by their normal counterparts. For instance, they tended to repeatedly scan the paths when searching for the second targets. These lower-ability visual search behaviors demonstrated by the participants with mental retardation might have been partially explained by the higher irregularities of their visual lobes.

Theoretical Relationship among Attention, Working Memory, and Visual Search

One of the aims of the third study was to examine the relationships among attention, working memory, and visual search behavior. Different scores on the standardized tests were obtained to determine the abilities of the participants with regard to different attentional functions. The score on the SART was designed to measure the vigilance function for achieving and maintaining an alert state. The time score on Part A of the Color Trails Test (CTT) was designed to measure the orienting function for shifting attention to sensory events, and the interference score on the CTT was designed to measure the executive function for controlling brain areas to enable complex cognitive tasks to be performed. The span and sequence scores on the Digit Span Backward (DSB) were intended to measure the supervisory attention function for working memory. In addition, various eye-tracking parameters were used to reflect the visual search performances of the participants. The overall number of fixations was intended to represent the participants' efficiency in searching for components in the conjunctive search task. The overall fixation duration was used to reflect the participants' efficiency in mentally processing the target stimuli. The scanpath duration mediated the entire searching and processing of the conjunctive search task, and the fixation duration on each of the first and second targets was the time taken to process the information contained in these targets (Goldberg & Kotval, 1999; Jacob & Karn, 2003).

In general, we found that the orienting, executive, and supervisory attentional functions were related to almost all the eye-tracking parameters. In particular, the orienting attention function (time score on the CTT) was positively and strongly correlated with the overall number of fixations, moderately correlated with the scanpath duration and overall fixation duration, and weakly correlated with the fixation duration on the second target. The executive attentional function (interference score on the CTT) was positively and strongly correlated with the scanpath duration, moderately correlated with the overall fixation duration and fixation duration on the first target, and weakly correlated with the fixation duration on the second target.

Similarly, the supervisory attentional function for working memory also had strong to moderate relationships with the eye-tracking parameters, but they were negatively correlated.

The strong and positive correlations between the orienting attention function and the conjunctive search performance suggest that orienting attention would be required when the participants searched for as well as extracted information from the spatial configuration of the display elements (including targets and distractors). In the existing conjunctive search task, the participants first moved their eyes and fixated on a particular location for searching for the target. The participants would then extract the information displayed in the elements with the fixated visual field. When a fixated visual field only contained distractors, the participants withdrew their attention and disengaged from this fixated visual field. They would then shift to a new visual field and new location, and repeat the search. The participants would reengage their attention on the new visual field and location, and in this way, the target would be located. At this time, the target features within the visual field and location would be attended and selected. The features of the target would be extracted to form an object representation for matching with the features stored previously for the targets, called *the stored model* (Treisman, 1999). This process involved recognition and identification. If the attended object matched the stored model of the target, then the identification of the target was said to be completed. Otherwise, the participants would repeat the search process until the target identified was matched with the stored model. This operation required the participants to search and process the targets in the conjunctive search task. This searching operation involved the shifting of attention by means of eye movements. This would locate the stimuli onto the fovea in order to improve the efficiency of the processing of the target, which demanded orienting attention (Kinsella, 1998; Posner & Petersen, 1990).

The correlations between executive attention function and the eye-tracking parameters suggested that the visual search task demanded executive attention function. These eye-tracking parameters included the overall fixation duration and the fixation duration on the second targets, which are particularly related to the participants' efficiency in mentally processing the target in the conjunctive search task. Previous studies (e.g. Posner & Petersen, 1990; Posner & Raichle, 1997) revealed that the executive attention function was involved in the task in which the participants were required to handle distracting items. In the existing conjunctive search task, the participants searched for targets in the visual display. Since the visual display consisted of a number of distractors, executive attention function was required to prevent the participants from being distracted in searching for the targets. This would involve attentional resources, which further increased the overall cognitive demands throughout the search process. These demands would be in turn be reflected in an increase in the fixation times during which the participants extracted information from the distractors and targets appearing on the visual display. Previous studies (e.g. Posner & Petersen, 1990; Posner & Raichle, 1997) also suggested that executive attention function was involved in working memory tasks. In our visual search task, when the participants moved their eyes and fixated on a particular location to search for the second target, they would simultaneously hold the information on the previously examined locations of both targets and distractors in the working memory (Beck et al., 2006a, 2006b). This operation would require extra attentional resources and hence increase the overall cognitive demands throughout the search process. This also explained why the visual search task involving the control of the working memory would result in longer fixation times for holding the information on the previously examined locations of both targets and distractors. As a short conclusion, the participants were required to search for the targets from among a number of distractors, as well as to hold the information about the locations of previously examined targets and distractors in our visual search task. These processes indicated that the visual search task used in this study relied heavily on the participants' orienting attention and executive attention for the control of the working memory. As the participants with mental retardation had lower orienting attention and executive attention for the control of the working memory, their performance in our visual search task would be reflected in an increase in eye-tracking parameters, such as scanpath duration and overall fixation duration.

Visual Search Performance of People with and without Mental Retardation

Visual search strategies and oculomotor behaviors. A search strategy is defined as a cognitive control process that guides the visual focus to the target stimulus (Hu et al., 2005). Our observations indicated that the participants without mental retardation (i.e., the normal counterparts) appeared to employ more consistent search strategies across trials. This is reflected in the scanpath, which appeared to follow the spatial configurations of the stimuli. In other words, they tended to start the search from where the fovea landed, and then proceeded according to the spatial arrangement of the targets and distractors within the visual display. Hence, they tended to follow the scanpath using the circular strategy to search and process the nearby stimuli within the visual display. This scanpath also appeared to be optimal for the search. In contrast, the participants with mental retardation had less consistent scanpaths across trials. They tended to use random sequences of fixations and saccades, which did not largely correspond to the spatial configuration of the visual display. In other words, they rarely used the circular scanpath for identifying the second target. Instead, they would have extra fixations on some locations before identifying the second targets. These locations included the area of the previously inspected target, the location of distractors, and some blank areas that did not contain any targets or distractors. Another observation is that the participants with mental retardation showed a greater likelihood of adopting an ANB strategy. It is a search strategy following the pattern of moving from A—a first target, to N—nontargets, then to B—a second target. Alternately, they tended to adopt an ANBA strategy. This strategy follows the pattern of moving from A—a first target, to N—nontargets, then to B—a second target, then back to A—a first target. These two strategies confirmed that the participants with mental retardation tended to form more fixations than their normal counterparts. One plausible explanation for this is that because of the deficiencies of these participants in coding the stimuli, they tended to lose the spatial orientation of the search and hence select inappropriate fixation locations throughout the search task. Another is that the participants with mental retardation had difficulty in planning, updating, and memorizing the scanpaths, which would result in their retracing previously inspected fixations and scanning parts of the stimulus display that did not have the target.

Mechanisms underlying deficiencies in visual search performance. This part of the study aimed to investigate the mechanisms underlying the deficiencies in the visual search performance of the participants with mental retardation. The visual search task required a certain amount of working memory, which the participants were required to use to memorize the target or distractors, or both, throughout the scan and search task. This would prevent them from returning to the targets or distractors that were previously scanned or searched. This demands working memory from the participants, or holding onto the visual information for up to several seconds

(Posner & Cohen, 1984). This is a retrospective memory process called *inhibition of return* (Klein, 2000; Klein & MacInnes, 2000), which was mediated by spatial working memory (Castel et al., 2003). Therefore, those participants who had impairments in these functions would fail to identify the stimuli (e.g., first target and/or distractors), as well as memorize the spatial locations of the search that ultimately led the participants to repeatedly attend to the same target or distractor stimuli, or locations. As a result, these participants' performances on the visual search task would be much poorer, as reflected in lower accuracy and slower response times.

The visual search task also required the participants to encode the visual stimulus displayed on the screen. The participants would first code the spatial properties of the stimuli and construct a visual-spatial representation based on which search path strategies were formed. This process involves a special form of memory called *prospective memory* (Beck et al., 2006a, 2006b; Findley & Brown, 2006). The successful performance of the visual search task therefore required the participants to encode the spatial properties of the stimulus display and adapt their own appropriate strategies for guiding oculomotor activities (Zihl & Hebel, 1997). Meanwhile, those participants who failed to encode the stimulus patterns and develop the search strategies might form additional fixations on nontarget areas and reexamine the previously attended stimuli.

These results revealed that the participants with mental retardation committed more errors and had slower response times than their normal counterparts in the visual search task. The results for the eye-tracking parameters further revealed that the participants with mental retardation had longer scanpath durations and longer overall fixation durations than the normal participants. This was also likely to have been due to the failure of the visual-spatial coding of the stimulus and the lower working memory capacity to hold the stimuli and to remember the scanpath plan among people with mental retardation.

The successful planning of saccade activities as well as the continual updating of the previously scanned locations or stimuli would prevent the participants from returning to the locations which had previously been scanned or searched. The actions of those participants who failed to remember the appropriate strategies or to update the fixation locations of the previously examined target or distractor stimuli held in the working memory would also be consistent with the increased numbers of fixations as well as the longer scanpath duration (overall searching time) in the visual search task.

Baddeley (2000) indicated that the capacity of the working memory is limited. This notion is particularly true if the task involves processes of retaining the task-relevant information in the buffer and simultaneously inhibiting the information that is irrelevant to the task goal and competes for attention (Engle, Kane, & Tuholski, 1999; Tuholski, Engle, & Baylis, 2001). While the participants continued to search for the targets in the visual display, they held the relevant information (e.g., the locations of the first targets in the buffer) and at the same time, inhibited the information that was not relevant to the goal (e.g., the distractors). As a consequence, their working memory load would become heavier, while the mental resources available for interpreting other stimuli in the visual display would have decreased (Tuholski et al., 2001). As the search task progressed, the complexity of the visual information to be retained and interpreted would be increased, which in turn would reduce the availability of the mental resources and hence increase the overall fixation durations for processing the information in the visual display. A possible explanation for the increase in the overall fixation durations was the limited working memory capacity of the participants with mental retardation. As a result, they required more fixation durations to extract and interpret the visual information in the display (Tuholski et al., 2001; Zihl & Hebel, 1997).

Our findings for the visual search task may explain why the people with mental retardation had lower accuracy and longer response time than those without mental retardation. The deficits in different processes—impaired spatial coding ability, planning of search strategies, and updating of previously scanned stimuli—may be generalized to other diagnostic groups such as those with brain damage involving the posterior parietal cortex (for the visual-spatial coding of stimulus configuration) and the frontal cortex (for planning of saccade activities and updating of the locations of previously examined stimuli), or those with problems in attention and working memory.

Moreover, the current study's findings concur with those revealed in other studies that memory-based mechanisms were involved in performing the visual search task. Despite the fact that our visual search task was conducted in a laboratory setting, the results can be generalized to other natural search tasks, such as visually searching for grocery items on the shelves of a store. It is important, however, to note that the demands placed on the memory-based mechanism in the real world might be different from those in an experimental environment. It follows from this that further studies are required to compare these two conditions.

Conjunctive Search of People with Mental Retardation

One question addressed in this section is whether or not conjunctive search can be used by the participants with mental retardation. In the past 20 years, significant theoretical developments have occurred in the study of the visual search behaviors of normal subjects. For instance, Treisman and her associates (e.g., Treisman, 1986, 1999; Treisman & Gelade, 1980) developed a standardized experimental paradigm for studying feature (pre-attentive) and conjunctive (attentive) visual search. The former task involves participants identifying whether the target is present or absent in a set of simple stimuli representing contrasting values (e.g., lime green versus dark green) on a specific dimension (e.g., color). A feature is coded during an early phase of visual processing (i.e., pre-attentively). In feature search, no shift of attention is deployed and hence there is no effortful eye movement to orient and identify the target stimulus. If a target cannot be identified right away, a focused and effortful serial search of the visual array is required to determine whether the target stimulus is present or not, a search in which the target is defined by a conjunction of features (e.g., color and size). Performance in a conjunctive search task involves the shifting of attention, and hence some eye movement is needed to shift the attention (like spotlight attention) from one visual field to another, and at the same time conjoin the features by which the target can be defined. This conjoining of features allows more complex processes, such as object recognition (i.e., target identification), to occur.

The conventional method of studying visual search is to use the search rate, that is, the reaction time (RT) divided by the search set size (N) (Treisman & Gelade, 1980). The general rule is that RT does not increase with N because a parallel search would not require attention to be deployed to each stimulus item. In the situation where the search requires attention, RT increases with the increasing values of N. This phenomenon suggests that the visual search which participants engaged in was a conjunctive search. However, the analysis using the search rates has seldom been used for participants with mental retardation. With the advancement of eye-tracking technology, Zelinsky and Sheinberg (1995) and Peterson et al. (2001) showed that monitoring eye movements in a conventional visual search task facilitated the testing of whether an eye movement-based search required attention; it also allowed the explicit examination of feature and conjunctive visual search. First, the oculomotor scanpath of the normal participants was investigated to indicate whether or not the visual search task used in this study would suggest that the participants employed a conjunctive search to identify the target items. The normal participants scanned the stimuli items throughout the screen sequentially by deployment of their spotlight attention to each stimulus item. This sequential nature of the attentional process indicated that it would not be possible to move the eye directly to the target. This result suggested that the visual search task could not be carried out in parallel. Rather, the results from the oculomotor scanpath of the normal participants indicated that several attention shifts would, in general, occur before the participants' spotlight attention was directed to the targets. This serial deployment of attention throughout the scene is used to conjoin the features by which the target can be defined, and according to Treisman and Gelade (1980), this is called *serial* or *conjunctive search*. Our results from the eye movement indicated that despite the high incidence of rescanning the previously examined stimuli, the participants with mental retardation appeared to undertake a serial search by shifting their spotlight attention across the search field until a target was detected. This shifting constituted a conjunctive search that was compatible with that of their normal counterparts. Furthermore, this further suggested that the high incidence of rescanning might be attributable to the lower level of attention and memory of the former group when performing the visual search task. This postulation will be further explored in the next section.

Visual Search Behaviors in a Human-Computer Interface

Efficiency of Search across Distances and Orientations of Two Target Stimuli

This part of the study aimed to explain the effect of the manipulation of the visual elements in the display, including the distances and orientations of the two target stimuli, on modulating the visual search performances of the participants with mental retardation. The manipulation of these two variables was meant to test the extent to which attention and working memory would modulate the participants' visual search performances.

To minimize the confounding effects of peripheral vision and the effective visual field on search performance, the spacing of the targets was controlled by the size of the visual lobe (e.g., Chan & So, 2006; So, 2003). The premise was that the participants could only gaze on a single target at each fixation, and the identification of the second target would require them to shift their attention and gaze.

In our visual search task, the concept of manipulating the distance between the two target stimuli put a varying load on the participants' working memory for retaining the spatial features of the first target but at the same time searching for the second target (or not being distracted by the distractors) (e.g., Gibson, Li, Skow, Brown, & Cooke, 2000). Previous studies generally agreed that this visual search task is strongly influenced not only by attention (i.e., orienting attention or inhibition of return) but also by working memory (e.g., Shore & Klein, 2000). When a visual search task with a greater working memory load is performed, the visual search efficiency is reduced. Therefore, for the far-distance condition (2 visual lobe), the participants would scan through more distractors than for the close-distance condition (1 visual lobe). The load on the working memory would be heavier in the far-distance condition and hence the visual search efficiency would be greatly reduced.

Previous studies have demonstrated that loading on the spatial working memory during a visual search task would slow down the search process (e.g. Han & Kim, 2002; Oh & Kim, 2002, 2004). For instance, Oh and Kim (2004) investigated whether or not loading on the working memory would interfere with the visual search process. In their experiment, the participants had to perform two tasks: one task relied on spatial working memory to memorize the locations of four squares, while the other task relied on visual working memory to memorize the color of four squares in the memory array. This was followed by a visual search array in which the participants were instructed to report whether or not an “upright L-shaped figure” target was present. This was followed by the memory test probe in which the participants were asked to indicate whether the location (task 1) or the color (task 2) of the test probe was the same as the one presented previously. The results of this study indicated that the visual search process and spatial working memory storage relied on a similar mechanism that had limited capacity. The spatial working memory load was found to slow down the search process and impact on the efficiency of the search in terms of the response time.

In this study, we used eye-tracking parameters to reflect the load on the attention and working memory of the participants. The scanpath and fixation durations are common parameters used by previous studies as measures of the capacity of memory demanded in an oculomotor search task.

The concept of manipulating the horizontal, vertical, and oblique orientations between the two target stimuli is to put different demands on the participants’ visual field and visual search abilities (Lee & Chan, 2000a). The participants without mental retardation in this study were undergraduate students and Chinese-English bilinguals. The bilingual linguistic experience of the latter group may have predisposed them to perform equally well in both horizontal and vertical searches. On the other hand, the participants with mental retardation were native Chinese students attending a special school program. The curriculum used in this special school program is primarily taught in Chinese. Similarly, it was expected that the participants with mental retardation would perform equally well in the horizontal and vertical scans.

Previous studies on linguistic experience revealed that native English speakers saw random letters arranged in horizontal rows better than if they were arranged in vertical columns (Freeman, 1980). This suggested that individuals would scan more effectively when the stimuli were placed horizontally rather than in other orientations. However, among the native Chinese, there was no such corresponding preference for horizontal orientation. For example, Freeman (1980) found that when the native Chinese were presented with Chinese characters in horizontal as opposed to vertical arrays, there was no corresponding difference for horizontal and vertical orientations. In contrast, the Chinese-Americans, who had not learned to read and write Chinese, showed results similar to other American participants. It seems that the experience of reading Chinese does have some effect on a fundamental visual process. Freeman attributed this effect to the possibility of reading and writing Chinese text vertically as well as horizontally, unlike English. Hoosain (1991) further indicated that the human visual system appeared to have a built-in preference for a certain direction of visual scanning. He suggested that because the direction of flow of Chinese scripts allowed them to be printed and written horizontally as well as vertically, Chinese participants would perform equally well in horizontal and vertical searches.

The results from eye tracking indicated that the hypothesis set for the distance variable was supported for participants both with and without mental retardation. Both groups had the longest scanpath duration and fixation duration in the far-distance condition. These results indicated that the longer the distance between the two targets, the higher the loading required on the working memory when the participants searched for and identified the targets in the visual search task. Furthermore, the normal participants used a shorter searching time to identify the targets than the participants with mental retardation (e.g., scanpath duration = 1357 ms and 2455 ms for participants without and with mental retardation, respectively, in the far-distance condition). A similar result was observed in the overall fixation duration, and the normal participants were found to take a shorter time to interpret the visual stimuli, including targets and distractors, in the conjunctive search display, than those with mental retardation (1107 ms and 2038 ms for participants with and without mental retardation, respectively, in the far-distance condition). These results indicated that the visual search performances of people with and without mental retardation are different. In other words, the manipulation of the distance between the two targets, which placed different loads on working memory, appeared to influence to different extents the visual search performances of these two groups. The normal participants appeared to have a lower error rate (only 4% of overall trials) and a shorter scanpath duration and overall fixation duration in the far-distance condition compared with the participants with mental retardation in all distance conditions. Similar results were observed in the measure of overall fixation duration. The participants with mental retardation tended to have longer scanpath durations in the far-distance condition than in the close-distance condition and the medium-distance condition, but there were no differences between the medium-distance and close-distance conditions. Together with the participants with mental retardation who appeared to have a higher error rate (15%), this was probably attributable to the fact that the participants with mental retardation did not have enough working memory capacity to search for and interpret the targets when they were separated by the far-distance condition, but did have adequate working memory capacity when the two targets were separated by a medium or close distance.

In contrast, the results did not support the hypothesis set for the orientation variable in both groups. Significantly longer scanpath durations and overall fixation times were found for targets located in oblique and horizontal rather than in vertical orientations. Such results suggested a facilitative effect of the vertical orientation. As mentioned previously, this facilitative effect does not seem to be related to the participants' linguistic experience. Another plausible reason is the mechanical advantages brought by the anatomy of the muscles that produce ocular movements.

There are three pairs of extraocular muscles responsible for putting the eye into different gaze positions (Lens, Langley, Nemeth, & Shea, 1999). They are the superior rectus and inferior rectus (vertical muscles), the medial rectus and lateral rectus (horizontal muscles), and the superior oblique and inferior oblique (oblique muscles). The superior and inferior rectus muscles are responsible for the primary actions, elevation and depression movements (eye moves up and down); secondary actions, intorsion and extorsion movements (top of eye rotates toward nose and away from nose); and tertiary actions, adduction movements (eye moves toward nose). The superior and inferior oblique muscles are responsible for the intorsion and extorsion movements, respectively, but they are also responsible for depression and elevation, respectively, as well as abduction. The medial and lateral rectus muscles are responsible for adduction and abduction, respectively. Coordinated by specific nerves, these three pairs of ocular muscles undergo simultaneous relaxation and contraction (Lens et al., 1999). The simultaneous relaxation and contraction of these three pairs of ocular muscles operate in a coordinated fashion (von Noorden & Campos, 2002), and due to this, the advantages possessed by different eye muscles do not seem to adequately account for the facilitation found in vertical orientation during visual search.

The facilitative effect of vertical orientation would be explained by the bias introduced by the shape (ellipse shape) of the visual lobe. To further verify this, we subsequently used speed (taking into account distance traveled) as the unit to rerun the comparisons between the orientation variables for the two groups of participants. The results did not seem to be different. In other words, the use of the visual lobe did not confound our observations. Another plausible reason to account for the advantage of vertical orientation is the processing of visual material in the peripheral versus foveal visions.

In relation to this, Courtney and Chan (1985) reported that the peripheral region of the visual lobe was apparently insensitive so that visual stimuli outside the visual lobe could no longer be detected and recognized. In our experimental design, it was assumed that visual search could only process items which were within the visual lobe. The processing of a particular item could be similar wherever within the region of thevisual lobe. However, Findlay (1997) demonstrated that this was probably not the case. Findlay examined the initial eye movements of participants (first saccade) in two types of visual search task: the feature (color or shape) search task and the conjunctive (color and shape) search task. In the feature search task, he found that the participants used over 80% of first saccades that were going directly to the target accurately. In the conjunctive search task, the participants were able to locate targets with a single saccade on 60-70% of occasions in the inner circular ring (small eccentricity from the central fixation point) and on 16-40% of occasions in the outer ring. These results indicated that searches for color and shape among conjunctive targets involved more errors when these targets were located more peripherally. He concluded that the processing of targets could both be carried out in the peripheral vision and the foveal vision, although more errors appeared with the peripheral vision (Gilchrist & Harvey, 2000; Findlay, 1997). Furthermore, there was a parallel processing of stimuli in the central and peripheral locations. The effect of peripheral processing seems to plausibly account for the facilitative effect of vertical orientation for both groups. A possible reason is that during each fixation of the first target, there is the capacity to process items adjacent to the current fixation (possibly including the second target as the features of the second target are similar to those of the first target). Therefore, some items, including the second target aligned in the peripheral vision, had been simultaneously processed while the information in the first target was still being analyzed, thereby helping to guide the saccade to the location of the second target. This is because Findlay (1997) explained that the targets in the peripheral region were disadvantaged simply by reason of their increased eccentricity. Thus, in the vertical case, as the eccentricity of the second target from the first target was the smallest, the saccade landing on the second target, which was located in a vertical orientation, could be more readily detected.

Generalization of Results to other Screen Displays

In this study, we adopted the visual lobe concept for estimating the size of the visual field in which visual acuity was achieved in one single fixation (So, 2003). The size of the visual field is calibrated according to the set-up of a 17-inch visual display (240 mm horizontal x 270 mm vertical) with a viewing distance of 500 mm. The loading on the participants' working memory is henceforth specific to these dimensions (Gibson et al., 2000; Oh & Kim, 2004). As a result, the dimensions of the experimental paradigm and the quantitative data obtained in this study are specific to this physical set-up. There would therefore be problems if they are to be generalized to other designs or physical dimensions. Future studies should calibrate the visual field based on the viewing distance, the features of the stimuli, and the total number of stimuli, as well as the minimum distance between the target and/ or distractor.

Implication for the Designs of a Human-Computer Interface

The results from the visual search experiment indicated that the distance and orientation of the target stimuli would have effects on the performances of participants in searching on a visual screen. Below is a list of the specific findings that may serve as a blueprint for designing graphical or other types of human-machine interface for people with mental retardation:

1. The visual lobe of the participants with mental retardation (0.059 $rad.^2$ or 1.8 cm^2 at a viewing distance of 50 cm) is smaller than that of the normal participants (0.036 $rad.^2$ or 2.95 cm^2 at a viewing distance of 50 cm).
2. A closer distance between two relevant target stimuli would facilitate the search and identification of the target stimuli in participants with mental retardation.
3. There were problems in searching for and identifying targets separated by a far distance (two visual lobes).
4. The vertical orientation of the target stimuli, in more than one visual lobe, would facilitate visual search performance.

These guidelines could possibly be applied to the design of a graphical interface or other types of human-machine interface for people with mental retardation. A graphical interface includes menu structures such as toolbars (e.g., the “formatting” toolbar in the Microsoft Word program), tool palettes (e.g., the color palettes in the

Paint program), and the information presented on a Web page. Our discussion will focus on the design of menu structures.

A hierarchical menu structure usually consists of a main menu screen and a number of submenu screens. The participant who starts at the main menu screen may select the next submenu screen or previous submenu by selecting from the choices available from the menu (Gray, 1986). The main purpose of using a hierarchical menu is to maximize the total number of menu items for selection (Zhao, Agrawala, & Hinckley, 2006).

Navigation using the menu demands that the participants search across the menu from the main menu to the next submenu (second level). The participant would continue to scan for the appropriate levels of submenu, for example, at the fourth level, where a particular target item could be located. Even at the same main menu or submenu level, the participants also need to scan or search through the menu, extract the visual information, and then identify the target items from the menu.

The increase in menu depth will increase the total number of menu items available. Menu items located in the deeper hierarchies take the participants more time to access. In addition, greater demands will be placed on working memory, which stores all the previous visual information before identifying the right target menu item. Increasing menu breadth would yield shallower hierarchies, but too many menu items presented at the same submenu level would lead to the participants easily becoming lost and failing to accurately process information on the menus, resulting in the rechecking of previously examined menu items. This phenomenon is attributed to the increasing demands of the spatial working memory for the participants (Gray, 1986). In general, menu breadth is preferable to depth (Jacko & Salvendy, 1996; Kiger, 1984; Larson & Czerwinski, 1998; Schultz & Curran, 1986). A “good” menu should comprise two levels, and at each level, there should be a breadth of eight items (e.g. Gray, 1986, Miller, 1981; Kurtenbach & Buxton, 1993). The reason for recommending eight items is that this breadth fits with Miller's (1956) findings on the limits of short-term memory (i.e., 7 +/- 2 items; Zhao et al., 2006).

If these are the desirable standards on the depth and breadth of a hierarchical menu structure, recommendations can then be made based on this in order to facilitate the use of menus by people with mental retardation.

Size of icons at a single menu or submenu level. When we used the existing graphical interface or human-computer interface, for example, Internet Explorer or Microsoft Word, we found that the size of computer icons within these programs is varied. So that the alphanumeric and graphical pieces of information appearing in the computer icons could be presented in such a way that their perception was as accurate, fast, and effortless as possible, Lindberg and Nasanen (2003) investigated the effects of the spacing (Experiment 1) and size (Experiment 2) of individual interface elements (i.e., icons) on the visual search performance of younger normal participants. The experimental stimuli were the Windows 2000 computer icons. The stimuli in Experiment 1 consisted of 25 different icon matrix configurations of five different sizes (2 x 2, 3 x 3, 5 x 5, 7 x 7, and 10 x 10) and five different interelement spacings (0 icon, 1/4 icon, 1/2 icon, 1 icon, and 2 icon sizes). The stimuli in Experiment 2 were the 10 x 10 icon matrices with the inter-element spacing of one icon. The participants were asked to identify whether the target icon was present or absent, and then click the appropriate button as a response. The result in Experiment 1 showed that spacing did not have any effect on search times. However, the size of the interface icons was found to have a great effect. Icons which were smaller than 0.7 degrees resulted in significantly increased search times. Concerning the design standard for the mainstream population, the minimum size of icons should not be less than 0.7 degrees of visual angle, which corresponds to about 5 mm at a viewing distance of 400 mm, and about 9 mm at a viewing distance of 700 mm.

The question then arises as to whether or not the previous literature has suggested any standard regarding the size of computer icons for people with deficits in visual perception or visual search. Lindberg, Nasanen, and Muller (2006) have recently studied the effect of age on performance in icon searches and whether or not a possible age effect was related to icon size or spacing. In their task, the stimuli were Windows 2000 computer icons placed in 10 x 10 icon matrices. The size of the icons (0.5 degree, 1 degree, or 1.5 degree at a viewing distance of 400 mm) and the inter-icon spacing (0 degree, 1 degree (1 icon size), or 2 degree (2 icon size) at a viewing distance of 400 mm) were manipulated. The participants were older adults who were instructed to identify whether the target icon was present or absent, and then click the appropriate icons with the mouse as a response. The results indicated that the visual search performance was slower with increasing age. Their explanation was that the longer search time could be attributed to the lower attentional resources and smaller visual lobes of older adults. This would probably result in a greater need for shifting eye fixations and attention, which in turn resulted in longer search times. Lindberg, Nasanen, and Muller further suggested that the icons used in the graphical interface designed for the majority of older participants should be at least about 1 degree in size (about 7 mm at a viewing distance of 400 mm). In our study, we found that the visual lobe of the participants with mental retardation (18 mm^2 at a viewing distance of 500 mm) was smaller than that of normal participants (29.5 mm^2 at a viewing distance of 500 mm). Consistent with Lindberg et al.’s (2006) observations, the difficulties that the people with mental retardation had in searching for and identifying the target stimuli in the display could be attributed to this smaller visual lobe. Concerning the interface design for people with mental retardation, the optimal size of the computer icons should not be less than 18 mm^2 at a viewing distance of 500 mm. If a smaller icon than that recommended here were used, the participants with mental retardation would be unable to extract the fine detail of the information in the icon and thus the icon would appear blurred to them. If a larger icon than that recommended here were used, a single fixation landing on this icon might not be large enough to cover the whole icon and thus the participants might have to make extra fixations within this larger icon in order to extract all the information.

Arrangement of menu alignment at the same menu or the submenu level. In the IE software, we can see that a "shortcut function" toolbar is aligned horizontally and is located in the upper part of the screen. If we change the alignment of this "shortcut function" toolbar to vertical and put it on the left-hand side of the screen, then would this vertical orientation better facilitate individuals in searching and identifying the target function item as compared to the original horizontal one? To rephrase this question, we asked what particular orientation(s) in which the menu items might be located would facilitate the participants in searching and processing the visual information. Our study's findings revealed that the participants with mental retardation had both longer scanpath durations and overall fixation durations when the targets were separated by more than one visual lobe and were aligned in horizontal and oblique orientations rather than in vertical orientations. These results reflected the fact that the participants with mental retardation used longer times to search for the target menu item and to interpret and extract the visual information displayed in the menu aligned in horizontal and oblique orientations than that in the vertical one. Despite the fact that menu items aligned in oblique orientation are rarely observed in hierarchical menus and linear pull-down menus, they are quite commonly observed in marking menus (Kurtenbach & Buxton, 1993; Zhao et al., 2006). Marking menus are a gesture-based menu selection technique in which the menu items are arranged radically, and a participant draws a stroke toward a desired item in order to select it. From our study's results, we can draw the conclusion that it is better to align the menu items in the menu toolbar in a vertical orientation in order to enhance the performance of individuals in searching and extracting the information in the menu display. The answer to our above question about the alignment of the shortcut function toolbar therefore appears to be the vertical one. Reviewing many existing HCI programs operated by the mainstream population (e.g., Microsoft Word, Excel, PowerPoint, Internet Explorer), we find that the toolbars serving some common functions, (i.e., editing, drawing) are likely to be aligned in a horizontal orientation (Figure 5.1). Furthermore, according to the results, this kind of alignment of menu items may not be very facilitative. Therefore, to enhance the participants' visual search performance, it is recommended that the commonly used toolbars be aligned in vertical orientations (Figure 5.2). Actually, many existing programs such as Microsoft Word already provide the flexibility to allow the participants to arrange the toolbars in anyway. Thus, we suggest positioning these common-use toolbars toward the left- or right-hand edges of the screen so that the visual information can be aligned in these vertical orientations, which are in turn likely to be more easily scanned and the identifications more readily made. However, this vertical design hypothesis can only be verified by developing an enhanced prototype and then comparing the performance of the participants between the original and the enhanced prototypes.

Figure 5.1

Horizontal menu aligned in most existing types of human-computer interface

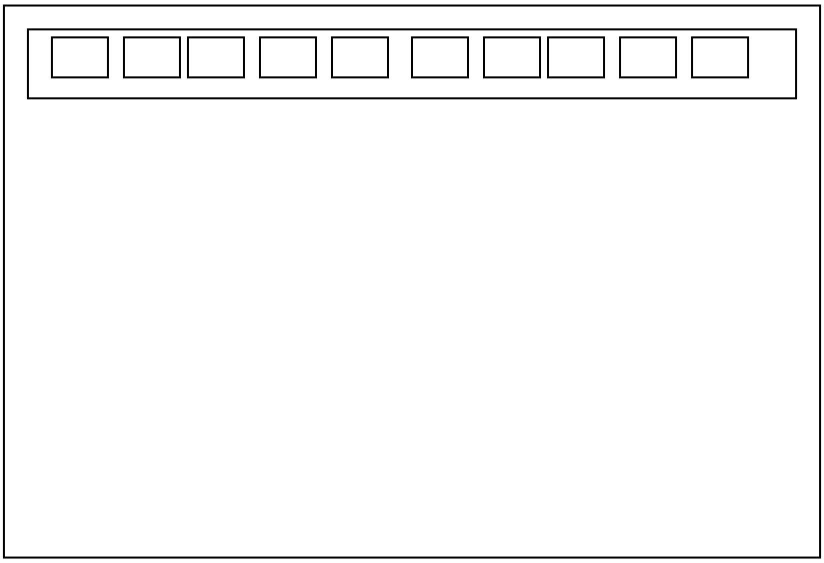
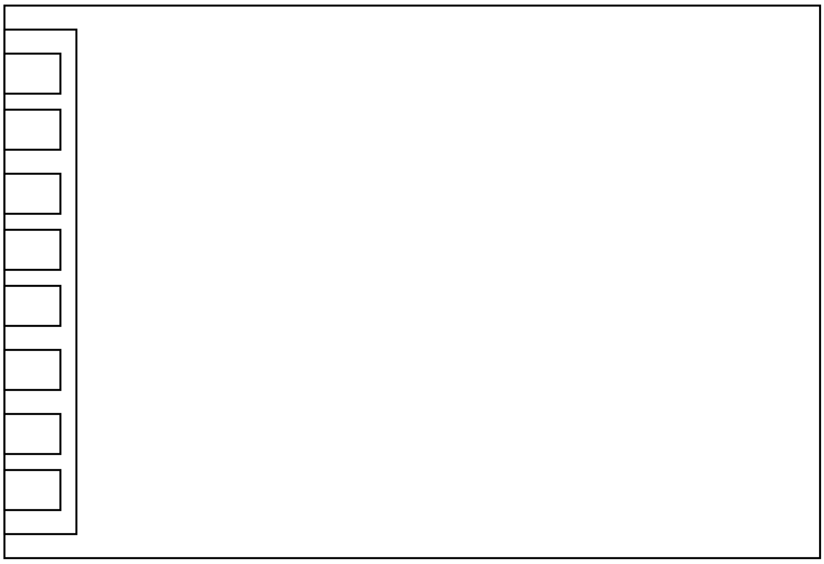


Figure 5.2

Vertical menu aligned in the enhanced human-computer interface prototype

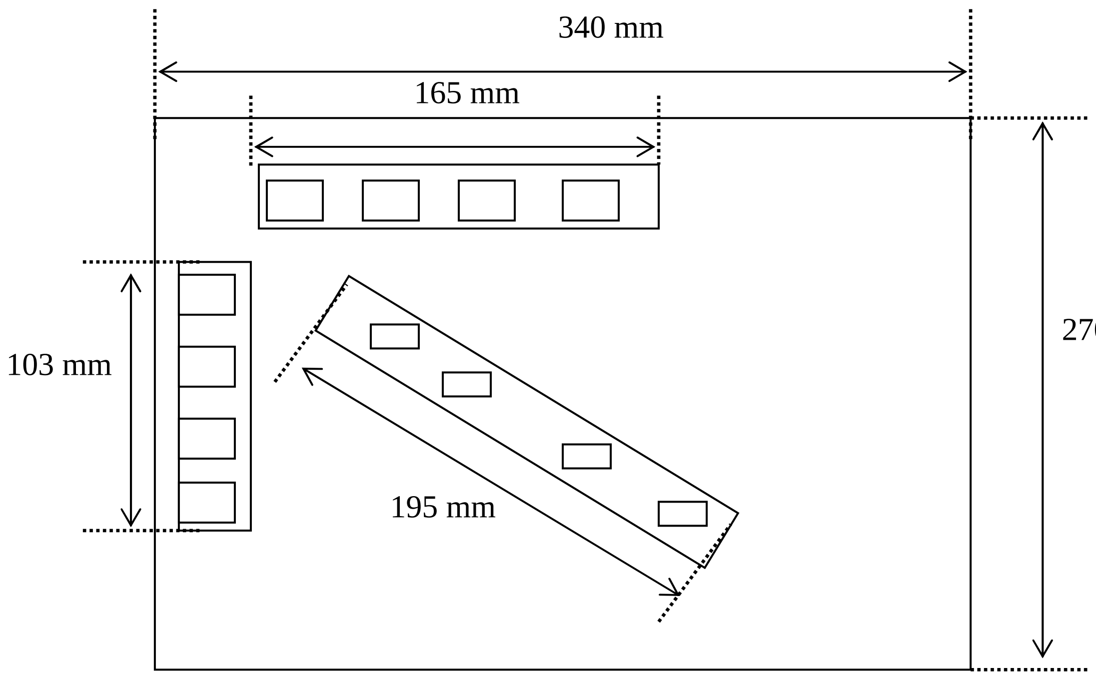


Optimal breadth of a single menu or submenu. From the above, we have learned that vertical orientations helped the participants with mental retardation in searching and extracting information from a single menu. The question then arises as to whether or not their performances on searching and extracting information from menu items will be changed if the breadths of the vertical menu and even the horizontal or oblique menus are increased. Before addressing this issue, the common observations on how participants read the pull-down menu will be discussed. In relation to this, Aaltonen, Hyrskykari, and Raiha (1998) conducted an eye movement study to understand how participants read a drop-down menu. In their experiment, the participants were asked to read the instructions on which target icons needed to be found and then were asked select the target icons in the drop-down menu in the test program. At the same time, their scanpaths were recorded. After analysis of the scanpath they made, in summary, two observations are made. First, the participants read the menus in consecutive passes, presumably beginning from the top then going down, and from the bottom of the menu made a quick hop to an item high up in the menu. Second, the overall upward movement was shorter than the overall downward movement in terms of both length and in duration. They explained that the shorter duration was attributed to the “quick hopping” upward movement back to the top of the menu. The shorter length is partly caused by a return to a menu item that had just been passed and which the participants wanted to recheck before proceeding. Looking at their observations, we were interested in the extent to which the participants not only scanned the menu items in a top-to-bottom direction but also needed to make some “return” upward saccade movements. These upward saccade movements seemed to indicate that the participants with mental retardation did not have enough spatial working memory to hold the visual information when they continued to search the menu items, in particular, when these items were aligned in a lengthy menu (Lohse, 1997; Oh & Kim, 2004). Our study's results indicated that the participants with mental retardation used both longer scanpath durations and overall fixation durations to search for and identify the visual stimuli in the far-distance condition than in the close-distance and medium-distance conditions. Thus, the maximum breadth of a menu should not be more than the medium-distance condition. Based on the results of these experiments, guidelines can now be given to interface designers on the optimal breadths of the single menu aligned in horizontal, vertical, and oblique orientations. These recommendations are appropriate for individuals using a graphical interface on a 17-inch monitor (340 mm horizontal x 270 mm vertical) and who sit at a viewing distance of 500 mm.

To achieve an optimal breadth of horizontal menu for the participants with mental retardation, it would be better to align the menu items within not more than 165 mm or 18.9 degrees. Around four menu items should be included in the entire horizontal menu (provided that the spacing between two consecutive items in a horizontal menu is 55 mm). To arrive at an optimal breadth of the vertical menu for the participants with mental retardation, the menu items should be aligned within not more than 103 mm or 11.8 degrees. Around four menu items are permissible for the entire vertical menu (provided that the spacing between two consecutive items in a vertical menu is 34 mm). To achieve an optimal breadth of an oblique menu for the participants with mental retardation, the menu items should be aligned within not more than 195 mm or 22.3 degrees. Again, around four menu items are permissible for the entire oblique menu (provided that the spacing between two consecutive items in an oblique menu is 65 mm). Great caution should be exercised when considering the number of items to be located in the menu. The reason for this is that in our study, we assumed that only one target item could be processed within one fixation, with reference to the theories and dimensions of the visual lobe (e.g. Chan & So, 2006; So, 2003). However, in most of the existing computer programs, it can be seen that the human eye can see a few items within a single fixation (e.g. Lindberg & Nasanen, 2003). Therefore, the number of items that it is permissible to locate in a single menu suggested in our study may be smaller than those reported in previous studies. The standard breadths of the horizontal, vertical, and oblique menus displayed on a 17-inch monitor screen that subtended 39 x 31 degrees of horizontal and vertical visual angles, respectively, are presented in Figure 5.3.

Figure 5.3

Standard breadths of the menus in horizontal, vertical, and oblique directions as displayed on a 17-inch monitor screen



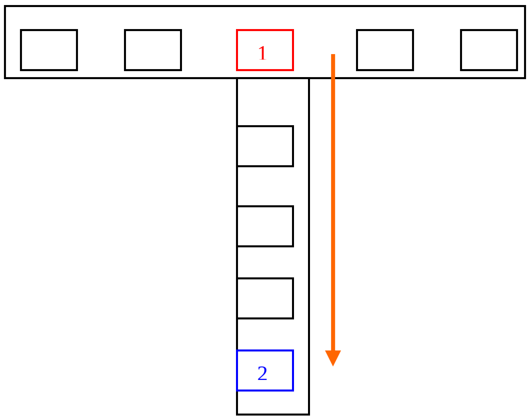
Arrangement of menu items in a hierarchical menu structure. Many existing programs, such as Microsoft Word or Internet Explorer, have many built-in functions so that the breadth of a single menu may not be long enough to include all of these "built-in function" icons. Therefore, the utilization of hierarchical menus seems to be one possible solution to this problem (Gray, 1986). However, searching and extracting information from multiple menus also creates a memory load problem because the participants need to repeatedly scan across a number of submenus until the appropriate deeper submenu is reached where a particular target item will be located. Some previous studies focusing on the breadth and depth tradeoff of menu structure design have concluded that a "good" menu configuration consisted of two levels with a breadth of eight items (Gray, 1986, Miller, 1981; Kurtenbach & Buxton, 1993), and our suggestions on hierarchical menu structure are therefore mainly based on this menu configuration.

A review of some software programs commonly utilized by the mainstream population indicated that at least three common hierarchical menu structures have been designed based on the above menu configuration. We have developed and presented these three menu structures in Figure 5.4. Menu structure A is a two-level hierarchical menu in which the main menu (first level) is horizontally aligned and the submenu (second level) is vertically aligned (Figure 5.4a). Menu structure B is a two-level hierarchical menu in which the main menu (first level) is vertically aligned and the submenu (second level) is horizontally aligned (Figure 5.4b). Menu structure C is a two-level hierarchical menu in which the main menu (first level) is vertically aligned and the submenu (second level) is also vertically aligned (Figure 5.4c).

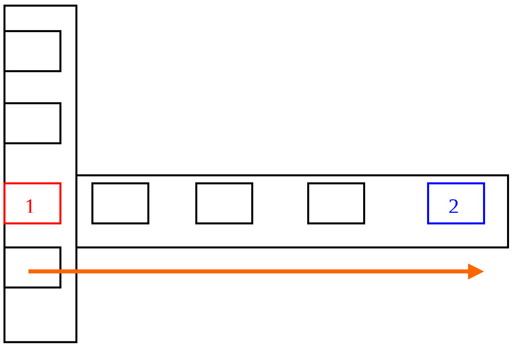
Figure 5.4

Examples of three common two-level hierarchical menu structures

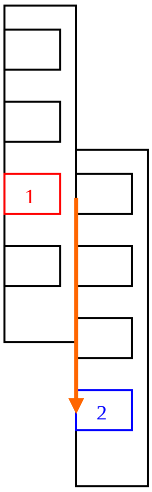
(a) Menu structure (A)



(b) Menu structure (B)



(c) Menu structure (C)

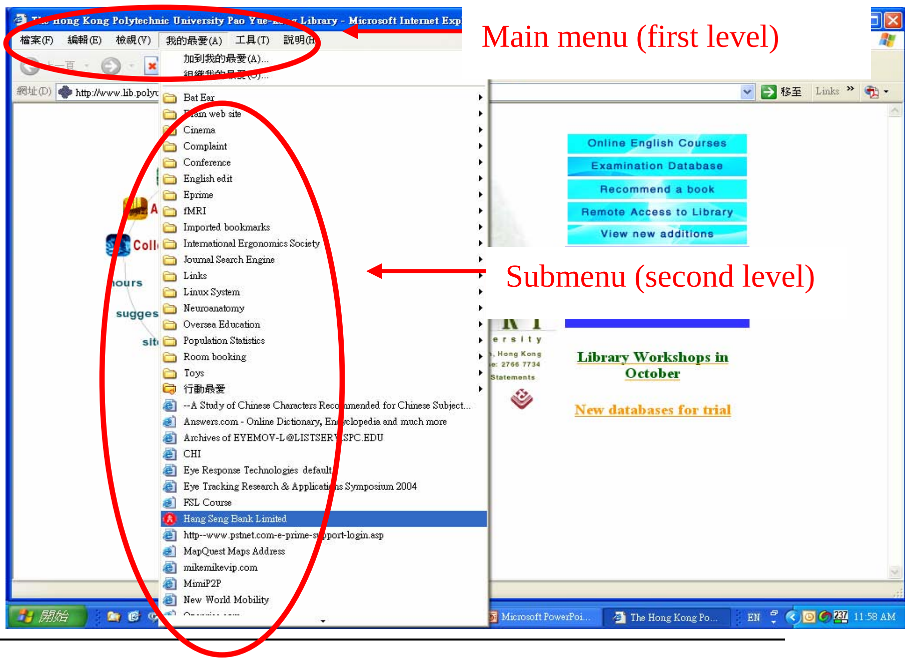


The search processes required in the design of Menu Structure A are horizontal search along the menu until half-way for the first target, followed by vertical search along the sub-menu for the the second target. Second, the search processes required in the design of Menu Structure B are vertical search followed by horizontal search. Lastly, the search processes required in Menu Structure C are two consequent vertical searches. The results indicated that the participants with mental retardation had longer scanpath durations and overall fixation durations in the horizontal- than vertical-orientation condition. Hence, it is anticipated that the design of Menu Structure C might facilitate individual's visual search along the menu. In some existing programs, such as Internet Explorer, the menu configuration follows the design of Menu Structure A, while for CorelDraw, the menu configuration follows the design of Menu Structure B (Figure 5.5). For people with visual search deficits, it is likely that these two designs are less facilitative. According to the findings, it is thus recommended that menu designs should consider modification into a structure similar to C. Nevertheless, the effectiveness and benefits of the recommended design would still need to be verified in future studies.

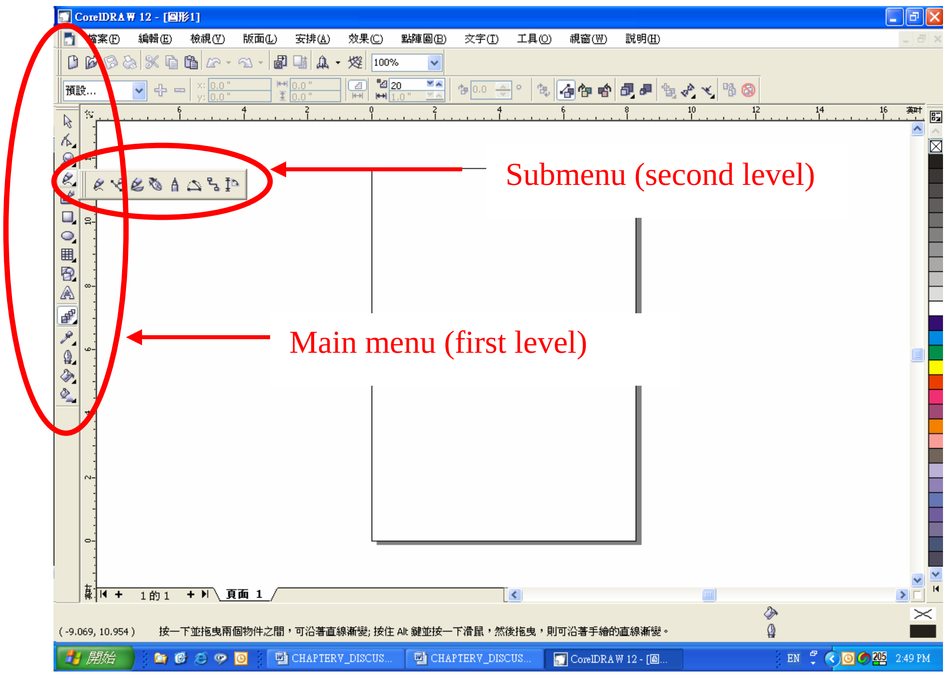
Figure 5.5

Examples of the hierarchical menu structure (A) in the Internet Explorer Web browsing software and the hierarchical menu structure (B) in the CorelDraw painting software

(a) Menu structure (A) in the Internet Explorer Web browsing software



(b) Menu structure (B) in the CorelDraw painting software



Implications for Clinical Practice

There are two major implications of our findings for clinical practice. The first one is based on the results of the IE competence test, while the second is the finding that visual search is integral to a successful operation of the human-computer interface.

Our study's findings from the IE competence test may form a good basis for developing screening and training programs for people with mental retardation and other groups with cognitive impairments, such as traumatic brain injury, to learn using IE or other human-computer interface. In general, the results indicate that those participants who had low performance in the test had limited capabilities in motor functions and had both low- (visual acuity, orientation, and attention) and high-level (working memory and language processing) cognitive abilities. Their problems rest in difficulties in using basic computer control devices such as the mouse and keyboard. The training programs for this category of potential computer users are twofold. One should aim to develop very specific training modules for improving basic computer operation skills, an example of which is using a mouse with a single click and a double click (e.g., Li-Tsang et al., 2005). Meanwhile, the other should be a perceptual-cognitive training program for improving essential functions such as orientation and attention. An example is the attention processing training program developed by Sohlberg et al. (2000). For those who had medium and high performance in the test, their performances were found to be limited by a deficiency in high-level cognitive functions only. The training programs for these two levels of potential computer users should therefore focus on the improvement of skills for more complex computer usage such as using a Web browser (e.g. Li-Tsang et al., 2005). Similarly, the skills need to be very specific and relevant to computer operation. The decision-tree classification derived in this study could also be useful for day-to-day clinical practice. It can be used as a screening test for identifying the computer competence of an individual, based on which the training programs can be assigned. The test involved testing the individual on three items which only lasts for about five minutes.

In the third study, we identified that working memory played an important role in visual search, which subsequently influenced individuals' performance in operating the human-computer interface. For further improving the capacity of individuals with mental handicaps in using the computer, training protocols with a focus on enhancing one's working memory capacity for holding visual stimuli could be useful. The content of such training modules, including the context of the task, training methods, and its link with the training of the actual operation of the human-computer interface, need to be developed and verified in future studies.

Limitations of the Study

In all three studies that comprise this project, convenience sampling was the main method adopted to recruit potential participants. In this method, individuals are chosen on the basis of availability. It was therefore not possible to know what attributes were present in those who presented themselves as participants compared with those who did not, and it is quite unclear also how these attributes may affect the generalizability of the results (Portney & Watkins, 2000). Our study's participants were recruited from among those who joined an IT training program specially designed for people with mental retardation. It is thus possible that these invited individuals would have been more interested or willing to participate than those who had not taken such a training program. Furthermore, our study's participants were those who had experience in using a computer so the opinions from those nonparticipants who were less likely to have used a computer were not fully collected; as such, the sample became further reduced to those who agreed to participate. If these other individuals had been recruited into the study, the overall performance would have declined, and the variability in the performance of the participants would have increased. Therefore, it seems that our study's results can only be generalized to individuals with mental retardation who have experience in using computer technology.

Another possible limitation of this project was the choice of appropriate cognitive and motor tests. For example, we used TONI-3 as the intelligence test to group the participants into different intellectual levels. Using TONI-3 which does not include verbal intelligence may not be the best way of estimating the full intellectual functioning of the participants. This is because the grouping of the participants according to their intellectual functioning might have changed if other intelligence tests, such as the Wechsler scale, had been used. Therefore, the results are seemingly not representative enough of people with mental retardation who have better verbal abilities. Furthermore, the selection of the ability constructs for the prediction model of IE competence for the participants with mental retardation in Study 2 was mainly based on the opinions of the expert panel members. Other factors, such as mood, personality, body orientation, and somatosensory function, that appeared to influence the IE performances of the participants were therefore not fully determined. Moreover, we sometimes selected a few instruments, or only one, to represent the entire cognitive construct. As such, some subfunctions corresponding to the relevant cognitive construct might not have been fully assessed. For example, we only used tests such as the memory subtest in the Cognistat and the Digit Span Backward to represent the whole memory construct. Some subfunctions, such as prospective memory and remote memory, which corresponded to the memory construct might not have been fully assessed, which may in turn have affected the overall prediction model.

The third limitation of this project was the choice of Internet Explorer as the core computer program for investigating the computer performance of people with mental retardation. The results obtained from this Web-browsing program seem to be limited to those programs or Web pages that involved the interaction between a graphical interface and the user. Hence, these results would not be good enough to be generalized to computer programs in which the participants would seldom need to interact with a graphical interface. For example, some programs in the LINUX system require individuals to “type the scripts” for executing actions, rather than clicking graphical icons on a visual screen. Besides, in our study, we selected Internet Explorer and Web browsing activities as the core computer program and tasks to assess participants' computer performance because we found that the Web browsing through the use of Internet Explorer was the most common computer function used by participants with mental retardation. However, as we know, different groups of people, i.e., the general population, have different preferences when using computers. Therefore, Web browsing through the use of Internet Explorer may not be the most common computer function preferred by other groups. Fortunately, previous studies showed that the mainstream population has increasingly relied on Internet-based technologies. For example, the number of Web sites operating on the Internet in United States grew to over 170 millions in 2003 (Downing et al., 2005). In 1995, there were around 10 million users of the World Wide Web and about 35 million e-mail accounts. These numbers were projected to grow to 200 million World Wide Web users and 300 million e-mail accounts by 2000 (Stanford University, 1998). A similar trend was also observed in Hong Kong, which ranked fifth in the world with respect to household access to the Internet in 2001. From 2000 to 2001, the percentage of households with computers increased from around 50% to 60% and that of households using the Internet increased from 36% to 49% (Hong Kong Special Administrative Region Government, 2001). With these evidences, it seems that Web browsing is one of the most common activities done by the mainstream population so that our results could probably be generalizable to them. Future studies can therefore explore the differences in preferences of computer program selected and tasks used among different groups of people.

The fourth limitation of this project is related to the data sampling of the eye-tracking machine. The eye tracker used in Study 3 had a low sampling rate (30 Hz), and the consequence of this low rate was the reduction of the temporal resolution for the whole data set obtained from the experiment. As a result, the precise time window for quantifying the scanpath and other eye movement parameters were not perfectly obtained. If an eye-tracking machine with a higher sampling rate had been used to collect the data in this experiment, then the temporal resolution of the data set would have been improved and hence the time window for quantifying the scanpath and calculating the fixation would have been more stable.

The fifth limitation of this project is related to the interface design recommendation drawn from the project. Though we provided some guidelines for an interface design for people with mental retardation, we did not conduct any field test to confirm the effectiveness of these design recommendations. Hence, these recommendations could be confirmed if we develop a prototype based on the design guidelines and then test their effectiveness as compared to that of original programs.

Suggestions for Future Research

The present study focused on providing information on the match and mismatch between the design of the existing human-computer interface and users who had mild to high-moderate grades of mental retardation, as well as on promoting the universal design concept for enhancing the usability of existing technological products for a wide range of individuals. This concept and technique is worth applying to other grades of mental retardation and to other populations, such as older adults or individuals with brain injuries. However, such applications might require modification of the choices of technological product, the cognitive tests, and the assessment approach used in the experiment. Moreover, a pilot study would be important to ascertain the relevance of the abovementioned factors to the target groups of these special populations.

This study focused on the deficiencies in visual search function because it emerged from our findings that this was the function which had the greatest limiting influence on the participants with mental retardation as they utilize widely used types of graphical interface like Internet Explorer. Future research should therefore investigate in more detail the mechanisms by which other functions, such as Chinese language processing and psychomotor functions, also contribute to the competence of people with mental retardation in using human-computer interface.

Our study's findings are also not able to explain clearly the mechanisms that hindered the participants with mental retardation from performing their visual search task. We have proposed that the underlying deficiencies could possibly be attributed to problems on the visual-spatial coding of stimulus pattern, storage and updating of fixation locations for planning the scanpath, or both. Further studies that design appropriate experimental paradigms to separate these two processes should thus shed light on these deficits.

In addition, gathering empirical evidence to map out the neural network of the visual search task through further study is recommended. This could be achieved using electrophysiological techniques, that is, EEG and neuroimaging techniques such as fMRI to map brain activation during the process of visual search. This would not only provide evidence on cortical activation, but more importantly, it would further consolidate a theoretical and scientific basis for the study of visual search functions of people both with and without mental retardation. In this way, more fundamental evidence would be gathered to support how we could modify the manipulation of visual elements, such as distances and orientations of menu items in a graphical display, in order to improve the interaction between users and the human-computer interface both for people with and without mental retardation.

Based on our study's findings, we offer guidelines for designing a human-machine interface that is more suitable for people with mental retardation. However, all the suggestions made for the interface design should be confirmed with empirical data. It is also clear, therefore, that future research should be carried out to develop the prototype based on the suggestions we made and then to conduct field tests for evaluating its usability and feasibility for people with mental retardation. In the same manner, it would be worthwhile to conduct cost-benefit studies to be able to determine the usability and feasibility tradeoff. Such studies might consider investigating the costs and benefits brought to the user group (including people with and without disabilities) and to technology-related corporations.

Our findings may form a good basis for software developers to design more user-centered types of graphical interface that cater to the specific profiles of people with mental retardation. Furthermore, these findings can seem to be generalized to other populations which demonstrate problems in using existing computing technologies, such as older adults. Some previous studies indicated that older adults, like people with mental retardation, have deficits in attention and visual search, language, and motor functions such as decline in selective attention and attention switching (Plude & Hoyer, 1985; Salthouse, Fristoe, McGuthry, & Hambrick, 1998), decline in visual search function (Plude & Doussard-Roosevelt, 1989; Madden, Gottlob, & Allen, 1999), decreased speed at which complex motor tasks are executed (Light & Spirduso, 1990), and decline in text comprehension (Park, 1992). These deficits could pose problems for them when using such technologies. Therefore, our suggestions for improving the design of future IE and for enhancing the universal design components of other types of human-computer interface might be seemingly applicable to them based on these findings. However, one should be cautious when generalizing these findings to other populations such as the elderly people. Although some previous studies revealed that older adults might demonstrate similar performances in visual search with people with mental retardation, the mechanisms attributed to the decline in visual search performance are not exactly the same between these two groups. In our study, the deficits in the decoding of stimulus, memory and updating of fixation locations, and planning scanpaths probably accounted for the poor performance of the people with mental retardation. However, Madden et al. (1999) and Kline and Scialfa (1997) showed that visual acuity seemed to be attributed to the decline in performance among older adults. It is hence important for readers to verify a similar underlying mechanism between the compared groups before generalizing the results reported in this study to other populations.

CHAPTER VI

CONCLUSION

The mechanisms which hinder people with mental retardation from being competent in using a computer interface are an important but underresearched topic in human-computer interaction. In response to this, the current research was divided into three interrelated studies to discover the underlying mechanisms. The first question we dealt with in the research was the following: What are the performance levels of people with mental retardation when operating a widely used computer interface such as the Internet Explorer (IE) program? To answer this question, we developed an IE competence test in which the operating process of this program was divided into 16 tasks and was further subdivided into 161 subtasks. The performances of the participants on these tasks were rated against a four-point scale. Our findings revealed that the performance of participants varied and could also be clustered into three performance levels. Two of the 16 tasks enabled us to differentiate these people into three performance groups: the general motor function task was useful for differentiating participants into low- and medium-performance groups, while the use customized bookmark task facilitated differentiation between medium- and high-performance groups.

Based on the findings of Study 1, we were able to determine that the performance of our participants with mental retardation in operating the IE program interface was varied. However, we still did not know how the mental deficiencies of these participants hindered their competence in operating the IE interface and, more importantly, which abilities were important in predicting the performance levels of these participants in operating the IE interface. To answer this question, we invited people with mental retardation to participate in the IE competence test (designed in Study 1) as well as to complete 13 tests on attention, visual-spatial memory, executive functions, language processing, and psychomotor functions. Our findings revealed that the core cognitive ability was the visual search function, followed by Chinese language processing and psychomotor functions; these were the best three functions for predicting the operation of the IE interface by people with mental retardation.

Based on the results obtained from Study 2, we selected the visual search function to explore how it limited people with mental retardation from being competent in operating the human-computer interface. We designed the visual search task based on Treisman and Gelade's (1980) Feature Integration Model in order to explore the efficiency of people with mental retardation in detecting two target stimuli embedded in a varying number of similar distractors at various distances (close, medium, and far) and orientations (horizontal, vertical, and oblique), and to compare it with that of their normal counterparts. Behavior data, or accuracy rates and response times, were thus recorded. As the participants performed the task, their oculomotor movements were recorded using the ERICA infrared corneal reflection system. Furthermore, the visual lobe shape characteristics were also measured by VILOMS (Chan & So, 2006; So, 2003), and the findings revealed that the participants with mental retardation had smaller visual lobes than their normal counterparts. They were less likely to use the typical search strategies than their normal counterparts, and they tended to form additional fixations and reexamine previously inspected locations more than their normal counterparts. Moreover, both the behavioral and eye movement results showed that the participants with mental retardation had lower performances on the visual search task than their normal counterparts. These findings provide a sensible model to explain why our study's participants with mental retardation had substantial problems in operating the human-computer interface compared with their normal counterparts. Their deficiency in visual search function as reflected in the findings is the greatest limiting factor which hinder people with mental retardation from effectively utilizing a computer. In the model that we adopted in this study, we believed that this problem possibly began with the smaller visual lobes of people with mental retardation, which confined their visual attentional field. As a result, they needed to form more fixations, in the manner of a spotlight, and shift this spotlight attention from one location to another more often than their normal counterparts. Their problems seem to be coupled also with deficits in spatial working memory, as well as deficits in coding the spatial configuration of the visual display and updating fixation locations. These deficits were reflected in the lack of consistent search strategies, and the longer scanpath durations and overall fixation durations compared with those of the normal participants. Because of their lower spatial working memory, the participants with mental retardation tended to forget what they had previously scanned. In addition, because of problems in spatial coding of the stimulus configuration, they tended to fail to construct the visual-spatial representation in which the search path strategies were formed. Moreover, the lower working memory of the participants with mental retardation reduced their capacity to store and update the executed eye movements, which in turn increased the time they needed to search and process the target stimuli in the visual display.

The findings regarding the visual lobe further revealed that the participants had smaller visual lobes than their normal counterparts. This result was found to be useful in providing recommendations on the size of computer icons. Particularly, the findings regarding the testing of efficiency in detecting two target stimuli at various distances and orientations revealed that the participants required a shorter time to search for and interpret the target stimuli aligned in the vertical orientation and at a shorter distance. These results were found to be useful in providing recommendations on the design of a human-computer interface, such as icon size, menu alignment, menu breadth, and the arrangement of menu items in hierarchical menus, for people with mental retardation.

Our study has attempted to adopt the principles of universal design for designing a human-computer interface, which should take into account the needs of everyone, including those with restricted abilities such as people with mental retardation. In view of this, basing the design of a human-computer interface on the suggestions we have made is considered useful for accommodating people with mental retardation in using such interface. Nevertheless, people with mental retardation, compared with their normal counterparts, are likely only to be able to search the visual stimuli in a relatively simple user interface, that is, with the visual items aligned at a shorter distance and with a vertical orientation. This would inevitably result in a reduction in functionality for all users, particularly for normal populations and for those who can successfully operate a more complex user interface. For example, normal participants would have no restriction in searching icons in a far-distance condition. Therefore, to accommodate the restricted abilities of people with mental retardation, we have suggested that the breadth of a single menu would be better manipulated at a medium distance. As compared to a far-distance menu, fewer icons would remain, which in turn would reduce the number of “function” keys placed in a single menu. This indicates that enhancing the human-computer interface to increase usability for people with mental retardation has an impact on the functionality of the product. When redesigning a graphical user interface to give it greater usability by people with mental retardation, the consequence is likely to take the form of a restriction on the number of functions that could remain in place in the interface. In this vein, it would thus be worthwhile to conduct cost-benefit studies to optimize the tradeoff between usability and functionality. Such studies should investigate the advantages and drawbacks of adopting a universal design for designing a human-computer interface for both users and interface designers. These would also stimulate further research on the feasibility of the adoption of a universal design for modifying modern technology to accommodate other grades of mental retardation, or other diagnostic groups.

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Appendix I

Descriptions and Quantification Methods of the 16 Shape Indices in the VILOMS Program

Sphericity

Sphericity mainly compares the shape of an object to a circle, which represents the most compact shape among all geometric figures. The Form Factor and Perimeter-Area Ratio measures are calculated based on the relationship between the perimeter and area, and yields a value of 0 for a line and 1 for a circle. The index for the Form Factor is expressed as

$$\frac{4\pi(\text{Area\_of\_the\_Shape})}{(\text{Perimeter\_of\_the\_Shape})^2}$$

The index for the Perimeter-Area Ratio is expressed as

$$\frac{\sqrt{\text{Area\_of\_the\_Shape}}}{0.282 * \text{Perimeter\_of\_the\_Shape}}$$

Perimeter-Area Ration of the Convex Hull is another similar but modified measure which uses a convex hull of the respective shape instead of computing the perimeter/area ratio of the shape itself. A convex hull is the minimum enveloping boundary fitted to a shape that has no concavity. The index of the Perimeter-Area Ration of the Convex Hull is expressed as

$$\frac{4\pi(\text{Area\_of\_Convex\_Hull})}{(\text{Perimeter\_of\_Convex\_Hull})^2}$$

Two other sphericity measures are based on the diameter and the area of the smallest circle that circumscribe the shape and the circle having the same area as the shape of the visual lobe. The index of the Area-Maximum Area Ratio and the index of the Ratio of Radii are yielded to increase from 0 (straight line) to 1 (circle) with increasing sphericity. The index of the Area-Maximum Area Ratio is expressed as

$$\frac{Area\_of\_the\_Shape}{Area\_of\_Smallest\_Circumscribing\_Circle}$$

The index of the Ratio of Radii is expressed as

$$\frac{Radius\_of\_a\_circle\_having\_the\_same\_area\_as\_the\_shape}{Radius\_of\_the\_circumscribing\_circle}$$

Boundary Smoothness

Some measures of Boundary Smoothness, including the Global Convex Deficiency and the Rugosity, are convex hull related. The Global Convex Deficiency depicts the porosity between the “porosity” between the nominal shape defined by the convex hull and the actual shape outline. It yields a value of 0 for an absolutely smooth shape without indentations and approaches 1 as the shape becomes rougher. The index of the Global Convex Deficiency is expressed as

$$\frac{(Area\_of\_Convex\_Hull - Area\_of\_Shape)}{Area\_of\_Convex\_Hull}$$

Rugosity yields a value of 1 for smooth shape and increases when the shape becomes rougher. The index of the Rugosity is expressed as

$$\frac{(Perimeter\_of\_the\_Particle\_Outline)}{(Perimeter\_of\_the\_Convex\_Hull)}$$

A non-convex hull measure of Boundary Smoothness is Spike Parameter which is a measure of abrasivenss. This index yields a value of 1 for shapes which are absolutely smooth and decreases towards 0 when the shape becomes more angular.

For details of the mechanism deriving the index, please refer to the work of So (2002).

Symmetry

Symmetry depicts how similar two halves of the shape are when a shape is divided through the imaginary vertical or horizontal axes. Horizontal Vertices Symmetry is expressed as

$$\frac{\sum |X_{Ri} - X_{Li}|}{\sum (X_{Ri} + X_{Li})}$$

where X_{Ri} and X_{Li} are the horizontal distances of the vertices of the *i*th right and left meridians from the vertical axis being compared. Similarly, Vertical Vertices Symmetry is expressed as

$$\frac{\sum |X_{Ti} - X_{Bi}|}{\sum (X_{Ti} + X_{Bi})}$$

where X_{Ti} and X_{Bi} are the vertical distances of the vertices of the *i*th top and bottom meridians from the horizontal axis being compared. They yield a value of 0 for symmetric shapes and increase until 1 as the shape becomes more asymmetric.

The concept of Area Symmetry can be formulated similarly. The Left-Right Area Symmetry is expressed as

$$\frac{|L - R|}{L + R}$$

where L is the area of the left quadrants. while R is the area of the right quadrants. The Top-Bottom Area Symmetry is expressed as

$$\frac{|T - B|}{T + B}$$

where T is the area of the upper quadrants, while B is the area of the lower quadrants. Both measures yield a value of 0 for symmetric shapes and increase to 1 as shapes become more asymmetric.

The Horizontal Symmetry of the Convex Hull and the Vertical Symmetry of the Convex Hull are defined in terms of half-widths of the convex hull. The index of the Horizontal Symmetry of Convex Hull is expressed as

$$\frac{W_{\max\ L}}{W_{\max\ R}}$$

where $W_{\max L}$ and $W_{\max R}$ are the half-widths of the left and right halves of the convex hull, respectively. Similarly, the index of the Vertical Symmetry of the Convex Hull is defined as

$$\frac{W_{\max\ B}}{W_{\max\ T}}$$

where $W_{\max B}$ and $W_{\max T}$ are the half-widths of the bottom and top halves of the convex hull, respectively. The value of 1 is obtained for symmetric shapes. Values smaller than 1 will result for shapes which have longer top and right half-widths, while values larger than 1 as the bottom and left half-widths become longer.

Elongation

A measure of the degree of elongation can be made with the Length-Width Ratio which is expressed as

$$\frac{L}{B}$$

where B is the greatest width and L is the greatest length. Here, L and B are measured horizontally and vertically, respectively. The measure yields a value of 1 for a square.

A value smaller than 1 indicates that the shape is vertically elongated, while a value larger than 1 indicates that the shape is horizontally elongated.

Regularity

A Boyce-Clark Index is developed based on a radial line method for comparing a shape to a standard. The index is expressed as

$$1 - \frac{\sum \left| \left(r_i / \sum r_i \right) \times 100 - (100/n) \right|}{200}$$

where r_i is the length of radial i from a reference point, and n is equal to the number of radials used. The range of values is from 1 for a circle to 0 for a straight line. In this study, the foveal fixation point is defined as the reference point for radials. The number of radials used is 24 as the lobe shapes are mapped on a 24-meridian basis.

Appendix II

Information Sheet and Informed Consent Form for Study 1 – Phase 1

參加者同意書

研究題目

製作給予弱智人仕電腦科技的心理及腦部功能的參數。

研究人員

副教授　　陳智軒博士
副教授　　李曾慧平博士
教授　　　林就勝博士
研究生　　黃榮楷先生

研究內容

研究弱智人仕操作電腦科技所遇到的困難及確認操作電腦科技時所需的心理及腦部功能指數，從而發展一個更適宜弱智人仕操作的電腦科技。

參加者將會被邀請做一個個別訪問，調查有關弱智人仕操作電腦科技的問題，約時十分鐘。是次訪問所得的資料有助找出弱智人仕利用電腦科技時的常用操作，常用的電腦軟件及操作電腦科技時所遇到的困難。

在整個研究過程中不會對參加者構成任何危險，參加者將不會與本項研究構成任何直接利益。

同意書

本人______________________之家長明白此項研究之細節，並聲明自願同意參加者參加此項研究。我明白可以隨時在不需作出解釋之情況下退出此項研究，而將不會受到處罰或歧視。我悉知參與本研究可能帶來之影響及願意對此承擔一切責任。我明白參加者之個人資料將不會向本研究以外之人仕公開，並且參加者的姓名或照片將不會出現於任何研究之報告內。

本人可致電 27667090 向研究員黃榮楷先生，或致電 27666727 向陳智軒博士查詢本研究事項，若果我對研究員有任何投訴，可致電 27665397 與梁小姐接洽。我將授予簽署同意書副本一份。

簽署 (參加者 或 參加者家長):　　　　　　　　日期:

簽署 (見證人):　　　　　　　　　　　　　　　日期:

Appendix III

Questionnaire for Computer Utilization by People with Mental Retardation for Study 1 – Phase 2

有關弱智人仕操作電腦科技調查

研究題目:
製作給予弱智人仕電腦科技的心理及腦部功能的參數
研究人員:
副教授陳智軒博士、副教授李曾慧平博士、教授林就勝博士、研究生黃榮楷先生

參加者姓名 : ________________　　學員編號: ________________
日期：______年______月______日　　課程編號: ________________

一、　個人背景（**請在適合的項目旁的□劃上 X**）

1) 年齡 : __________
2) 性別：□ 男　　□ 女
3) 診斷 {可選擇多於一項}:
□ 輕度弱智　□ 中度弱智　□ 嚴重弱智　□ 自閉症
□ 唐氏綜合症　□ 過度活躍症　□ 其他 (請註明: ________________)
4) 病歷：
□ 沒有　　□ 有（請註明：________________________）

5) 已知的上肢功能障礙：
□ 沒有　　□ 有（請註明：________________________）

6) 已知的大腦功能障礙，如讀寫困難、腦痙攣等：
□ 沒有　　□ 有（請註明：________________________）

7) 最高教育程度：

正規教育	特殊教育
□ 小學程度	□ 小學程度 (P.1-3)
□ 中學程度	□ 小學程度 (P.4-6)
□ 大專程度或以上	□ 中學程度 (F.1-3)
	□ 中學程度 (F.4-7)

8) 職業 :
□ 沒有　　□ 學生　　□ 日間中心學員
□ 展能訓練中心
(請註明主要訓練項目如家務訓練、包製訓練、電腦練:__________________________)
□ 庇護工場 (請註明工作類別如包製、電腦　字: ________________________________)
□ 輔助就業 (請註明工類: ____)

□ 公開就業 (請註明工類: ____)

二、 <u>應用電腦的經驗</u>

1) 你曾否使用過電腦（如：玩電腦遊戲、文書處理，瀏覽網頁等）?
□有 □ 沒有 (如沒有，請跳答第 17-19 條)

2) 當你用電腦時，你需要輔助工具如改裝滑鼠、特設給傷殘人士用的軟件或其他硬件?
□ 不需要 □ 需要 (如需要，請註明: ____________________)

3) 你通常在那裡使用電腦?
□ 家中 □ 學校 □日間中心
□ 展能訓練中心 □ 公司 (指庇護工場、輔助就業、公開就業工作的地方)
□ 餐廳 □ 其他 (請註明: _________________)

4) 你通常使用電腦作什麼用途?
□ 玩電腦遊戲
(請答第 5-6 條，再答第 16,18,19 條)

□ 文字處理
(請答第 7-8 條，再答第 16,18,19 條)

□ 上網尋找資訊 (請註明: □ 新聞 □ 娛樂、如音樂 □ 卡通 □ 其他:________)
(請答第 9-11 條，再答第 16,18,19 條)

□ 上網通訊 (請註明: □ ICQ □ MSN □ 電郵 □ 其他:______________)
(請答第 12-13 條，再答第 16,18,19 條)

□ 其他用途如畫畫、音樂播放等 (請註明: ____________________________________)
(請答第 14-15 條，再答第 16,18,19 條)

5) 當你**玩電腦遊戲**時，你會選擇什麼軟件?

■ <u>感官刺激遊戲</u>
(指一些娛樂性豐富的遊戲軟件，透過此類遊戲可以達到官能刺激和娛樂作用)

□ Blaster Ball 2 □ 射擊遊戲
□ 小朋友齊打交 □ 其他 (請註明: _____________)

■ <u>教育性遊戲</u>
(指一些著重教學的遊戲軟件，透過此類遊戲可以學習到新知識和學問)

□ 百萬富翁 □ 尋字遊戲
□ TOSS WORDS □ 其他(請註明: ______________)

■ <u>治療性遊戲</u>
(指一些著重改善能力的遊戲軟件，透過此類遊戲可以提升記憶力、認知能力等))

□ 折磚仔 □ Super Collapse
□ 迷宮 □ 其他(請註明: ______________)

6) 請講出選擇該軟件的原因 (軟件名稱: ________________________________) ?

____
____
____

7) 當你要**文字處理**時，你會選擇什麼軟件?
□ Microsoft Word □ Microsoft Excel
□ WorkPad □ 其他 (請註明: ______________)

8) 請講出選擇該軟件的原因 (軟件名稱: ________________________________) ?

____
____
____

9) 當你**上網尋找資訊**時，你會選擇什麼軟件?
□ Internet Explorer □ Netscape Communicator
□ 其他 (請註明: ______________)

10) 請講出選擇該軟件的原因 (軟件名稱: ________________________________) ?
____
____
____

11) 請問你常瀏覽那些網頁?
____
____
____

12) 當你**上網通訊**時，你會選擇什麼軟件?
□ ICQ □ MSN
□ 電郵 □ 其他 (請註明: ______________________________)

13) 請講出選擇該軟件的原因 (軟件名稱: ________________________________) ?

____

____

____

14) 當你**使用其他軟件如小畫家、音樂播放時**，你會選擇什麼軟件?

☐ 小畫家 ▫ Real Player

☐ Winamp ▫ Windows Media Player

▫ 其他 (請註明: ____________)

15) 請講出選擇該軟件的原因 (軟件名稱: ________________________________) ?

____

____

____

16) 當你使用電腦時，你有否面對困難？

▫ 沒有 ▫ 有 (如有，請給以下詳細資料)

(a) <u>在電腦方面:</u>

{導引問題：一、操作程序複雜; 二、版面複雜如太多按鈕；三、在網頁或軟件設計上運用英文作為通媒介等等。}

____

____

____

(b) <u>在自己方面:</u>

{導引問題：一、不懂文字只懂周圖像; 二、不懂英文； 三、不懂打字； 四、串字困難/詞彙少； 五、欠缺良好專注力； 六、欠缺良好配對能力； 七、欠缺良好記憶力； 八、欠缺良好計劃能力； 九、欠缺良好決定能力； 十、欠缺良好抽象思考能力； 十一、欠缺良好視覺空間能力； 十二、欠缺良好手指操作能力； 十三、欠缺良好姿勢或穩定能力等等。}

____

____

____

(c) <u>在當你運用電腦方面:</u>

{導引問題：一、找不到需要按的按鈕; 二、不能認出營光幕上的文字格式如在學校只學大揩不懂小楷英文； 三、不能自我監督有否打錯字或按錯按鈕等等。}

____

____

____

17) 如果沒有任何使用電腦的經驗，請講出主要原因：

（導引問題：一、沒有機會接觸；二、電腦太貴；三、沒有人可以教導使用；四、害怕或擔心電腦複雜；　五、沒有一個適合弱智人仕能力使用的軟件等等。）

____

____

18) 假設現在有一個無障外軟件發明，你最想用電腦作什麼用途?

☐ 玩電腦遊戲
□ 文字處理
☐ 上網尋找資訊 (請註明: □ 新聞 □ 娛樂、如音樂 □ 卡通 □ 其他:________)
☐ 上網通訊 (請註明: □ ICQ □ 電郵 □ 其他:_______________)
□ 其他用途 (請註明: __________________)

19) 有什麼你想可以幫助應用電腦？

____

____

____

20) 當你用電腦時，你常用那個操作系統？

□ Windows 98　　□ Windows 2000
□ Windows ME　　□ Windows XP
□ Linux　　□ Macintosh OS
☐ 其他 (請註明: ______________________________)

21) 當你利用瀏覽工具時，你常用那些功能？

☐ 瀏覽網頁　　□ 檢視網站記錄
☐ 閱讀及傳送電子郵件　　□ 利用我的最愛加入及選取喜愛的網頁
☐ 調整字型大小　　□ 儲取網頁
☐ 編碼　　□ 利用 Microsoft Frontpage 編輯網頁
☐ 列印網頁　　□ 利用搜尋引擎 MSN Web Search 搜尋網頁
☐ 討論　　□ 利用搜尋引擎 雅虎香港 搜尋網頁
☐ 其他 (請註明: ______________________________)

Appendix IV

Lists of Mental and Physical Ability Items for Coding the IE Tasks and Subtasks

Mental Functions	Definitions
1. Orientation	The process of using the senses to establish one's position and relationship to all other significant objects in one's environment (Case-Smith, Allen, & Pratt, 1996, p.730).
2. Sustained attention/ Vigilance	The ability to maintain information over a period of time (Cornish, Munir, & Cross, 2001).
3. Selective attention	The ability to select relevant stimuli while ignoring or inhibiting irrelevant information (Cornish et al., 2001).
4. Divided attention	The ability to attend to more than one source of information simultaneously (Cornish et al., 2001).
5. Visual scanning	The exploration of space by eye movements (Grieve, 2000, p. 161). It refers to two types of eye movements that are used to gather information from the environment: (1) Visual pursuit or tracking–the continued fixation on a moving object so that the image is maintained continuously on the fovea; (2) Saccadic eye movements or scanning–a rapid change of fixation from one point in the visual field to another (Case-Smith et al., 1996, p. 359).
6. Color perception/ discrimination	The ability to distinguish among colors with different light wavelengths.
7. Shape perception/ discrimination	The ability to distinguish among different shapes.
8. Size perception/ discrimination.	The ability to distinguish among different sizes of figures or patterns.
9. Left-right discrimination	The ability of differentiating one side from the other (Watson, 1997).
10. Immediate recall	This refers to registration or sensory memory–the ability to hold large amounts of incoming information briefly (1 or 2 seconds at most) in sensory memory before passing these on to short-term memory (Grieve, 2000, p. 56).
11. Delay recall	This refers to short-term memory/storage (primary memory)–the ability to hold information from the sensory memory lasting for up to 30 seconds before it is either transferred to permanent record (long-term memory) or lost due to interference from new items coming in. (Grieve, 2000, p. 56). It is differentiated from working memory because delay recall is highly attention dependent, dissipating rapidly with distraction.
12. Working memory	A short-term memory used to hold information temporarily while engaged in another task (e.g., in mental arithmetic, remembering the total of the columns added up so far while doing the rest of the sum) (Stuart-Hamilton, 1995). It also refers to the temporary storage of visuospatial and speech-based information controlled by a central executive

	(Grieve, 2000, p. 162).
13. Remote memory (long-tem memory)	Memory that stores and processes information over periods of time from a few minutes to many years (Grieve, 2000, p. 160).
14. Number concept	A concept which refers to stored mental representations of a set of objects, actions, or events that share certain characteristics (Grieve, 2000, p. 159). This refers to a set of numerical concepts, e.g., 1, 2, 3, 4, etc…
15. Alphabet concept	A concept that is the stored mental representations of a set of objects, actions, or events that share certain characteristics (Grieve, 2000, p. 159). This refers to a set of alphabetic concepts, e.g., a, b, c, d, etc…
16. Object recognition	The ability to note the key features of a stimulus (object, e.g., mouse, keyboard, etc…) and relate them to memory. This depends on the integration of visual perception with stored knowledge of known objects (Case-Smith et al., 1996, p. 361; Grieve, 2000, p. 27).
17. Chinese word recognition	The ability to note the key features of a stimulus (Chinese word, e.g., "確定", "取消" and etc…) and relate them to memory. This depends on the integration of visual perception with stored knowledge of known objects (Case-Smith et al., 1996, p. 361; Grieve, 2000, p. 27). It also involves the reading process responsible for recognizing the shape of the whole word (Stuart-Hamilton, 1995).
18. English word recognition	The ability to note the key features of a stimulus (English word, e.g., "cancel", "ok," etc…) and relate them to memory. This depends on the integration of visual perception with stored knowledge of known objects (Case-Smith et al., 1996, p. 361; Grieve, 2000, p. 27). It also involves the reading process responsible for recognizing the shape of the whole word (Stuart-Hamilton, 1995).
19. Graphic recognition	The ability to note the key features of a stimulus (graphic or figure, e.g., "Home" logo, "I.E. icon," etc…) and relate them to memory. This depends on the integration of visual perception with stored knowledge of known objects (Case-Smith et al., 1996, p. 361; Grieve, 2000, p. 27).
20. Visuospatial abilities	This term refers to the following three abilities: (1) Position in space─the determination of the spatial relationship of figures and objects to oneself or other forms and objects; (2) Depth perception─the determination of the relative distance between objects, figures, or landmarks and the observer and changes in planes of surfaces; and (3) Topographical orientation─the determination of the location of objects and settings and the route of location (Case-Smith et al., 1996, p. 361).
21. Figure-ground	The isolation of a shape or an object from its background (Grieve, 2000, p. 159).
22. Constancy	The recognition of objects as the same in various environments, positions, and sizes even though there are

	variations in their image on the retina (Case-Smith et al., 1996, p. 361; Grieve, 2000, p. 26).
23. Cognitive processing speed	The speed at which the thinking processes that enable people to perceive events including paying attention, storing information in the memory, recalling information, and making sense of events.
24. Response inhibition	The ability to inhibit overlearned responses in favor of an unusual one.
25. Command comprehension	The ability to understand an item (typically, a passage of text) (Stuart-Hamilton, 1995).
26. Planning	Any hierarchical process in the organism that can control the order in which a sequence of operations is to be performed (Kirlik & Bisantz, 1999).
27. Decision making	The ability to reason about uncertain decision alternatives in ways that correspond to mathematical probability, and the alternative with the highest expected benefits or utilities could be determined (Kirlik & Bisantz, 1999).
28. Abstract thinking	The ability to comprehend abstract ideas and representations (Cromby, Standen & Brown, 1996). It is the same as abstract intelligence: the ability to process abstract concepts (Stuart-Hamilton, 1995).
29. Reasoning	The ability of logical thinking, comprehension of relationships and practical judgments.
30. Concept formation	The ability to detect similarities between discriminable objects and to treat such objects as a class or category in which the process essentially involves learning the common properties that characterize a class of discriminable stimuli.

Note. Visual scanning and left-right discrimination were added to the original list of ability items by the panel members.

Physical Functions	Definitions
1. Auditory	The ability to be aware of and interpret sounds, and to discriminate background sounds. (Watson, 1997)
2. Tactile	The ability to be aware of and interpret light touch, pressure, temperature, pain, and vibration through skin contact/ receptor. (Watson, 1994)
3. Propriception	The ability to be aware of and interpret stimuli originating in the muscles, joints, and other internal tissues that give information about the position of one body part in relation to another. (Watson, 1994)
4. Visual acuity	The capacity to discriminate the fine details of objects in the visual field (Case-Smith et al., 1996, p. 359).
5. Stabilizes	Stabilizing the body for balance (Fisher, 2003).
6. Aligns	Aligning the body in a vertical position (Fisher, 2003).
7. Positions	Positioning the body or arms appropriate to the task (Fisher, 2003).
8. Walks	Moving about the task environment (level surface) (Fisher, 2003).
9. Reaches	Reaching for task objects (Fisher, 2003).
10. Bends or rotates	Bending or rotating the body appropriate to the task (Fisher, 2003).
11. Coordinates	Coordinating two body parts to securely stabilize task objects (Fisher, 2003).
12. Manipulates (dexterity)	Manipulating task objects (Fisher, 2003).
13. Flows	Executing smooth and fluid arm and hand movements (Fisher, 2003).
14. Moves	Pushing and pulling task objects on level surfaces or opening and closing doors (Fisher, 2003).
15. Transports	Transporting task objects from one place to another (Fisher, 2003).

16. Lifts	Lifting objects used during the task (Fisher, 2003).
17. Calibrates	Regulating the force and extent of movement (Fisher, 2003).
18. Grips (power)	Maintaining a secure power grasp on task objects (Fisher, 2003).
19. Grips (lateral pinch)	Maintaining a secure lateral pinch on task objects (Fisher, 2003).
20. Endures	Enduring for the duration of the task performance (Fisher, 2003).
21. Paces	Maintaining an even and appropriate pace during task performance (Fisher, 2003).
22. Release	The intentional letting go of an object from the hand or a finger at a specific time and place (Case-Smith et al., 1996, p. 268).
23. Eye-hand coordination	This refers to visual-motor integration: the ability of coordinating the interaction of information from the eyes, with body movement during activity (Watson, 1997).

Appendix V

Information Sheet and Informed Consent Form for Study 1 – Phase 3

參加者同意書

研究題目

製作給予弱智人仕電腦科技的心理及腦部功能的參數。

研究人員

副教授　　陳智軒博士
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研究生　　黃榮楷先生

研究內容

研究弱智人仕操作電腦科技所遇到的困難及確認操作電腦科技時所需的心理及腦部功能參數，從而發展一個更適宜弱智人仕操作的電腦科技。
參加者將會被邀請參與為時約一小時的測試，第一部份是完成一個智力評估，第二部份是做一個電腦應用測試，調查有關弱智人仕操作電腦科技的情況。是次調查所得的資料有助找出弱智人仕操作電腦科技時所遇到的困難，並找出那些主要的步驟使弱智人仕不能如常操作電腦科技，作為日後修改電腦科技程式參考之用。
在整個研究過程中不會對參加者構成任何危險，參加者將不會與本項研究構成任何直接利益。

同意書

本人______________________之家長明白此項研究之細節，並聲明同意參加者自願參加此項研究。我明白可以隨時在不需作出解釋之情況下退出此項研究，而將不會受到處罰或歧視。我悉知參與本研究可能帶來之影響及願意對此承擔一切責任。我明白參加者之個人資料將不會向本研究以外之人仕公開，並且參加者的姓名或照片將不會出現於任何研究之報告內。

本人可致電 27667090 向研究員黃榮楷先生，或致電 27666727 向陳智軒博士查詢本研究事項，若果我對研究員有任何投訴，可致電 27665397 與梁小姐接洽。我將授予簽署同意書副本一份。

簽署 (參加者 或 參加者家長):　　　　　　　日期:

簽署 (見證人):　　　　　　　　　　　　　日期:

Appendix VI

IE Competence Test Form

		1	2	3	4
General orientation and recognition	Mouse Keyboard Screen (monitor) Central processing unit Printer Speaker Moving the cursor through the mouse Pressing the keyboard Watching the screen (monitor) Distinguishing the left and right buttons on the mouse Distinguishing the alphabet, numbers, and function keys in the keyboard				
General motor functions	Single click in the left mouse button Release after clicking Double click in the left mouse button within 1 second Press key "A" Press key "B" and release Press key "C" and release within 1 second Hold and move the mouse from the top left to the right bottom of the screen Drag the mouse to move the "My Computer" icon into the right bottom corner of the screen				
General language functions	Read words "上一頁" on Internet Explorer's first page Explain words "上一頁" on Internet Exlorer's first page Read graphic "停止 logo" on Internet Explorer's first page Explain graphic "停止 logo" on Internet Explorer's first page				
Shut down the computer	Know the target area ("開始" icon) Move and locate the cursor onto the target area (" 開始" icon) Single click the target area (" 開始" icon) with the left mouse button				
	Know the target area ("關機" icon) Move and locate the cursor onto the target area ("關機" icon) Single click the target area ("關機 " icon) with the left mouse button				
	Know the target area ("關閉這台電腦" icon) Move and locate the cursor onto the target area ("關閉這台電腦" icon) Single click the target area ("關閉這台電腦" icon) with the left mouse button				
	Know the target area ("確定" icon) Move and locate the cursor onto the target area ("確定" icon) Single click the target area ("確定" icon) with the left mouse button				
Turn on the computer	Know the power button in the computer Know the power button in the screen (monitor) Press the power button in the computer Press the power button in the screen (monitor)				
Start Web browser	Know the target area ("I.E." icon) Move and locate the cursor onto the target area ("I.E." icon) Double click the target area ("I.E." icon) with the left mouse button				
Close Web browser	Know the target area ("x" icon)				
	Move and locate the cursor onto the target area ("X" icon) Single click the target area ("x" icon) with the left mouse button				
		1	2	3	4

Add bookmark	Know the target area ("我的最愛" icon) Move and locate the cursor onto the target area ("我的最愛" icon) Single click the target area ("我的最愛" icon) with the left mouse button				
	Know the target area ("加到我的最愛" icon) Move and locate the cursor onto the target area ("加到我的最愛" icon) Single click the target area ("加到我的最愛" icon) with the left mouse button				
	Know the target area (words end in "名稱" bar) Move and locate the cursor onto the target area (words end in "名稱" bar) Single click the target area (words end in "名稱" bar) with the left mouse button Press the "Backspace" key in the keyboard until all words are deleted Press on keys "R" and "S" in the keyboard for renaming Check whether the words were pressed correctly or not				
	Know the target area ("確定" icon) Move and locate the cursor onto the target area ("確定" icon) Single click the target area ("確定" icon) with the left mouse button				
Explore Web site	Know the target area ("網址" bar) Move and locate the cursor onto the target area ("網址" bar) Single click the target area ("網址" bar) with the left mouse button				
	Recall the Web site address Press on the keys in the keyboard for the Web site address (www.yahoo.com.hk) Check whether the words were pressed correctly or not Press "Enter" key in the keyboard				
Use customized bookmark	Know the target area ("我的最愛" icon) Move and locate the cursor onto the target area ("我的最愛" icon) Single click the target area ("我的最愛" icon) with the left mouse button				
	Recall the name of that Web site already present Know the target area ("雅虎香港" icon) Move and locate the cursor onto the target area ("雅虎香港" icon) Single click the target area ("雅虎香港" icon) with the left mouse button				
Direct print	Know the target area ("列印" icon) Move and locate the cursor onto the target area ("列印" icon) Single click the target area ("列印" icon) with the left mouse button				
Indirect print	Know the target area ("檔案" icon) Move and locate the cursor onto the target area ("檔案" icon) Single click the target area ("檔案" icon) with the left mouse button				
	Know the target area ("列印" icon) Move and locate the cursor into the target area ("列印" icon) Single click the target area ("列印" icon) in the left mouse button				
	Know the target area (words end in "份數" bar) Move and locate the cursor onto the target area (words end in "份數" bar) Single click the target area (words end in "份數" bar) with the left mouse button Press the "Backspace" key in the keyboard until all words are deleted				
	Press on the key "2" in the keyboard				
	Know the target area ("列印範圍") Move and locate the cursor onto the target area ("列印範圍") Know the target area ("頁數" icon) Move and locate the cursor onto the target area ("頁數" icon)				

	Single click the target area ("頁數" icon) with the left mouse button				
	Know the target area ("確定" icon) Move and locate the cursor onto the target area ("確定" icon) Single click the target area ("確定" icon) with the left mouse button				
Save Web site	Know the target area ("檔案" icon) Move and locate the cursor onto the target area ("檔案" icon) Single click the target area ("檔案" icon) with the left mouse button				
	Know the target area ("另存新檔" icon) Move and locate the cursor onto the target area ("另存新檔" icon) Single click the target area ("另存新檔" icon) with the left mouse button				
	Know the target area ("儲存於" bar) Move and locate the cursor onto the target area ("儲存於" bar) Single click the target area ("儲存於" bar) with the left mouse button				
	Know the target area ("我的文件" icon) Move and locate the cursor onto the target area ("我的文件" icon) Single click the target area ("我的文件" icon) with the left mouse button				
	Know the target area (words end in "檔案名稱" icon) Move and locate the cursor onto the target area (words end in "檔案名稱" icon) Single click the target area (words end in "檔案名稱" icon) with the left mouse button Press the "Backspace" key in the keyboard until all words are deleted Press on the keys "Ctrl+B," "Ctrl+A," "Ctrl+L," and "Ctrl+L" in the keyboard for renaming Check whether the words were pressed correctly or not				
	Know the target area ("存檔" icon) Move and locate the cursor onto the target area ("存檔" icon) Single click the target area ("存檔" icon) with the left mouse button				
Open saved Web site	Recall the location of the Web site saved, e.g., 我的文件 Know the target area (e.g., "我的文件" icon) Move and locate the cursor onto the target area (e.g., "我的文件" icon) Double click the target area (e.g., "我的文件" icon) with the left mouse button				
	Know the target area (e.g., "BALL" I.E. icon) Move and locate the cursor onto the target area (e.g., "BALL" I.E. icon) Double click the target area (e.g., "BALL" I.E. icon) with the left mouse button				
Use search engine	Know the target area ("網址" bar) Move and locate the cursor onto the target area ("網址" bar) Single click the target area ("網址" bar) with the left mouse button Recall the Web site address Press on the keys in the keyboard for the Web site address (www.yahoo.com.hk) Check whether the words were pressed correctly or not				
	Press the "Enter" key in the keyboard				
	Know the target area ("娛樂") Move and locate the cursor onto the target area ("娛樂") Single click the target area ("娛樂") with the left mouse button Know the target area ("上一頁" icon) Move and locate the cursor onto the target area ("上一頁" icon) Single click the target area ("上一頁" icon) once				
	Know the target area ("休閒與生活") Move and locate the cursor onto the target area ("休閒與生活")				

	Single click the target area ("休閒與生活") with the left mouse button				
	Know the target area ("遊戲") Move and locate the cursor onto the target area ("遊戲") Single click the target area ("遊戲") with the left mouse button Know the target area ("上一頁" icon) Move and locate the cursor onto the target area ("上一頁" icon) Single click the target area ("上一頁" icon) twice				
	Know the target area ("電腦與互聯網") Move and locate the cursor onto the target area ("電腦與互聯網") Single click the target area ("電腦與互聯網") with the left mouse button				
	Decide to search further with given words, e.g., "電腦遊戲" Know the target area ("電腦遊戲") Move and locate the cursor onto the target area ("電腦遊戲") Single click the target area ("電腦遊戲") with the left mouse button				
	Know the target area ("網上遊戲平台") Move and locate the cursor onto the target area ("網上遊戲平台") Single click the target area ("網上遊戲平台") with the left mouse button Know the target area ("上一頁" icon) Move and locate the cursor onto the target area ("上一頁" icon) Single click the target area ("上一頁" icon) thrice				
Respond to the dialogue box	Know the dialogue box, e.g., advestisement box Decide which icons to click, e.g., "取消" or "X" Move and locate the cursor onto the target icon ("取消" or "X" icon) Single click the target icon ("取消" or "x" icon) with the left mouse button				

Appendix VII

Standardized Instructions of the IE Competence Test

電腦科技測試

你好！現在我們會為你進行一項弱智人仕電腦科技應用的研究。首先，請問你是否還記得我剛給你的 "雅虎香港" 網址。 [要求參加者講出，如有錯，並作更正及記錄。] 我們要求你做 15 項測試，每項測試前會分別有講解，說明你需要做的工作。記住每個項目你都要努力嘗試去做，當你遇到困難或錯誤時，我會在旁指導你。

未開始測試之前，先問你 2 個簡單問題，第一、你有沒有用電腦的經驗，平均每星期花多少小時用電腦？第二、你有沒有用互聯網的經驗，平均每星期花多少小時用互聯網？

Remark:

1) 如參加者利用其他方法 (不相同於 Assessment Form 的方法) 完成工作，達到相同結果，請註明。

第 1 個項目 (General orientation and recognition):
{在開始這項測試前，先開啟電腦於桌面上}

1) 請你指出那一個是滑鼠？
2) 請你指出那一個是鍵盤？
3) 請你指出那一個是營光幕/顯視器？
4) 請你指出那一個是主機？
5) 請你指出那一個是列印機？
6) 請你指出那一個是揚聲器？
7) 請你利用滑鼠移動游標。
8) 請你按一下鍵盤其中一個鍵。
9) 觀察參加者有否望營光幕。
10) 請你指出滑鼠中那一個是左鍵、那一個是右鍵。
11) 請你指出鍵盤中那些是字母鍵、那些是數字鍵、那些是功能鍵如輸入鍵、空白鍵、刪除鍵等。

第 2 個項目 (General motor functions):
{在開始這項測試前，先開啟電腦於桌面上}

1) 請你單擊滑鼠上的左鍵。
2) 觀察參加者有否在單擊滑鼠後把手指放離左鍵。
3) 請你雙擊滑鼠上的左鍵。 {觀察參加者是否在一秒內完成}
4) 請你按一下鍵盤上的 "A" 鍵。
5) 請你按一下鍵盤上的 "B" 鍵。{觀察參加者是否在按鍵後把手指放離 "B" 鍵}
6) 請你按一下鍵盤上的 "C" 鍵。{觀察參加者是否在一秒內完成按 "C" 鍵及放

離“C”鍵}

7) 請你把游標從營光幕上的左上角移動到營光幕上的右下角。
8) 請你把“我的電腦”這個圖像移到營光幕上的右下角。

第 3 個項目 (General language function):
{在開始第 1 及第 2 條測試前，先開啟 Internet Explorer 的首頁}

1) 請你指出“上一頁”這個按鈕
2) 請你說明“上一頁”這個按鈕的意思

{在開始第 3 條測試前，先開啟 Internet Explorer 的首頁，並在<自訂>/ <文字選項> 中選擇 <不顯示文字標籤> }

3) 請你指出“停止圖像”這個按鈕
4) 請你說明“停止圖像”這個按鈕的意思

第 4 個項目 (Shut down the Computer):
{在開始這項測試前，先開啟電腦於桌面上}

1) 以下的測試是評估你是否懂得正確關關電腦，請你現在把電腦關關，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

2) 當參加者單擊“關機”`按鈕後，立即要求他指示出四個按鈕選擇中，那一個是用來關閉電腦的，然後叫他按他選擇的按鈕，看看他是否懂得正確地單擊滑鼠上的左键。

第 5 個項目 (Turn on the Computer):
{在開始這項測試前，確保電腦和營光幕以關閉}

1) 以下的測試是評估你是否懂得正確開啟電腦，請你現在把電腦及營光幕開啟，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

第 6 個項目 (Start Web browser):
{在開始這項測試前，先開啟電腦於桌面上}

1) 以下的測試是評估你是否懂得正確開啟瀏覽網頁軟件 Internet Explorer，請你現在開啟瀏覽網頁軟件 Internet Explorer，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

第 7 個項目 (Close Web browser):
{在開始這項測試前，先開啟 Internet Explorer 的首頁}

1) 以下的測試是評估你是否懂得正確關閉瀏覽網頁軟件 Internet Explorer，請你現在關閉瀏覽網頁軟件 Internet Explorer，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

第 8 個項目 (Add bookmark):
{在開始這項測試前，先開啟 Internet Explorer 並到 http://www.rs.polyu.edu.hk 的網頁}

1) 以下的測試是評估你是否懂得把指定一個網址加入書籤中，請你現在把這個“理工大學康復科學”的網址加入書籤中，把它改名為另一個名字，而且要用英文細楷表示出來 ，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

2) 觀察參加者在改名時是否懂得分辨英文字母大小楷，並記錄參加者分辨英文字母大小楷的能力。

第 9 個項目 (Explore Web site):
{在開始這項測試前，先開啟 Internet Explorer 的首頁}

1) 以下的測試是評估你是否懂得正確利用瀏覽網頁軟件 Internet Explorer 瀏覽網頁，請你現在登上先前吩咐你記著的“雅虎香港”網頁，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

第 10 個項目 (Use customized bookmark):
{在開始這項測試前，先開啟 Internet Explorer 的首頁}

1) 以下的測試是評估你是否懂得利用書籤功能把預先保留在書籤中的網頁按出來瀏覽，請你現在從書籤中把“雅虎香港”的網頁按出來，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

第 11 個項目 (Direct Print):

{在開始這項測試前，先開啟 Internet Explorer 的首頁}

1) 以下的測試是評估你是否懂得列印網頁上的資訊，請你現在利用 <工具列> 的“列印”這個按鈕直接列印 1 份這個網頁的資訊，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

第 12 個項目 (Indirect Print):

{在開始這項測試前，先開啟 Internet Explorer 並到 http://www.lib.polyu.edu.hk 的網頁}

1) 以下的測試是評估你是否懂得列印網頁上的資訊，請你現在列印 2 份這個網頁的資訊，列印範圍是從第一頁到第一頁，並如有需要請依照電腦的指示完成工作，記住，這條測試不想你利用 <工具列> 的“列印”這個按鈕直接列印，明唔明白？好、開始！

第 13 個項目 (Save Web site):
{在開始這項測試前，先開啟 Internet Explorer 並到 http://www.nba.com 的網頁}

1) 以下的測試是評估你是否懂得儲存網頁於電腦中，請你現在把這個 “美國職業籃球” 的網頁儲存於電腦 “我的文件” 中的位置，把它改名為另一個名字，而且要用英文大楷表示出來，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

2) 觀察參加者在改名時是否懂得分辨英文字母大小楷，並記錄參加者分辨英文字母大小楷的能力。

第 14 個項目 (Open saved Web site):

{在開始這項測試前，先開啟 Internet Explorer 的首頁}

1) 以下的測試是評估你是否懂得把已儲存於電腦中的網頁開啟，請你現在把這個已儲存的 “美國職業籃球” 的網頁開啟，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

第 15 個項目 (Use search engine):

{在開始這項測試前，先開啟 Internet Explorer 的首頁}

1) 以下的測試是評估你是否懂得利用搜尋資訊功能的網頁 “雅虎香港” 去搜尋資訊，請你現在登上先前吩咐你記著的 “雅虎香港” 網頁。

i. 第一、要求你搜尋的資訊是 “娛樂”，當你找到“娛樂” 資訊後, 請你回到 “雅虎香港” 的首頁，如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

ii. 第二、要求你搜尋的資訊是 “休閒與生活” 中的 “遊戲”，當你找到“遊戲” 資訊後，請你回到 “雅虎香港” 的首頁，如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

iii. 第三、要求你搜尋的資訊是 “電腦與互聯網” 中的 “電腦遊戲” 裏的 “網上遊戲平台”，當你找到 “網上遊戲平台” 資訊後，請你回到 “雅虎香港” 的首頁，如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

第 16 個項目 (Response to dialogue box):

{在開始這項測試前，先開啟Internet Explorer並按 A: http://one2free.com/chi or B: http://www.et-express.com or C: http://www.sanrio.com 於網址欄上}

1) 以下的測試是評估你是否懂得處理一些電腦給予你的訊息，請你現在按輸入鍵一下，然後把那個電腦訊息關閉，並如有需要請依照電腦的指示完成工作，明唔明白？好、開始！

Appendix VIII

Information Sheet and Informed Consent Form for Study 2

參加者同意書

研究題目
製作給予弱智人仕電腦科技的心理及腦部功能的參數。

研究人員
副教授　陳智軒博士
副教授　李曾慧平博士
教授　林就勝博士
研究生　黃榮楷先生

研究內容
研究弱智人仕操作電腦科技所遇到的困難及確認操作電腦科技時所需的心理及腦部功能參數，從而發展一個更適宜弱智人仕操作的電腦科技。

參加者將會被邀請做一些有腦神經心理學及動作機能的測試，分兩次進行，每次約時兩小時。是次測試所得的資料有助找出弱智人仕腦功能及動作機能的能力，有助發展一個更適合弱智人仕使用的電腦藍本。

在整個研究過程中不會對參加者構成任作危險，參加者將不會與本項研究構成任作直接利益。

同意書
本人__________________或其家長明白此項研究之細節，並聲明自願同意參加者參加此項研究。我明白可以隨時在不需作出解釋之情況下退出此項研究，而將不會受到處罰或歧視。我悉知參與本研究可能帶來之影響及願意對此承擔一切責任。我明白參加者之個人資料將不會向本研究以外之人仕公開，並且參加者的姓名或照片將不會出現於任何研究之報告內。

本人可致電 2766 7090 或 2766 6764 向研究生黃榮楷先生，或致電 2766 6762 向陳智軒博士查詢本研究事項，若果我對研究員有任何投訴，可致電 2766 5397 與梁小姐接洽。我將授予簽署同意書副本一份。

簽署 (參加者或參加者家長):　　　　　　日期:

簽署 (見證人):　　　　　　日期:

Appendix IX

Information Sheet and Informed Consent Form for Study 3

The Hong Kong Polytechnic University
Department of Rehabilitation Sciences

香港理工大學
康復治療學系

Research Project Informed Consent Form
研究計劃同意書

Project title: Parameters for the design of computer-based program for people with mental retardation
研究題目: 設計給智障人仕的電腦程式的參數

Investigator(s): Prof. Chetwyn C. H. Chan, Dr. Cecilia W. P. Li-Tsang, Prof. Chow S. Lam, Mr. Alex W. K. Wong

研究人員: 陳智軒教授、李曾慧平博士、林就勝教授、黃榮楷先生

Purpose of the Study:
The purposes of this study are (1) to investigate the visual search behaviors of people with and without mental retardation as presented in a conjunctive search experiment, and (2) to investigate the general shape characteristics of the visual lobes of people with and without mental retardation.

研究目的:
進行是次研究目的是有兩點：1) 調查智障人仕及非智障人仕在進行結合性搜尋實驗時的視覺搜查能力，以及 2) 調查智障人仕及非智障人仕的視野形狀。

Project Information:
Participation in this project will include (1) completing some standardized cognitive and motor tests, (2) completing a training session for familiarization with the experimental visual-search task, (3) completing a testing session on performing the experimental visual-search task, and (4) completing a session on performing the VILOMS program for visual lobe mapping. During the experiment, the eye-tracking machine will be used to track your eye movement. The project will be administered to you, which will take about 3 to 4 hours to complete. The investigators will guide you throughout the experiment, and a rest break will be provided if you express fatigue or boredom. Our findings will help develop a blueprint for the design of computer-based programs for people with mental retardation.

研究內容:
每位參加者需完成四個部份：(1) 數個肌力和智力測驗，(2) 結合性視覺搜尋測驗的訓練，使參加者熟習實驗項目中的要求，(3) 結合性視覺搜尋測驗，(4) 量

度視野形狀測試。在測試過程中，我們會使用視覺追蹤儀器去量度視覺的移動。整個測驗大約需要 3 至 4 小時去完成。過程中，研究人員會給你指示，當疲倦時也可休息。研究結果將會有助發展電腦程式給予智障人仕。

Potential Risks and Rights:
In the process of this study, there will be no danger or discomfort imposed on you. All information provided will be treated as strictly confidential. Participation is on a voluntary basis, and you are free to withdraw from the study at any time or for any reason. You will obtain an incentive of HK $200 after you complete the whole experiment.

潛在危險和利益：
整個研究過程不會對參加者構成任何危險。所有資料絕對保密。參加是次研究是自願性質，參加者有權在任何時間退出這項研究。參加者需要盡力完成實驗的要求，而整個實驗完結後將會獲得港幣$200 之酬勞。

Consent:
I, _________________________, have been made aware of the details of this study. I therefore voluntarily consent to participate in this study. I understand that I can withdraw from this research at any time without giving my reasons, and my withdrawal will not lead to any punishment or prejudice against me. I am also aware of any potential risk in joining this study. I understand that my personal information will not be disclosed to people who are not related to this study, and my name or photograph will not appear on any publications resulting from this study.

I can contact the project coordinator, Mr. Alex Wong, at 2766 4843, or the project supervisor, Professor Chetwyn Chan, at 2766 6727 for any questions about this study. If I have complaints related to the investigator(s), I can contact Mrs. Michelle Leung, secretary of the Departmental Research Committee, at 2766 5397. I also know that I will be given a signed copy of this consent form.

同意書:
本人 ___________________________已接受以上研究的詳細解釋。本人自願參予是次研究。我承認我有權問是次研究的任何問題及有權利在任何時間退出這項研究而不會使得到任何的處罰。我明白有關是次研究的好處與危險。我明白參加有關是次研究是自願的。我明白是次研究得來的資料會作將來研究及出版之用。但是，對個人資料的權利將會保留，我的任何個人資料將不會公開。

本人可致電 27664843 向研究員黃榮楷先生，或致電 27666727 向陳智軒博士查詢本研究事項，若果我對研究員有任可投訴，可以致電 27665397 與梁小姐接洽。我將授予簽署同意書副本一份。

______________________________ ______________________________
Signature (Participant or Guardian) Date
簽署 (參加者或監護人) 日期

______________________________ ______________________________
Signature (Witness) Date
簽署 (見證人) 日期

Appendix X

Previous Studies Using the ILAB Eye Movement Analysis Software for Displaying and Analyzing Eye Movement Data

Assums, A., Marshall, J. C., Ritzl, A., Noth, J., Zilles, K., & Fink, G. R. (2003). Left inferior parietal cortex integrates time and space during collision judgments. *NeuroImage, 20,* S82-S88.

Grujic, Z., Mapstone, M., Gitelman, D. R., Johnson, N., Weintraub, S., Hays, A., Kwasnica, C., Harvey, R. & Mesulam, M. M. (1998). Dopamine agonists reorient visual exploration away from the neglected hemispace. *Neurology, 51,* 1395-1398.

Gitelman, D. R., Nobre, A. C., Parrish, T., LaBar, K. S., Kim, Y.-H., Meyer, J. R., & Mesulam, M. M. (1999). A large-scale distributed network for covert spatial attention: Further anatomical delineation based on stringent behavioral and cognitive controls. *Brain*, 122, 1093-1106.

Gitelman, D. R., Parrish, T. B., LaBar, K. S., & Mesulam, M. M. (2000). Real-time monitoring of eye movements using infrared video-oculography during functional magnetic resonance imaging of the frontal eye fields. *NeuroImage, 11*, 58-65.

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LaBar, K. S., Gitelman, D. R., Parrish, T. B., & Mesulam, M. M. (1999). Neuroanatomic overlap of working memory and spatial attention networks: A functional MRI comparison within subjects. *NeuroImage, 10*, 695-704.

LaBar, K. S., Mesulam, M. M., Gitelman, D. R., & Weintraub, S. (2000). Emotional curiosity: Modulation of visuospatial attention by arousal is preserved in aging and early-stage Alzheimer's disease. *Neuropsychologia, 38*, 1734-1740.

Lux, S., Marshall, J. C., Ritzl, A., Zilles, K., & Fink, G. R. (2003). Neural mechanism associated with attention to temporal synchrony versus spatial orientation: An fMRI study. *NeuroImage, 20*, S58-S65.

Manjaly, Z. M., Marshall, J. C., Stephan, K. E., Gurd, J. M., Zilles, K., & Fink, G. R. (2003). In search of the hidden: An fMRI study with implications for the study of patients with autism and with acquired brain injury. *NeuroImage, 19*, 674-683.

Mapstone, M., Rosler, A., Hays, A., Gitelman, D. R., & Weintraub, S. (2001). Dynamic allocation of attention in aging and Alzheimer disease: Uncoupling of the eye and mind. *Archives of Neurology, 58*, 1443-1447.

Mapstone, M., Weintraub, S., Nowinski, C., Kaptanoglu, Gulustu, Gitelman, D. R., & Mesulam, M. M. (2003). *Neuropsychologia, 41*, 1396-1409.

Meegan, D.V., Purc-Stephenson, R., Honsberger, M. J. M., & Topan, M. (2004). Task analysis complements neuroimaging: An example from working memory research. *NeuroImage, 21,* 1026-1036.

Mesulam, M. M., Nobre, A. C., Kim, Y. H., Parrish, T. B., & Gitelman, D. R. (2001). Heterogeneity of cingulate contributions to spatial attention. *NeuroImage*, *13,* 1065-1072.

Pinsk, M. A., Doniger, G. M., & Kastner, S. (2004). Push-pull mechanism of selective attention in human extrastriate cortex. *Journal of Neurophysiology, 91*, 622-629.

Rosler, A., Mapstone, M. E., Hays, A. K., Mesulam, M. M., Rademaker, A., Gitelman, D. R., & Weintraub, S. (2000). Alterations of visual search strategy in Alzheimer's disease and aging. *Neuropsychology*, *14*, 398-408.

Thiel, C. M., Zilles, K., & Fink, G. R. (2004). Cerebral correlates of alerting, orienting and reorienting of visuospatial attention: An event-related fMRI study. *Neuroimage, 21,* 318-328.

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Appendix XI

The 161 Subtasks as Divided by the Expert Panel

IE Tasks	Sub-tasks	Content
General orientation and recognition	1	Mouse
	2	Keyboard
	3	Screen (monitor)
	4	Central processing unit
	5	Printer
	6	Speaker
	7	Moving the cursor with the use of the mouse
	8	Pressing the keyboard
	9	Watching the screen (monitor)
	10	Distinguish the left and right buttons of the mouse
	11	Distinguish the alphabet, numbers, and function keys in the keyboard
General motor functions	12	Single click the left mouse button
	13	Release after clicking
	14	Double click the left mouse button within 1 second
	15	Press key "A"
	16	Press key "B" and release
	17	Press key "C" and release within 1 second
	18	Hold and move the mouse from the top left to the right bottom of the screen
	19	Drag the mouse to move the "My Computer" icon into the right bottom corner of the screen
General language functions	20	Read the words "上一頁" on Internet Explorer’s first page
	21	Explain the words "上一頁" on Internet Explorer’s first page
	22	Read the graphic "停止 logo" on Internet Explorer’s first page
	23	Explain the graphic "停止 logo" on Internet Explorer’s first page
Turn on the computer	24	Know the power button in the computer
	25	Know the power button in the screen (monitor)
	26	Press the power button in the computer
	27	Press the power button in the screen (monitor)
Shut down the computer	28	Know the target area (" 開始" icon)
	29	Move and locate the cursor onto the target area (" 開始" icon)
	30	Single click the target area ("開始" icon) with the left mouse button
	31	Know the target area ("關機" icon)
	32	Move and locate the cursor onto the target area ("關機" icon)
	33	Single click the target area ("關機 " icon) with the left mouse button
	34	Know the target area ("關閉這台電腦" icon)
	35	Move and locate the cursor onto the target area ("關閉這台電腦"

		icon)
	36	Single click the target area ("關閉這台電腦" icon) with the left mouse button
	37	Know the target area ("確定" icon)
	38	Move and locate the cursor onto the target area ("確定" icon)
	39	Single click the target area ("確定" icon) with the left mouse button
Start Web browser	40	Know the target area (“I.E." icon)
	41	Move and locate the cursor onto the target area ("I.E." icon)
	42	Double click the target area ("I.E." icon) with the left mouse button
Close Web browser	43	Know the target area ("X" icon)
	44	Move and locate the cursor onto the target area ("X" icon)
	45	Single click the target area ("x" icon) with the left mouse button
Explore Web site	46	Know the target area ("網址" bar)
	47	Move and locate the cursor onto the target area ("網址" bar)
	48	Single click the target area ("網址" bar) with the left mouse button
	49	Recall the Web site address
	50	Press on the keys in the keyboard for the Web site address (www.yahoo.com.hk)
	51	Check whether the words were pressed correctly or not
	52	Press the "Enter" key in the keyboard
Response to the dialogue box	53	Know the dialogue box, e.g., advertisement box
	54	Move and locate the cursor onto the target icon ("取消" or "X" icon)
	55	Single click the target icon ("取消" or "x" icon) with the left mouse button
Use customized bookmark	56	Know the target area ("我的最愛" icon)
	57	Move and locate the cursor onto the target area ("我的最愛" icon)
	58	Single click the target area ("我的最愛" icon) with the left mouse button
	59	Recall the the name of that Web site already present
	60	Know the target area ("雅虎香港" icon)
	61	Move and locate the cursor onto the target area ("雅虎香港" icon)
	62	Single click the target area ("雅虎香港" icon) with the left mouse button
Add bookmark	63	Know the target area ("我的最愛" icon)
	64	Move and locate the cursor onto the target area ("我的最愛" icon)
	65	Single click the target area ("我的最愛" icon) with the left mouse button
	66	Know the target area ("加到我的最愛" icon)
	67	Move and locate the cursor onto the target area ("加到我的最愛" icon)
	68	Single click the target area ("加到我的最愛" icon) with the left mouse button
	69	Know the target area (words end in "名稱" bar)

	70	Move and locate the cursor onto the target area (words end in "名稱" bar)
	71	Single click the target area (words end in "名稱" bar) with the left mouse button
	72	Press on the "Backspace" key in the keyboard until all words are deleted
	73	Press on keys "R" and "S" in the keyboard for renaming
	74	Check whether the words were pressed correctly or not
	75	Know the target area ("確定" icon)
	76	Move and locate the cursor onto the target area ("確定" icon)
	77	Single click the target area ("確定" icon) with the left mouse button
Direct print	78	Know the target area ("列印" icon)
	79	Move and locate the cursor onto the target area ("列印" icon)
	80	Single click the target area ("列印" icon) with the left mouse button
Indirect print	81	Know the target area ("檔案" icon)
	82	Move and locate the cursor onto the target area ("檔案" icon)
	83	Single click the target area ("檔案" icon) with the left mouse button
	84	Know the target area ("列印" icon)
	85	Move and locate the cursor into the target area ("列印" icon)
	86	Single click the target area ("列印" icon) with the left mouse button
	87	Know the target area (words end in "份數" bar)
	88	Move and locate the cursor onto the target area (words end in "份數" bar)
	89	Single click the target area (words end in "份數" bar) with the left mouse button
	90	Press on the "Backspace" key in the keyboard until all words are deleted
	91	Press on key "2" in the keyboard
	92	Know the target area ("列印範圍")
	93	Move and locate the cursor onto the target area ("列印範圍")
	94	Know the target area ("頁數" icon)
	95	Move and locate the cursor onto the target area ("頁數" icon)
	96	Single the click target area ("頁數" icon) with the left mouse button
	97	Know the target area ("確定" icon)
	98	Move and locate the cursor onto the target area ("確定" icon)
	99	Single click the target area ("確定" icon) with the left mouse button
Save Web site	100	Know the target area ("檔案" icon)
	101	Move and locate the cursor onto the target area ("檔案" icon)
	102	Single click the target area ("檔案" icon) with the left mouse

		button
	103	Know the target area ("另存新檔" icon)
	104	Move and locate the cursor onto the target area ("另存新檔" icon)
	105	Single click the target area ("另存新檔" icon) with the left mouse button
	106	Know the target area ("儲存於" bar)
	107	Move and locate the cursor onto the target area ("儲存於" bar)
	108	Single click the target area ("儲存於" bar) with the left mouse button
	109	Know the target area ("我的文件" icon)
	110	Move and locate the cursor onto the target area ("我的文件" icon)
	111	Single click the target area ("我的文件" icon) with the left mouse button
	112	Know the target area (words end in "檔案名稱" icon)
	113	Move and locate the cursor onto the target area (words end in "檔案名稱" icon)
	114	Single click the target area (words end in "檔案名稱" icon) with the left mouse button
	115	Press the "Backspace" key in the keyboard until all words are deleted
	116	Press on the keys "Ctrl+B," "Ctrl+A," "Ctrl+L," and "Ctrl+L" in the keyboard for renaming
	117	Check whether the words were pressed correctly or not
	118	Know the target area ("存檔" icon)
	119	Move and locate the cursor onto the target area ("存檔" icon)
	120	Single click the target area ("存檔" icon) with the left mouse button
Open saved Web site	121	Recall the location of the Web site saved, e.g., 我的文件
	122	Know the target area (e.g., "我的文件" icon)
	123	Move and locate the cursor onto the target area (e.g., "我的文件" icon)
	124	Double click the target area (e.g., "我的文件" icon) with the left mouse button
	125	Know the target area (e.g., "BALL" I.E. icon)
	126	Move and locate the cursor onto the target area (e.g. "BALL" I.E. icon)
	127	Double click the target area (e.g. "BALL" I.E. icon) with the left mouse button
Use search engine	128	Know the target area ("網址" bar)
	129	Move and locate the cursor onto the target area ("網址" bar)
	130	Single click the target area ("網址" bar) with the left mouse button
	131	Recall the Web site address
	132	Press on the keys in the keyboard for the Web site address (www.yahoo.com.hk)
	133	Check whether the words were pressed correctly or not
	134	Press the "Enter" key in the keyboard

	135	Know the target area ("娛樂")
	136	Move and locate the cursor onto the target area ("娛樂")
	137	Single click the target area ("娛樂") with the left mouse button
	138	Know the target area ("上一頁" icon)
	139	Move and locate the cursor onto the target area ("上一頁" icon)
	140	Single click the target area ("上一頁" icon) once
	141	Know the target area ("休閒與生活")
	142	Move and locate the cursor onto the target area ("休閒與生活")
	143	Single click the target area ("休閒與生活") with the left mouse button
	144	Know the target area ("遊戲")
	145	Move and locate the cursor onto the target area ("遊戲")
	146	Single click the target area ("遊戲") with the left mouse button
	147	Know the target area ("上一頁" icon)
	148	Move and locate the cursor onto the target area ("上一頁" icon)
	149	Single click the target area ("上一頁" icon) twice
	150	Know the target area ("電腦與互聯網")
	151	Move and locate the cursor onto the target area ("電腦與互聯網")
	152	Single click the target area ("電腦與互聯網") with the left mouse button
	153	Know the target area ("電腦遊戲")
	154	Move and locate the cursor onto the target area ("電腦遊戲")
	155	Single click the target area ("電腦遊戲") with the left mouse button
	156	Know the target area ("網上遊戲平台")
	157	Move and locate the cursor onto the target area ("網上遊戲平台")
	158	Single click the target area ("網上遊戲平台") with the left mouse button
	159	Know the target area ("上一頁" icon)
	160	Move and locate the cursor onto the target area ("上一頁" icon)
	161	Single click the target area ("上一頁" icon) thrice

Appendix XII

Permission Letter for Reprinted Material for Figure 2.5

<<...OLE_Obj...>>

Dear Dr. Wong:

We hereby grant you permission to reproduce the material detailed below in your thesis at no charge, subject to the following conditions:

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