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A Usability Assessment of a Specific Alternative Computer Input Device for Users with Spinal Cord Injuries

Dilys Tsai-Hsuan Tsai

Ph.D THESIS

2006

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

2006

ABSTRACT

The salient point of this research was to investigate the key factors of assistive devices for people with severe physical disabilities, i.e. spinal cord injury, when selecting and using an input device. The area of study was also concerned with validating a new computer device to enable those individuals with upper-limb impairments to engage the benefits of computer technology, via both user-issue and scientific-based evaluations.

A specific methodology, concerning both user-issue and scientific-evidence, was proposed for the studies related to assistive technology outcome measures. In order to validate the proposed methodology, the research work began with an in-depth survey (Study A), to give an insight into the present selection and utilisation of input devices among those computer users with spinal cord injuries and identify their specific needs when using a computer. Following the findings of this contextual survey, a SCI users' needs hierarchy was proposed for input device selection and use. Specific touchscreen devices, which matched the criteria in the hierarchy, were suggested as a possible solution for users with severe upper-limb disorders. Then, a series of user-centred validation studies, involving a pilot simulation study associated with a dimensional issue of an input device (Study B), followed by usability evaluations at the introductory phase (Study C), after short-term use and training (Study D) and after longer-term use and outcome comparisons (Study E), were carried out. The user perspectives and scientific data obtained from the usability assessments form the SCI subjects were used not only to demonstrate the effectiveness and efficiency of the assistive device, but also to fill the gap between the merely psychological/psychosocial-based measures and the merely scientific-focus evaluation.

By merging a specific research technique and a systematic measuring procedure, a conceptual model for evaluating assistive technology outcome measures has been provided for this field of study. Moreover, this research has shown that the integration of user-issue and scientific-evidence can increase the reliability and validity of this type of device outcome measures and, therefore, attain a good match between users and the technology employed.

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Finally, the author dedicates this thesis to her parents and family whom she is mostly deeply indebted. Also her love and gratitude goes to Dr. Kevin C. Tseng who has been supportive and good company along those studying years.

Dilys Tsai-Hsuan Tsai

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NOMENCLATURE

SYMBOL	DEFINITION
ADA	Americans with Disabilities Act
AT	Assistive Technology
ATD	Assistive Technology Device
CP	Cerebral Palsy
CSI	Cervical Spinal Cord Injury
CTD	Cumulative Trauma Disorder
CTS	Carpal Tunnel Syndrome
DDA	Disability Discrimination Act
DIP	Distal interphalangeal
DPPA	Disabled Persons Protection Act
ICT	Information and Communication Technologies
IP	Interphalangeal
LSI	Lumbar Spinal Cord Injury
MCP	Metacarpophalangeal
MPT	The Matching Person and Technology
MSD	Musculoskeletal Disorder
PIADS	Psychosocial Impact of Assistive Devices Scale
PIP	Proximal Interphalangeal
PWD	Person With Disability
QoL	Quality of Life
QUEST	Quebec User Evaluation of Satisfaction with assistive Technology
RSI	Repetitive Strain/Stress Injuries
RTW	Return to Work
SCI	Spinal Cord Injury
SCSRC	Taoyuan County Spinal Cord Injury Rehabilitation Centre (Consortium Corporation)
SLE	Systemic Lupus Erythematosus
SOP	Standard Operating Procedure
SSI	Sacral spinal cord injury

TATA	Taiwan Assistive Technology and Vocational Rehabilitation Association
TPESCI	Taipei Spinal Cord Injury Association
TSI	Thoracic spinal cord injury
ULD	Upper Limb Disorder
WRMSD	Work-Related Musculoskeletal Disorder
WRULD	Work-Related Upper Limb Disorder

CHAPTER 1 INTRODUCTION

1.1 Overview

Spinal Cord Injuries (SCI) are worldwide. Based on ICCP (2005), it is estimated that globally over 130,000 people suffer traumatic SCI annually. The conservative average annual incidence in the western and developing world is 22 people per million[1](ICCP 2005; UN 2004). In the United Kingdom, two people become permanently paralysed from SCI damage every day leading to 700 new SCI patients annually. In the population which is estimated to be living with SCI, there are approximately 40,000 patients in the U.K. with spinal cord injuries - equating to around 1 in 1,500 (SIA 2004; SIA 2005). In Asian countries, such as Taiwan, approximately 23,000 traumatic SCI discharges were reported with an average increase of 1,200 new cases every year[2] (IOSH 2003; MOI 2005).

1.1.1 Current Situation Faced by SCI Sufferers

SCI takes two main forms, paraplegia and tetraplegia. Patients with a high lesion (i.e. cervical region) are likely to suffer paralysis of all limbs (i.e. tetraplgia), whereas those with a low lesion (i.e. thoracic, lumbar, or sacral region) are likely to exhibit paralysis of their lower limbs and lower part of the body but with their upper limbs maintaining full function (i.e. paraplegia). Unlike other types of disabilities, SCI sufferers are more likely to find it difficult to return to their previous jobs because of their physical impairments, and begin a different life which depends on assistive devices such as wheelchairs. These SCI people are likely to be permanently excluded from the job market. Increasingly legislation is being enacted that prohibits discrimination on the grounds of disability. Examples include Americans with Disabilities Act (ADA) (1990) and the UK's Disability Discrimination Act (DDA) (DfEE 1995). Other countries in Europe, such as Germany, Ireland, Italy, Netherlands, and Sweden, continue efforts to

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1 Total world population is 6,464,750 (thousands) in 2005 (UN, 2004).

2 Total Taiwan population is 22,770 (thousands) in 2005 (MOI, 2005)

increase employment rates of persons with disabilities (Wynne and McAnaney 2004). This includes requirements for businesses and industries to take a heightened responsibility to make reasonable accommodation for persons with disabilities. However, could SCI people manage with conventional office-/labour-based activities? SCI employees cannot perform heavy labour. Many persons with thoracic spinal cord injuries (TSI), lumbar spinal cord injuries (LSI), or sacral spinal cord injuries (SSI) become mobile with a wheelchair and are able to extend the parameters of their work responsibilities to match those of other workers in an office area. However, persons who suffer cervical spinal cord injuries (CSI) appear to have many return-to-work (RTW) barriers because of their partial or very limited functional performance. For instance, a particular consideration of transportation (a distance to work) is one important issue for those CSI workers.

1.1.2 ICT for Individuals with SCI

Gerhart (1991) and Scherer (1996) pointed out that a high percentage of SCI patients were discharged home after completing a rehabilitation programme. Hence, it can be said that the idea of home-based work/home-office could be a practicable idea for those employees with physical disabilities, such as spinal cord injuries. Computers, accompanied by the rapid growth in Information and Communication Technologies (ICT), are widely used in a variety of fields and are emerging as a major trend. For those persons with SCI, computer technology may help lessen the impact of mobility limitation and bring special benefit (Kruse et al. 1996; Pell et al. 1997). Some research also indicated that telework, which permits home-based work through the use of ICT, alleviates many of the return-to-work barriers for individuals with SCI, bringing them new opportunities, and offer the possibility to employment unhampered by considerations of job demands, mobility limitations, transportation needs, interpersonal demands or fatigue imposed by medical complications (Anderson et al. 2001; Bricout 2004; Hesse 1995; Murray and Kenny 1990; West and Anderson 2005).

Vocational training also plays an influential role in supporting employment for persons with spinal cord injuries (Athanasou et al. 1996; SCSRC 2006b). Computer skills training especially is one of the significant predictors of employment outcomes for SCI people (Kruse et al. 1996; Pell et al. 1997). Even Assistive Technology (AT) plays a significant role in the life of individuals with severe disabilities and this has helped them more than they thought possible. Assistive technologies include wheelchairs, magnifying equipment for eating and grooming, and other reading and computer input devices. With the variety and well-accommodated adaptive assistive technology devices (ATDs), many persons who sustained spinal cord injuries are able to access a computer (ABLEDATA 1996; Pell et al. 1997). Traditionally, computer users operate a computer with a standard point and click mouse and a QWERTY keyboard. Many spinal-cord-injured computer users, may hit the computer keys or move a pointer only by a single finger or/and another part of their body (e.g. head, mouth, or wrist, etc.), may not be able to use these standard computer input devices effectively. Mainstream input devices often limit the access opportunity and virtually neglect the special needs of individuals with hand and arm control impairments. Because of this, alternative computer input devices which are made for users with severe disabilities are required.

1.1.3 Requirements of an Appropriate Alternative Input Device

Computer technology provides a means of communicating and accessing information. In addition to its positive effects, potential adverse effects, such as cumulative trauma disorders (CTDs), repetitive strain/stress injuries (RSI), musculoskeletal disorders (MSDs)/work-related musculoskeletal disorders (WRMSDs), and work-related upper limb disorders (WRULDs), have arisen among computer users. Bergqvist et al. (1995b) investigated that the high-prevalence rate (over 20%) of musculoskeletal disorders especially in the neck-shoulder region, and over 60% of neck-shoulder discomfort, reported by the 260 participants who regularly used a computer in their workplace. Keyboards and mice are the most conventionally used devices when accessing computers. Some studies, Swanson et al. (1997), Cooper and Straker (1998), Amell and Kumar (1999), Lincoln et al. (2000), Cail and Aptel (2003), Delisle et al. (2004) and Szeto et al. (2005a; 2005b), revealed that the standard keyboard is a causal factor in promoting awkward work postures which are associated with neck, shoulder, arm, hand/wrist, and low back discomfort among keyboard operators. In the use of conventional mice, Karlqvist et al. (1994) explored the differences in upper limb posture and movement during work-processing with and without mouse use. It was found that mouse users seemed to work with extreme wrist and shoulder postures in comparison with non-mouse users. Keir et al. (1999) assessed carpal tunnel pressure of 14 subjects while they performed multidirectional dragging tasks with three different computer mice. The results showed that pressures were significantly greater during operating a mouse than when resting the hand on the mouse (static posture) and also indicated that long-term intensive mouse use may increase risks of upper extremity musculoskeletal disorders. No differences were found between the three mice. That repetitive motion in computer mouse use may result in work-related musculoskeletal disorders/upper-limb disorders was also reported in some studies (Atkinson et al. 2004; Blatter and Bongers 2002; Cail and Aptel 2003; Finsen et al. 2001).

For many spinal-cord-injured sufferers, especially those with upper limb impairments (i.e. cervical spinal cord injury), having access to and independent control over a computer system is highly desirable and essential (Evans et al. 2000; Hwang et al. 2001). Nowadays, a number of assistive input devices have been developed in many shapes and dimensions in order to accommodate individuals with disabilities in computer use. SCI sufferers perform unique and individual motor abilities in operating assistive technology devices, and these alternative input devices allow users to activate a computer in a variety of ways, such as using their head (Chen et al. 2003; Evans et al. 2000; Radwin et al. 1990), eye (Park and Lee 1996), mouth (Lau and Oleary 1993), single finger or other part of body (Tanimoto et al. 2005; Tanimoto et al. 2003). Assistive technology devices can help individuals with spinal cord injuries to compensate for functional limitation, overcome barriers to computer utilisation, and enhance their computer skills/ ability. However, SCI computer users, who with upper-limb impairment in particular, seem to work with more considerable postural stress from neck, shoulder, hand, wrist and back than computer users with normal upper-limb motion. To consider the work-related musculoskeletal disorders/upper-limb disorders among persons with spinal cord injuries, most of recent studies focused only on shoulder pain/ upper-limb pain associated with highly repetitive wheelchair activities (Curtis et al. 1999; Gironda et al. 2004; Mulroy et al. 2005). There is the lack of attention paid to the prevalent musculoskeletal pain and discomfort associated with repetitive computer operation among those users with upper extremity disorders. As a result, how could those SCI computer users be prevented from secondary injuries post-SCI, such as computer work-related musculoskeletal disorders? Some studies focused on ergonomic considerations which can influence computer operators' response to risk factors for work-related musculoskeletal disorders, such as workstation layout (OSH 1996), exercises programme (Lee et al. 1992), postures (seating and chair) (Rutter and Dainoff 1996), etc. Moreover, some focused on many computer-related ergonomic products, the most common ones being ergonomic/ alternative input devices (AbilityNet 2005; ABLEDATA 2002; MacKenzie 1995). Bertuca (2001) described the inherent weakness of conventional input devices and addressed the alternative input devices, such as trackball, touchpad, graphic tablet, or touch screen, which may help enhance productivity/efficiency and reduce stress and potential injuries from computer use. From the above point of view, the purpose of this study, then is to give an appropriate alternative input device which could limit secondary injuries and be applicable to those SCI operators with severe physical impairments and users' working milieu, and thereby improve the work efficacy and quality of life (QoL)[3] (Medicine 1999).

1.1.4 Rationale for Assessments on User-issue and Scientific-data

Scherer (1996) emphasized that to enhance users' quality of life by application of assistive technologies there should be a focus on user involvement in the selection and evaluation of appropriate assistive technologies, and ways to make technologies more widely available and affordable. When factors associated with persons with disabilities are typically included, environments of device use, device features and functions, disability- specific determinants and characteristics of the user's preferences and expectations should be taken into account (Brown-Triolo 2002; Phillips and Zhao 1993; Scherer 1988; Scherer 1996). Furthermore, the Matching Person and Technology (MPT) Model, first presented in 1989, has been formulated to account for these numerous influences and accompanying assessment instruments (Scherer 1998). The MPT model addressed three primary areas to assess as follows: (a) milieu/ environment factors influencing use; (b) consumer personal and psychosocial characteristics, needs and preferences; and (c) functions and features of the most desirable and appropriate technology. Characteristics within these three components can each contribute either a

[3] Quality of life is defined as "a personal, global, evaluation of well-being or general satisfaction with life experienced by people under their current life conditions (quoted in *Outcomes following traumatic spinal cord injury: A clinical practice guideline for health care professionals*, Consortium for Spinal Cord Medicine, P.24).

positive or a negative influence on technology use (Scherer 1998; Scherer 2000c). According to the concept of the MPT model, ATD assessments and evaluations are divided into two sessions, user-issue consideration and scientific-data demonstration in this study.

- User-issue consideration

The relationship between AT and persons with disabilities raises many difficult questions. The most essential basis for evaluating an assistive device is whether it meets the special needs of the disabled users (Batavia and Hammer 1990). There are many influential differences between those motion-impaired users and able-bodied users when they interact with a computer. Many researches indicated the importance, when designing a special ATD, is to consider the needs of users, the workplace environment, and the job estimation (Covington and Hannah 1996; Cushman and Rosenberg 1991; Hwang et al. 2001). Without a proper understanding of users' differences and special needs, an alternative ATD would remain impressive only in appearance rather than in usability.

The methods of observation and contextual analysis are applied in the ATD assessments in order to read users' characteristics, behaviour and performance, and interactions between users and devices. Yeh (2001) and Teng and Chen (2003) investigated two types of disability group respectively (i.e. single upper limb amputees and muscular dystrophy) via the contextual observations. In this study, the methods, interview and contextual observation, were selected for the purpose of understanding the interactive influence between users and ATDs and for obtaining direct feedbacks from users.

- Scientific-data demonstration

Day et al. (2001) pointed out that the functional aspect of an ATD, such as effectiveness of the device, was one of the determinants of users' adoption or abandonment. Muhleher and Miesenberger (2004) indicated that the lack of usability assessments is the significant problem for uses of alternative input devices. Once an AT device is designed in conjunction with consumers of the device, it is necessary to measure its performance and determine whether it is functioning effectively (Cook and Hussey, 1995). In this study, the scientific data were collected from usability assessments from those SCI computer users for the purpose of evaluating users' effectiveness and efficiency when operating an ATD and demonstrating its validity and reliability.

1.2 Taiwan Perspective

In 2002, the author devoted herself to the literature documentary research, and also planned the first protocol which followed and which is listed in the research framework. Based on the purpose of the research, the people issue, especially persons with severe physical disabilities, was crucial to the study. The author had contacted and visited the social workers in the Leicester City's Social Care and Health Department and the Glenfield Hospital Social Work Team. With their great help, the author visited and observed the care centre in Glenfield Hospital. In accordance with the rules, the visitors could observe people's activities but were not allowed to interrupt. It was found that there were approximately five or six patients with mixed diseases, such as cerebral palsy, spinal cord injury, or muscular dystrophy, and at least five carers or social workers at the time. Each patient in the centre had received great support from these carers. Particularly, the persons with severe physical disabilities were looked after by a personal carer. It was also a place for meeting persons with disabilities as a social community. After three visits, a proposal was submitted with the purpose of obtaining permission from the city council to launch the planned experiments on those disabled people. The author was informed, however, that all proposed communication and human participation should be conducted in a professional manner with due care and respect afforded to all individuals concerned; a social-worker-qualification was, unfortunately, also demanded. In addition, even if the research could proceed with the help of professionals/qualified social workers, an approximate two-year period time still had to elapse to approach both governmental and NHS systems. It was overwhelming and disappointing news for a researcher (i.e. the author) at that time. For the time consideration of the research, it seemed to necessitate finding another entrance into the fulfilment of the research. Luckily, there was an opportunity for the author to join a project which was led by Prof. J.G. Wu, National Taiwan Normal University, Taiwan and Dr. R. C. C. Chen, De Montfort University (DMU), U.K., and funded by the Department of Labour, Taipei City Government, Taiwan (the author's mother country).

The project which aimed to develop a new alternative assistive input device for computer users with severe hand movement disorders was closely related to the author's research. The research team at the National Taiwan Normal University was devoted to the design and development of an assistive device. The team at De Montfort University was to be responsible for the assessments and evaluations of device suitability and usability with real disabled users at their actual workplaces. It should be noted that, the author, was the only research member in the DMU research team except for the co-investigator, Dr. R. C. C. Chen on this two-year Government funded Project. In addition to the funding support obtained from the Taipei City Government, some Taiwan associations, such as Taiwan Assistive Technology and Vocational Rehabilitation Association (TATA)[4], Taipei Spinal Cord Injury Association (TPESCI)[5], and Taoyuan County Spinal Cord Injury Rehabilitation Centre (SCSRC)[6] provided great assistance in subject recruitment. Consequently, a total of thirty-six Taiwanese SCI subjects were selected and participated in this study.

Taiwan, also called the Republic of China, is world-famous for IT development and production. In other fields of achievement, such as AT design and research, Taiwan has been keeping pace with Japan and is at the summit of its field in Asian countries.

Based on the demographic statistics in Taiwan, the majority neurologic category reported at discharge of SCI persons was LSI (42.1%), the followed by CSI (40.3%) (SCSRC 2006a). Many SCI sufferers used to have the sole responsibility for the family finance prior to their injuries. Even though, disabled people benefited from financial aid, the money is not sufficient to support a family and relevant medical expanses post-injury, therefore, numerous families would suffer a financial crisis. For this reason, financial security encourages Taiwanese SCI sufferers to return to work as the priority motivation; in addition, Yasuda et al. (2002) pointed out that being employed for SCI people brings self-esteem, independence, social relationships, self-worth, and personal identify. The result was also demonstrated by those Taiwanese SCI workers as the second reason for returning to employment. The Taiwanese legislation plays a supportive role for the disabled. The Disabled Persons Protection Act (DPPA), be

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[4] TATA is the Taiwanese well-famous AT research association.
[5] TPESCI is the SCI corporation association supported by Taipei city government.
[6] SCSRC is the Taiwan biggest consortium corporation rehabilitation and vocational training centre.

enacted in 1997, was intended to build a legal basis in support of AT devices and services, against disability discrimination, and bring about improvements in environmental accessibility. Dejong et al. (1984) reported that accessible transportation fostered an active and productive lifestyle among persons with disabilities. Compared to the facilities provided for disabled people in the UK, environmental barriers are the typical reasons causing unemployment after SCI in Taiwan. Surprisingly, based on the author's intuitive observations in Taiwan, many SCI sufferers are optimistic and willing to attempt joining the social community with their mobility ATD, i.e. manual/ powered wheelchair, even those with severe physical functional limitations, i.e. persons with CSI. Nevertheless, the transportation concern still has a critical influence on SCI people when considering a job post-injury.

In 2003, Jang et al.(2005) investigated the post-injury employment status of one hundred and sixty-nine Taiwanese SCI subjects aged from 18 to 60 years. In their study, 47% of the Taiwanese SCI subjects were reported as returning to work. A rate of 79% had full-time jobs and 21% had part-time jobs among these employees. In another study, Yasuda et al. (2002) indicated that many SCI individuals who returned to work post-injury started with a new employer rather than return to work with their former employer. The same finding was reported by Jang et al. (2005). Results from those Taiwanese SCI employees, who returned to work after the onset of SCI, found that only 11% of SCI employees worked for their previous employer post-injury. In addition, an average interval of 4 years between the onset of SCI and the first employment was also reported in this Taiwan SCI employment survey (Jang et al. 2005).

In addition to encouraging disabled people to return to employment, increasing attention was focused on vocational training programmes aimed at developing the required skills. Effective vocational programmes also enhanced possibilities of returning to work for these disabled trainees (Athanasou et al. 1996; SCSRC 2006b). Nowadays, a considerable series of educational and vocational training programmes is promulgated to people who attempt to return to work in Taiwan. Based on the author's observational findings in occupational variables, sedentary or non-heavy-labour work is required by a majority of Taiwanese SCI people restricted by their physical functional impairments. The home-based or office-based jobs related with computer programming, graphic/website design, and office systems could be an employment alternative for those SCI job hunters. The author's findings also corresponded with Jang et al.(2005) who addressed that computer-related vocational training programmes were adopted by most of Taiwanese SCI vocational trainees, and a high percentage of employment rate was also shown by these computer vocational trainees after completing the programmes.

A number of trends and social changes has had a great impact on Taiwan, not only to enlighten and broaden views of the disabled population, but also to influence social work services and encourage the relevant AT research. Accordingly, many persons who suffered SCI are not now hiding at home but are willing to get into contact with society and participate in many activities. For instance, large number of subjects were even involved in research studies and volunteered to be research subjects. This study was implemented and achieved by the thirty-six Taiwanese SCI subjects, 22 of whom sustained CSI have a loss of feeling and movement in both upper and lower limbs; the remaining 14 TSI/ LSI subjects have normal functional performance of upper extremities but with no motion ability in their lower extremities. It can be said that the completion of the research relied on the contribution and cooperation of all involved subjects.

The author's experience was not intended to criticise the existing British legislation and system. In fact, the persons with disabilities are well protected in the UK. For instance, 8.7 million disabled people in the UK benefit from 80 billion pounds of spending power annually (DWP 2006); British society in general provides well-structured social services, and facilities demanded by disabled people when accessing buildings, shops, services, buses, train, leisure facilities, etc. Compared with the British social welfare and services, the Taiwanese disabled population is facing more struggles and challenges. Although these disabled people receive less social support and meet more environmental barriers in Taiwan than those suffered by the UK disabled population, they are endeavouring to overcome visible limitations both in self-physical-function and external help and to prove self-worth. These people are striving to play a decisive role in the development and improvements in Taiwan AT research. From the author's viewpoint, there is a general agreement that AT field requires reliable and valid measurements from users' perceptions and an over-protective social work system might impose bounds on the development of AT research and related studies.

The research was implemented in Taiwan and completed by those Taiwanese persons with SCI. However, the research outcome presented by the Taiwanese subjects involved can be represented not only the remaining SCI population in Taiwan, but also by the disabled individuals who have similar physical function limitation and who meet similar difficulties when accessing a computer. It can be applied even to SCI disabled people in the UK. Moreover, the strength of the author's research findings leave no doubt that, although her studies were carried out only in Taiwan and in the UK, they are equally relevant to SCI sufferers world-wide.

1.3 Aims and Objectives of Thesis

The research project aims to investigate the key factors of assistive devices and persons with severe physical disabilities, which influence AT design and research. The area of study is also related to validating a new computer device to enable persons with upper-limb disorders to engage the benefits of IT and enhance their quality of life.

The objectives of the research are to investigate and provide an adaptive assistive device for SCI users who meet difficulties in accessing a computer. This research necessitates enhancing the understanding of special needs of disabled users. In addition to the user issue, it also requires scientific data to demonstrate the ATD functional effectiveness and efficiency. The various stages of the project are:

- to conduct a comprehensive literature survey of relevant research articles, current trends and social changes, users' characteristics and needs, workplace environment and the job estimation, AT research and development;
- to investigate latest information on alternative computer assistive technologies, existing ATD development, and methods of measurements and evaluations;
- to generate surveys to explore the relationship between an ATD and disabled users when operating a computer, and to identify influential factors of adoption of an alternative input device;

- to provide a possible solution of an alternative input device for those users with hand movement impairments;
- to validate and evaluate suitability and usability of the newly developed computer assistive device on both people-issue consideration and scientific-data demonstration;
- to identify further research that is required.

1.4 Overview of Thesis

The remainder of this thesis is divided into 7 chapters. Following the introductory Chapter 1, Chapter 2 contains a comprehensive literature survey. The resources covered bring together the fields of characteristics of SCI including the limitations of physical function and return to work post-injury, AT research and development, user-centred and AT outcome measurement and assessment issues, computer technology and alternative devices for the disabled, and ergonomic aspects.

This thesis consists of a series of integrated survey and experimental studies. In Chapter 3, the Methodology chapter, an overview is provided for introducing the components of proposed research project and explains a working scenario, such as summary and research plan, methods for gathering data or evidence, subject selection, instruments and environments, and procedure. Subsequent chapters in this thesis will elaborate further on each study.

An in-depth survey of the utilisation of computer ATDs among SCI operators is addressed in Chapter 4. A systematic observational survey is proposed for the purposes of identitying SCI users' specific requirements and exploring key factors associated with ATD use. In addition, a newly developed touchscreen alternative device is suggested in this chapter as a possible solution for individuals who have difficulties.

A series of three systematic experimental studies for validation of the provided assistive device is described in Chapter 5 which covers the usability assessments based on ISO standard 9241, the results of intensive training programmes, and the comparison study between the currently used pointing device and the newly developed touchscreen prototype. Details, such as trial protocols and data analyses, are also outlined.

Chapter 6, many results from those trials undertaken which are related to each other are discussed, conclusions are drawn and the overall benefits of the research findings are given. Finally, the remarks and suggestions for further research are outlined in Chapter 7.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

In this chapter, the previous work available in the literature concerning the theme of research is reviewed. Section 2.2 provides an overview of the incidence of spinal cord injury, causes, the relationship between level of injury and a realistic expectation of functional activities.

The role of assistive technology for spinal cord injury is shown in Section 2.3. How assistive technology helps SCI patients enhance their functional ability and provide opportunities for returning to the labour market are described. Factors related to post-injury employment are also attached.

Section 2.4 provides an overview of the application of ICT for persons with spinal cord injuries, the comparison of up-to-date alternative input devices for the disabled, and the occurrence and prevention of computer work-related musculoskeletal injuries.

Approach to measurements and evaluations of assistive technology are outlined in Section 2.5. The concept models, psychosocial factors and usability issues, which are associated with AT assessments, are reviewed in this section.

Finally, a critical appraisal of the previous research work and scope of the present work are presented in Section 2.6 and 2.7.

2.2 Physical Aspects of Spinal Cord Injuries

The spinal cord is responsible for carrying messages between the brain and the rest of the body. In Figure 2-1, it can be seen that the spine is made up of a series of bones (vertebrae) that are linked together to form the spinal column. Movement of the spine is possible because each vertebra is separated by flexible discs of cartilage. Four anatomical regions make up the spine, from top to bottom, cervical spinal (vertebrae C1-C7, the neck), thoracic spine (T1-T12, the upper back, predominantly behind the chest), lumbar spine (L1-L5, the lower back), and the sacral spine (the sacrum and a group of fused vertebrae joined to the coccyx via the sacroiliac joint). Spinal cord injury (SCI) results in partial or complete paralysis, and stops messages being transmitted.

Spinal cord injury is caused by damage resulting from, or disease of, the spinal cord. SCI takes two main forms, resulting in complete or incomplete loss of movement and sensation affecting the lower limbs and lower part of the body (paraplegia), or both upper and body (tetraplegia). In addition, SCI has brought about a broad impact on medical, social, psychologic, and economic conditions for those directly affected, their paid or unpaid caregivers, and the community (Pulaski 1998; SIA 2004; SIA 2005; Trieschmann 1988; UAB 1991).

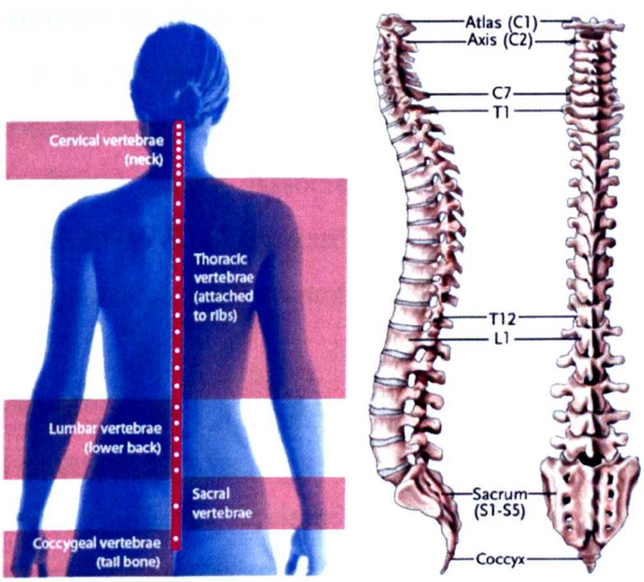

Figure 2-1 The place and names of vertebrae (SIA 2005; SpineLine 2005).

2.2.1 Statistics on Spinal Cord Injuries

Every day in the UK, two people are permanently paralysed from an accident that damages their spinal cord. It is estimated that the annual incidence of spinal cord injury is approximately 1 case per 1,500 population in Britain, or approximately 700 new cases each year. The number of people who live in Britain who have SCI has been estimated to be approximately 40,000 persons (SIA 2004; SIA 2005).

SCI primarily affects young male adults. Most injuries occurr between the ages of 16 and 30. In 2001, the British Association of Spinal Cord Injury Specialists (BASCIS) conducted a survey of all patients admitted to spinal injuries units. The results showed the most common causes of SCI in the UK are falls (45.5 %), road traffic accidents (39.2%) and sports injuries (10.2%) (Nichols et al. 2005; SIA 2004; SIA 2005).

2.2.2 Level of Injury and Functional Activities

The cause of each SCI is unique: similar injuries often do not incur the same loss of physical function and sensation. In addition, SCI patients react and adjust to their injuries in a variety of ways and over varying lengths of time (Krause and Crewe 1987; Trieschmann 1988). A spinal cord injury is evaluated and classified based on the International Standards for Neurological and Functional Classification of Spinal Cord Injury of American Spinal Injury Association/ International Medical Society of Paraplegia (ASIA/IMSP 2001). This standard indicates both the location of the spinal cord lesion and the lowest muscle with normal function.

Spinal cord injury normally leads to significant disability which results in either partial or total paralysis. In terms of paralysis of skeletal muscles, patients with a high lesion (i.e. cervical) are likely to suffer paralysis of all extremities (i.e. tetraplegia), whereas those with a lower lesion (i.e. thoracic or lumbar regions) are likely to present paralysis only of their lower limbs but maintain total function of their arms (i.e. paraplegia). That is to say, organs and body processes below the level of the lesion will be affected, whereas those above the lesion are normally unaffected. For instance, persons with a high cervical spinal lesion, who sustained lesions at the C1-C3 levels, would suffer diaphragm paralysis which invariably raises respiratory problems, and would be likely to require ventilation urgently and will need to be maintained on a long-term basis; individuals with injuries at the C5 and C6 levels could be able to perform some activities, such as eating, propelling a manual wheelchair, driving a van with a lift, modified control and other adapted equipment; patients with an injury at the C7 or C8 level might work independently with their hands, and may have functioning triceps[7] which presents a critical determinant for functional independence in self-care actions to get themselves in and out of their wheelchairs (Nichols et al. 2005; Welch et al. 1986; Yarkony and Chen 1996)

The main determinant of the degree of disability and organ dysfunction is the location of the lesion and whether it is complete or incomplete. 'Incomplete' injuries indicate that some sensation and/or controlled motor function has been preserved or has returned below the zone of injury. A patient with an incomplete injury could be able to sense heat or someone's touch, and might have only numbness or weakness in affected muscles instead of paralysis. Moreover, a person might have only some sensation preserved below the injured level but with complete loss of voluntary motor control. 'Complete' injuries indicate that the spinal cord has been so severely cut, bruised or crushed that there has been no preservation of either motor function or sensation below the zone of injury. For instance, a person with C4 complete injury is paralyzed from the shoulders down, with little or no sensation or motor function anywhere below the level of the injury.

According to SIA (2005), SCI could happen to anyone, at any time and any age, severely hampers mobility, and often drives its sufferers to become life-long wheelchair user. Nichols et al. (2005) indicated most patients admitted to spinal injuries units in Britain have cervical or high thoracic lesions which might cause them tetraplegia. Because of the very limited move function, would individuals with SCI be permanently excluded from the social communities and the job market after injuries?

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[7] Triceps: the upper, outer arm muscles we feel when doing push-ups.

2.3 Assistive Technology for Spinal Cord Injuries

Persons with physical disabilities, such as SCI, often require assistance to function more independently at home, school, work, and throughout the community. This assistance may come from another person or from an assistive technology device (ATD). The definition of Assistive Technology Device is most frequently cited in the US Technology-Related Assistance for Individuals with Disabilities Act of 1988 (Tech Act) (P.L. 100-407) as '*any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities.*'(1995). Scherer (2000a; 2000b) addressed that AT is meant to free people and enhance the independent functioning of people who have physical limitations or disabilities. AT helps these people become more self-determining, to have more choices in their lives beyond the mere physical capability, and to facilitate community participation; moreover, the potential role for AT is more far-reaching and can be conceptualised as improving users' every day competence and quality of life.

2.3.1 Assistive Technologies as an Opportunity to Return-To-Work

Assistive technology plays an even more significant role in the life of persons with severe disabilities, such as SCI. There is a close link between AT and SCI sufferers. Because of assistive technology devices, a great number of SCI sufferers can now lead more independent lifestyles than ever before in history. For instance, wheelchairs enable persons who suffered SCI to have the mobility to go outside like normal people (ABLEDATA 1994; Cooper 1998); alternative input devices bring opportunities to communicate world-wide via computers (ABLEDATA 1995; Hawking and ATAccess 2000a); and they could also participate in recreation and sports when provided with some specialized equipment (ABLEDATA 1993; Slater and Meade 2004). Accordingly, ATDs designed to increase users' physical functions and life independence can be instrumental in offering SCI individuals the highest possible level of function post-injury. In addition, ATDs enable those people to return to work following SCI. In other words, functional independence was selected as a strong factor predicting RTW (Anderson and Vogel 2002; Hess et al. 2000; Jang et al. 2005; Kannisto et al. 1998;

Krause 2003; Yasuda et al. 2002), and can clearly be revealed to fit in with the demands of the labour market based on the assistance of various ATDs. In Athanasou et al. (1996), around 31% of the 139 SCI sufferers who participated revealed being employed in full-/part-time jobs post-injury; Krause et al. (1999) revealed that a 24.8% post-injury employment rate assessed by Craig Handicap Assessment Reporting Technique (CHART) were performed by 3,756 SCI subjects; 37% of the 234 SCI persons and 51% of a total 195 SCI interviewees were engaged in gainful employment after injuries as reported by Tomassen et al. (2000) and Anderson and Vogel (2002) respectively; in addition, of the 169 SCI people, 47% subjects successfully returned to work post-injury (Jang et al. 2005). That is to say, assistive technology and its application improve functional independence of the disabled. Moreover, it enables them to gain employment as an opportunity to return to work for those persons with physical disabilities.

2.3.2 Employment-Related Factors and Post-Injury Work

Despite functional independence, some work-related factors were significant predictors correlated with post-injury employment, such as educational level and post-injury education/ vocational training (Anderson and Vogel 2002; Hess et al. 2000; Krause 2003; Krause et al. 1999; Pell et al. 1997; Tomassen et al. 2000; Yasuda et al. 2002) and transportation needs (Bricout 2004; Jang et al. 2005; Kitchin et al. 1998) were pointed out. Attending post-injury education and vocational training enabled the disabled to gain in-demand qualified skills and enhanced job opportunities. Furthermore, Kruse et al. (1996) and Pell et al. (1997; 1999) investigated computer skills training which was adopted by most SCI subjects and the extension of computer access and computer training was to meet the needs of persons with physical disabilities. As expected, the transportation concern was also a significant influence in returning to employment among persons with SCI (Bricout 2004; Jang et al. 2005). SCI persons with greater mobility to use public or private transport showed a greater likelihood of returning to employment than those who were more disabled (Jang et al. 2005).

Because of the physical functional limitation inherent in disabilities, SCI job seekers were excluded from heavy labour and the highlighted transportation inconvenience was a matter of concern. Mills et al. (2001) defined that telework or telecommuting is a work arrangement which allowed employees to work regularly at a site, e.g. the place of business, homes, or other worksites. Bricout (2004) indicated that home-based teleworking would lessen many return-to-work barriers, such as transportation, for individuals with SCI. Working at home brings some advantages for SCI employees, such as flexible working pace, habitual workplace and equipment, and no transportation inconvenience. Furthermore, the reported potentialities of the computer revolution could not only widen employment opportunities for persons with disabilities, but also alleviate the impacts of physical restrictions which accompanied their disabilities (Anderson et al. 2001; Kruse et al. 1996; McKinley et al. 2004; Pell et al. 1997; Pell et al. 1999; West and Anderson 2005). Correspondingly, a high percentage of computer use was revealed among those SCI subjects (Drainoni et al. 2004; Kruse et al. 1996; Pell et al. 1997; Pell et al. 1999). Kruse et al. (1996) also found that the percentages of current computer use and experiences of attending computer training among SCI people were higher than in the general population; Pell et al. (1999) reported that quadriplegia subjects had higher level of computer ability than those with paraplegia; therefore, Jang et al. (2005) suggested that computer-related vocation should be considered as a top priority for those persons with SCI, especially the ones with CSI.

From the above points of view, it can be said that home-based teleworking via the use of information communication technologies (ICT) provides an applicable employment alternative for SCI people wishing to obtain post-injury employment.

2.4 Computer Technology for Spinal Cord Injury

Kruse et al. (1996) addressed that computer use and skills enhanced employment and earnings for individuals with SCI. It stands to reason that much of what individuals with disabilities want is simply access to a computer (Evans et al. 2000; Hawking and ATAccess 2000b; Hwang et al. 2001).

The traditional computer input devices, such as a point and click mouse, and a QWERTY keyboard (named for the top left-hand side of the rows), are designed to fit people who can effectively use both hands. Individuals with physical limitations, such as SCI, might not be able to use conventional devices and may benefit from using input alternatives (Hawking and ATAccess 2000b; Loy 2005). Alternative input devices are designed to replace conventional keyboards and mice which cannot be effectively operated by those users with variety of limitations. The available alternative input devices are made in many shapes and dimensions for fitting the wide ranges of requirements from users with a variety of functional limitations. Also, the alternative devices allow users to access a computer in many kinds of ways, for instance, persons who have sustained a high cervical lesion (CSI) who face difficulties of hand and finger movements and would activate a computer by using only the head, eyes, mouth, breath, thumb, or a single finger.

2.4.1 Existing Alternative Devices for Persons with Spinal Cord Injury

Many companies are now producing alternative devices for the disabled and attempt to achieve greater applicability and accessibility of their products, especially in the area of keyboard and mouse alternatives, including hardware, and software, such as AliMed, assist IT, Bellaire Electronic, Compusult Limited, Don Johnston, Inforgrip, Maltron, etc. The following lists (Table 2-1 and Table 2-2) categorize computer assistive input devices which might be applied to SCI users.

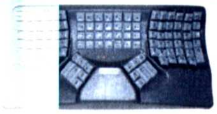
Many researches are focused on alternative input device for persons who can perform no or partial upper limb movements. For instance, Yang (2000) suggested an adaptive Morse code recognition method to apply on the alternative input devices; Park and Lee (1996) and Park and Lim (2001) developed an integrated eye and head-position monitoring device; Chen et al. (2003) focused on a head movement image controlled computer mouse system for the spinal cord injured; Tanimoto et al.(2005; 2003) measured the computer input ability of SCI patients with tetraplegia and developed a three time parameters input device for those patients.

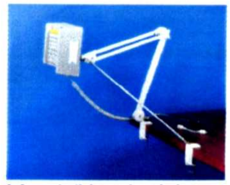
Based on the findings of Table 2-1 and Table 2-2, the pros and cons of existing alternative devices especially for SCI users are discussed in Table 2-3. It is found that most displayed alternative input devices in the current marketplace are more likely for the minor or moderately physically disabled or persons with no functional performance of their upper limbs. Many people who suffer SCI tetraplegia who still have partial or limited upper limb movement are unable to operate conventional keyboards and mice, and also experience difficulties using many alternative input products. Based on this viewpoint, Tseng (2003) and Chang (2004) attempted to design an alternate input specially for users with upper limb impairments and who are unsuited for ordinary alternative inputs. The idea is- touch screen could be a means for these SCI users for accessing a computer (Chang 2004; Tseng 2003).

Touch screens, which are computer display screens, are activated by human touch, are frequently used for information kiosks, automated teller machines (ATM), personal digital assistant (PDA), etc. Moreover, touch screens are designed to provide user-friendly and intuitive computer access without requiring a keyboard and mouse for the disabled. Holzinger (2003) proved that touch screens were simple and user-friendly for the elderly and/or disabled people who have low or no computer literacy and suggested to enhance its universal access to the whole information society. Tseng (2003) and Chang (2004) have developed an integrated touchscreen input device especially for persons who have sustained upper limb motion disorder.

Tseng (2003) and Chang (2004) indicated that most alternative input devices/ systems present only a specific function or single task. Tseng (2003) also pointed out that an alternative input device, combined with multiple functions, can be applied to a wider range of persons who have severe physical disabilities and who have a variety of functional limitations and requirements. Hence, the developed integrated touchscreen input devices have comprised both keyboard and mouse functions for persons with hand movement limitations. The system not only presents keyboard functions on the touch panel of a liquid crystal display, but also provides the mouse functions and additional options, i.e. Scanning input, Morse code and Personal digital assistant. In addition, the integrated touchscreen system provides two selections for users: a portable utilisation as the 5.7-inch touchscreen device, and the desktop use as the 9-inch device. However, there is no proven evidence and validation shown between this developed integrated touchscreen input device and those disabled users in their studies.

Table 2-1 Alternate keyboard descriptions.

Category	Character	Part of body to operate	Sample Product
Alternative keyboards	- Increase typing comfort for users who experience pain and fatigue when keyboarding - Customize many sizes and shapes (fixed split, adjustable split, or contoured keyboards) - Allow position and arrangement to user's preference - Designed with ergonomic considerations or for physically disabled users	- Hands and fingers	 L-type keyboard (Maltron)
Small keyboards	- Smaller than traditional keyboards - The actual size of keys is similar to standard keyboards - Space is saved by removing the numeric keys and reducing the gaps around the editing and function keys	- Hands and fingers - Specially suited to one-handed users	 Cherry G84-4100 Compact Keyboard (Cherry Corporation)
Expanded keyboards	- Typically flat, and smooth surface - Larger keys (i.e., one-inch square) - Special material overlay for its surface (Mylar, or nylon coating) - Designed for the physically disabled and visually impaired users	- Hands and fingers - Foot and toes	 Expanded keyboard (Maltron)
One-handed keyboards	- Provide more convenient single-handed entry and control - Shape matches natural hand movement	- Single-handed operator	 Left-hand Keyboard (Maltron)
Chording keyboards	- Smaller than conventional keyboards - Have limited number of keys, typically one for each finger and possibly the thumbs - Require simultaneous key presses for each character typed, similar to playing a musical chord on a piano - Training and practice are required to learn the chord patterns that represent individual letters and numbers	- Single-handed operator	 CyKey keyboard (Bellaire Electronic)
Head-/Mouth-pointer keyboard	- Operated by headpointer and mouthstick - The shape matches natural head movement - Key arrangement reduces finger or stick activity - Can be held by an articulated arm in a proper position for the use of head or mouthstick.	- Head (headpointer) - Mouth (mouthstick)	

			 Mouth/Head-stick keyboard (Maltron)
On-screen keyboard	- Software required - Images of standard or modified keyboard placed on computer screen - Keys selected via the use of a mouse, touch screen, trackball, joystick, switch, or electronic pointing device	- Hand and fingers	
Voice recognition system	- Allows activation of a computer by vocal stimulation - Involves both hardware and software systems - Time required for the systems being trained to recognise the speaker	- Speech	

Source: Ability Net (2005), Hawking and AT Access (2000a), Loy (2005); Bellaire Electronics (2003), Cherry Corporation (2005), Maltron (2006a; 2006b; 2006c; 2006d).

Table 2-2 Alternate Mouse/ Pointing Descriptions.

Category	Character	Part of body to operate	Sample Product
Alternative mouses	- Variations of conventional click and point mouse - Designed to help persons with different motion limitations who cannot grip a traditional mouse - Provide variable sizes and shapes - Require different amounts of pressure on buttons	- Hand and fingers	 VerticalMouse (Infogrip)
Trackball mouses	- An upside-down mouse - Use a single digit or a pointing aid to activate the movable ball on the top of a stationary mouse base - Press buttons on the device to activate the cursor as similar to a standard mouse - Larger trackballs can be suitable for foot operation	- Hands and fingers - Foot	 BIGtrack mouse (Infogrip)
Joysticks	- Similar to joystick controls on a wheelchair - Offer three types of control: digital, glide and direct - The mouse pointer can be moved fastest when pushing the joystick fully forward - Provide a guard, a drag lock button and a button which sends a double click	- Hands and fingers - Any part of the body	 HelpiJoy Joystick Mouse ((Infogrip)
Switches	- Plug into the computer like other input devices - Come in various sizes, shapes, colours, method of activation, and placement options - Enter information using a switch - Require certain software to scan functions and operate computer processes with a click of the switch - Allow operation of switches by any part of the body	- Hand and fingers - Any part of the body	 Jelly Bean Switch (Don Johnston Incorporated)
Pen tablet	- Allow direct pen-on-tablet and fingertip-on-tablet to input and control - A cordless pen has a pressure sensitive tip, and two side switches for clicks and pressure sensitive eraser - Use the pen to draw a sketch or write a note on the clear plastic overlaid tablet	- Hand and fingers	 Graphire 4x5 (WACOM)

Touch Pads	- Normally displayed on laptops - Operated by sliding a finger across the stationary surface, tapping lightly on surface, or clicking buttons - Held in the hand or placed on a desk	- Hands and fingers	 Easy Cat touchpad ((Infogrip)
Head mouse	- Replaces a mouse - Moves of the head moves the cursor on the screen - Makes selections by exhaling down the tube - Requires an on-screen keyboard program for inputting data	- Head	 HeadMaster Plus (Prentke Romich)
Mouth operated mouse	- Controlled by the mouth - Moving the precision joystick moves the cursor, the further the joystick moves, the faster the cursor moves - Can be held by the articulated arm and positioned on the desk - Requires an on-screen keyboard program for inputting data	- Breath and mouth	 Jouse2 mouse (Compusult Limited)

Source: Ability Net (2005), Hawking and AT Access (2000a), Loy (2005); Compusult Limited (2006), Don Johnston Incorporated (2006), Infogrip, Inc. (2003a; 2003b; 2003c; 2003d), Prentke Romich (2006), Wacom (2006).

Table 2-3 Advantages and Disadvantages for SCI users with hand motor impairment.

Category	Potential SCI users	Advantages	Disadvantage
Alternative keyboards	- Limited one/ two hand motor skills - (single-input operation)	- Can be customized in many sizes and shapes - Easily found in market - Affordable	- Replace only the keyboard - Designed for full use of hands - They keys are too far apart - May incur early tiredness and fatigue
Small keyboards	- Limited one/ two hand motor skills - (single-input operation)	- Have the standard key size but the entire layout is smaller - Reduce large-area operation	- Replace only the keyboard - Require additional products, e.g. numeric keypad
Expanded keyboards	- Limited one/ two hand motor skills - (single-input operation)	- The same operations as traditional keyboards - Flat and smooth surface - Avoid input errors because of the build-in keyguard - Heavier construction	- Replace only the keyboard - Have larger surface area than conventional keyboards and require wider-area movements - Not portable
One-handed keyboards	- Limited one hand motor skills - (single-input operation)	- Shape matches natural hand movement - Suitable for single-handed users	- Replace only the keyboard - Designed for full use of one hand - Induction, training and practice are in demand
Chording keyboards	- Limited one/ two hand motor skills - (single-input operation)	- Reduce larger-area operation - Have few keys - Press keys in different combinations to obtain almost any command or symbol	- Replace only the keyboard Need software to translate the keyboard functions to the computer - May require two hands to press combinations simultaneously - Induction, training and practice are in demand
Head-/mouth-pointer keyboards	- No functional performance of both hands	- Can be operated without the use of hands	- Replace only the keyboard - Need additional products for holding the device, e.g. an articulated arm - They keys are too far apart for head/ mouth operation - Require training and practice of headpointer / mouthstick operation for reducing input errors
On-screen keyboards	- Limited one/ two hand motor skills - (single-input operation)	- May allow the standard and alternate keyboards to be used at the same time - Display images of keyboard on the computer screen	- Replace only the keyboard - May need software to translate the keyboard functions to the computer - Require related pointing products to select keys, e.g. a mouse, trackball, joystick, switch, etc.
Voice recognition systems	- No functional performance of both hands	- Allow users to navigate a computer by voice	- Replace mouse and keyboard - Involve both hardware and software systems - Systems must be trained to respond to a particular voice of the user - Require users having good enunciation and using consistent, organized and sequenced speech

Alternative mice	- Limited one/ two hand motor skills - (single-input operation)	- Can be customize in many sizes and shapes - Easily found in market - Affordable	- Replace only the mouse - May face difficulties of controlling buttons and use of correct pressure
Trackball mice	- Limited one/ two hand motor skills - (single-input operation)	- Use few hand movements or a pointing device to perform mouse functions - May adjust cursor speed and sensitivity - A variety of choices of ball diameters ranged from 1" to 4" - Design for maximum comfort of the user	- Replace only the mouse - Time being taken to adjust and well control the cursor speed and sensitivity appropriately
Joysticks	- No or partial functional performance of both hands	- Can be operated by different part of the body, e.g. chin, or head - Operate similar to a joystick control of wheelchair - A simple method of input	- Replace only the mouse - Time being taken to adjust and correctly control the stick
Switches	- No or partial functional performance of both hands	- Can be operated by any part of the body, e.g. mouth - Come in a wide range of sizes, shapes, and colours - Facilitate choice-making - Provide many different operating modes for users, e.g. pressing, interrupting a light beam, pulling, squeezing, bending, sound, or blink of an eye	- Replace keyboard and mouse - Usually require the specialized interface device and software - Need to set up a series of responses using multiple switches - Time being taken to adjust and control the operation - Training in cause and effected efficiently is required
Pen tablets	- Limited one/ two hand motor skills - (single-input operation)	- Allow pen and fingertip to input data or drawing - Speed and sensitivity of the pen can be adjustable	- Replace only the mouse - Need two fingertips to operate pen functions - May not able to grip the pen properly - Time taken to adjust and control the operation well
Touch Pads	- Limited one/ two hand motor skills - (single-input operation)	- Operated by a fingertip - Can be mounted on any surface - Can be portable	- Replace only the mouse - Light pressure or touch may not be sensed when sliding a finger across the surface
Head and mouth-operat ed mice	- No or partial functional performance of both hands	- Operated by head movement or mouth-puffing	- Replace only the mouse - Need specific software support - Work with on-screen keyboard - May require the head to be held still - Induction, training and practice are in demand

2.4.2 Computer Work-Related Musculoskeletal Disorders and Ergonomic Considerations

Information and Communication Technologies (ICT) are one of the fastest growing innovations worldwide, and have been proven to be an easy and convenient means of communicating and accessing information, and brings benefits to the majority of the population. In recent years, the occurrence of work-related musculoskeletal disorders (WRMSDs), also known as work-related upper limb disorders (WRULDs), repetitive strain or stress injuries (RSI), and cumulative trauma disorders (CTDs), has risen dramatically in global society. Unfortunately, computer users who performed intensive and prolonged operations have become one of the target groups with a high risk of suffering the occupational injuries. Szabo (1998) reported 7897(21%) out of 37,804 cases reported work-related carpal tunnel syndrome (CTS) attributed to repetitive typing or key entry data in 1994. Similarly, the group of display screen equipment/computer users presents a particularly high risk of work-related upper limb disorders in the UK population today (Sleator et al. 1998). Accordingly, many studies have demonstrated that intensive computer work results in a high prevalence and incidence of musculoskeletal disorders (MSDs)/ upper limb disorders (ULDs) among the operators (Babski-Reeves et al. 2005; Bergqvist et al. 1995a; Bergqvist et al. 1995b; Devereux et al. 2002; Faucett and Rempel 1994; Hales et al. 1994; Haufler et al. 2000; Malchaire et al. 2001; Sauter et al. 1991; Tittiranonda et al. 1999; Zennaro et al. 2003).

Several studies have investigated the relationship between the keyboard and mouse and risk factors related to computer work-related injuries (Cail and Aptel 2003; Cooper and Straker 1998; Fagarasanu and Kumar 2003). Some studies indicated keyboard usage, which has become an integral part for data entry tasks, is a causal and crucial factor incurring musculoskeletal/ upper limb disorders among computer operators (Amell and Kumar 1999; Amell and Kumar 2000; Bergqvist et al. 1995a; Bergqvist et al. 1995b; Feuerstein et al. 1997; Liao and Drury 2000; Sauter et al. 1987; Swanson et al. 1997; Szeto et al. 2005b; Woods and Babski-Reeves 2005); Some studies investigated mousing tasks and found that mouse use is also highly associated with an increased risk of neck and upper limb disorders but this is not the case with keyboarding (Atkinson et al. 2004; Blatter and Bongers 2002; Cooper and Straker 1998; Delisle et al. 2004; Finsen et al. 2001; Karlqvist et al. 1994; Keir et al. 1999; Sillanpaa et al. 2003).

Potential risk factors, such as sedentary work, awkward positions, static work posture, repetitive movements, inactivity, overuse injury, limited rest break opportunity, time on task, non- use of low arm support, inappropriate monitor and keyboard position and placement, stress reactions on bone and connective tissue, pressure on blood vessels, nerves, and eyes, may cause MSDs in computer workers (Bergqvist et al. 1995a; Carter and Banister 1994; Fagarasanu and Kumar 2003). Exposures relevant to the prevention of musculoskeletal disorders for computer workers would be most successful if approach to ergonomics/ human factors[8] that emphasize, for example, the ergonomic design of workstation, equipment, and work organization to match capabilities and limitations of the operators (Amell and Kumar 2001; Coury 2005; DHHS(NIOSH) 1995; Fallentin et al. 2001; Kilbom 1999; Westgaard and Winkel 1997). A variety of extrinsic and individual intrinsic ergonomic factors linked to computer-intensive work, such as postural issues, force risk, personal habitual preference and practice, the design and organization of work tasks, workstation adjustability, placement of equipment, work materials, accessories, equipment redesign, etc, has been identified (Amell and Kumar 2001; Bergqvist et al. 1995b; Feuerstein et al. 1997; Ortiz-Hernandez et al. 2003; Pascarelli and Kella 1993; Sauter et al. 1991; Sillanpaa et al. 2003; Szeto and Lee 2002).

Thus, the use of conventional keyboards and mice appeared to be potential hazards and the ergonomic factors are proposed as a viable means of prevention of computer work-related injuries. Woods and Babski-Reeves (2005) emphasised that several changes to computer peripherals are required, especially in keyboard designs. Wagner et al. (2003) addressed the arrangement of letters on a keyboard is a influential factor which directly affects typing speed, user comfort and repetitive injuries. That is to say that the need for better keyboard layout and design of has emerged. Some studies focused on replacing the traditional keyboard layout typically referred to as the QWERTY design (the first six letters of the left portion of the top alphabet row) with alternative designs (Anson et al. 2001; Dvorak 1943; Eggers et al. 2003; Gerard et al. 1994; Hedge and Powers 1995). Moreover, the alternative keyboards which followed ergonomic principles were promoted in terms of offering an impressive range of

[8] Ergonomics is the science and discipline which encompass a relationship between the workers and the job and focus on the design of jobs and workplaces for enhancing the quality and performance of the job.

adjustable features, improving efficacy and comfort in keyboard operation, and significantly reducing muscle strain in keyboard operation (Gerard et al. 1994; Swanson et al. 1997). Some ergonomic alternative keyboards were designed and developed, such as Maltron keyboards (Hobday 1988), Kinesis Keyboard (Gerard et al. 1994), Split keyboard (Cakir 1995; Hedge and Powers 1995; Lincoln et al. 2000; Marklin and Simoneau 2001; Marklin et al. 1999; Smith et al. 1998), OPEN keyboard and FIXED keyboard (Zecevic et al. 2000).

Compared with the usage of conventional keyboards, several studies indicated that alternative keyboards could be easily accepted and rapidly adapted by the users; results also showed that alternative keyboards could provide advantages for reducing occupational risk factors of work-related musculoskeletal disorders (Marklin and Simoneau 2001; Marklin et al. 1999; Smith et al. 1998; Zecevic et al. 2000). That is to say, ergonomic alternative keyboards are designed to benefit a great number of computer users during prolonged and intensive computer operation. However, could it give effect to the disabled population, such as SCI sufferers?

Persons with SCI are encouraged to re-enter the labour market, and occupation related computer work is suggested as a better opportunity suitable for the severely physically disabled. However, musculoskeletal disorders associated with problems in hands, forearms, elbows, wrists, shoulders, and neck, would follow repetitive computer work and cause these employees to be susceptible to secondary injury post-SCI. In other words, it can be believed that SCI computer users would be a high-risk WRULD target population. This assumption could be established by Pascarelli and Kella (1993). Pascarelli and Kella (1993) who investigated computer work-related musculoskeletal injuries among the 53 keyboard operators who sustained severe disabilities. Results showed that the prevalence of upper limb injuries (e.g. pain in neck, shoulders, elbows, forearms, wrists, and hands) was found among the subjects. In this clinical survey, both internal and external ergonomic risk factors associated with keyboard use are addressed and suggested to be a consideration linking computer operation and potential musculoskeletal disorders.

Alternative input devices are designed not only for normal computer users but also for the disabled, even those with severe physical disabilities. For individuals with SCI, the appropriate support of alternative input devices can be instrumental in overcoming barriers to computer utilisation, bringing about a possible higher level of function ability, gaining in-demand qualified skills and employment; in addition, it may prevent injury and limit secondary injury correlated with intensive and repetitive computer operation. Consequently, to offer a suitable alternative input device to many SCI computer users, especially those who cannot operate conventional products, requires immediate attention.

2.5 Assessment and Evaluation of Assistive Technology

The fields of assistive technology (AT), i.e., knowledge, design, practice and research, have developed and become well-grounded and recognized over the past 20 years (DeRuyter 1995; Weiss-Lambrou 2002). Gitlin (2002) itemized five strategies for assistive technology: structural alteration, special equipment, assistive device, material adjustments, and environmentally-based behavioural modification. *Structural alterations* correlate changes made with the physical environment; *special equipment* involves attachments to the original structure of the physical environment; *assistive device* specifies an item can be applied to or directly operated by a person; *material adjustments* refers to alternations to the nonpermanent features of the physical environment; *environmentally based behavioural modification is* related to a person's interaction with the physical dimensions of the environment (Gitlin 2002). Correspondingly, the widespread and up-to-date research related to AT measures and assessments most typically documented a multitude of factors associated with clinical results, device performance, functional status, design improvements, cost, quality of life, specific consumer concerns and satisfaction (Batavia and Hammer 1990; DeRuyter 1995; Phillips and Zhao 1993). Some measures pinpointed user utilisation and abandonment (Brooks 1991; Fuhrer et al. 2003; Lenker and Paquet 2003; Phillips and Zhao 1993; Rogers and Holm 1992; Scherer 1988; Scherer 1990; Scherer 1996); some assessments were concerned with personal and psychosocial factors (Day and Jutai 1996; Demers et al. 1996; Jutai et al. 2000; Louise-Bender Pape et al. 2002); some studies pointed out the measurement of satisfaction is considered to be very essential in the management of assistive technology device outcomes (Demers et al. 1996; Demers et al. 2000; Demers et al. 1999; DeRuyter 1995; Kohn et al. 1991; Simon and Patrick 1997; Trachtman 1994; Weiss-Lambrou 2002; Weiss-Lambrou et al. 1999); some measures particularly addressed the standpoint of a multiple-stakeholder view of AT and the related services (DeRuyter 1995; DeRuyter 1997; Fuhrer 2001; Fuhrer et al. 2003; Smith 1996); some provided economic evaluation/ cost analyses in assistive technology research (Andrich et al. 1998; Harris and Sprigle 2003; Tinker and Lansley 2005; Warren 1993).

2.5.1 Conceptual Models of AT Measurement and Assessment

Kondraske (1990) defines a measurement as '*a process in which an absolute standard is used to quantify a single dimension of an object or event*' (Kondraske 1990). Nowadays, numerous assistive technology-related models have appeared and been used to describe how assistive technology impacts the end-user. The conceptual models of AT measurement and assessment provided a theoretical basis for advancing scientific knowledge and improving professional practice (Cushman and Scherer 1996; Lenker and Paquet 2003). Three conceptual models are reviewed here: Cook and Hussey's Human-Activity-Assistive Technology model; Scherer's Matching Person and Technology model; and Fuhrer's Assistive Technology Device-Specific Framework. Details are given in the following sections.

Human Activity Assistive Technology (HAAT) model

The human activity assistive technology model has been developed by Cook and Hussey (1995) as a framework which typically describes the performance of a person (human operator) in a given task/goal (activity) involving technology (the assistive technology)within a give situation (context). Each of the components plays a unique role in the total system as shown in Figure 2-2 (Cook and Hussey 1995).

Each component of the HAAT model plays a role in assisting individuals to engage in activity. Firstly, the 'activity' is the fundamental element of the HAAT model. It defines the goals of the system and represents the functions depending on human performance being categorized within three basic performance areas: self-care, work/school, and leisure/play. Secondly, 'human' refers to the person attempting to engage in an activity involving assistive technology. In addition, the human component of the HAAT models showed the major 'intrinsic enablers' normally represented by the sensors, central processing, to the effectors. Next, 'context' indicates the physical and social environments in which the activity is being performed. It has been expanded to include setting (e.g. individual home, group home, employment, school and community), social aspects (e.g. peers, strangers, alone) and cultural aspects (e.g. use of time, balance of work and play, sense of personal space, etc) as well as environmental and physical conditions (e.g. light, sound, heat) and its relationship to the other system components is altered. Finally, the 'assistive technology' of the HAAT model has been offered the basis by which human performance is improved in the presence of disability as well as 'extrinsic enablers'. The portion of assistive technology encloses four components: the human/technology interface, the processor, the activity output, and the environmental interface. The 'human/technology interface', refers to the contact between the human and the assistive technology. In terms of the 'processor' component, it is a linkage between the human/technology interface and activity output; in other words, it relays or interprets information and forces received from the human into signals that are used to control the activity output. This 'activity output' component refers to the accomplishment of functional performance provided by the technology. The 'environmental interface' connects the output of the device with the input from the environment (Cook and Hussey 1995).

Once an assistive technology system has been designed, it is essential to measure the performance of the technology and determine its functional effectiveness in conjunction with the consumer. The HAAT model provides the basis by which system performance can be evaluated.

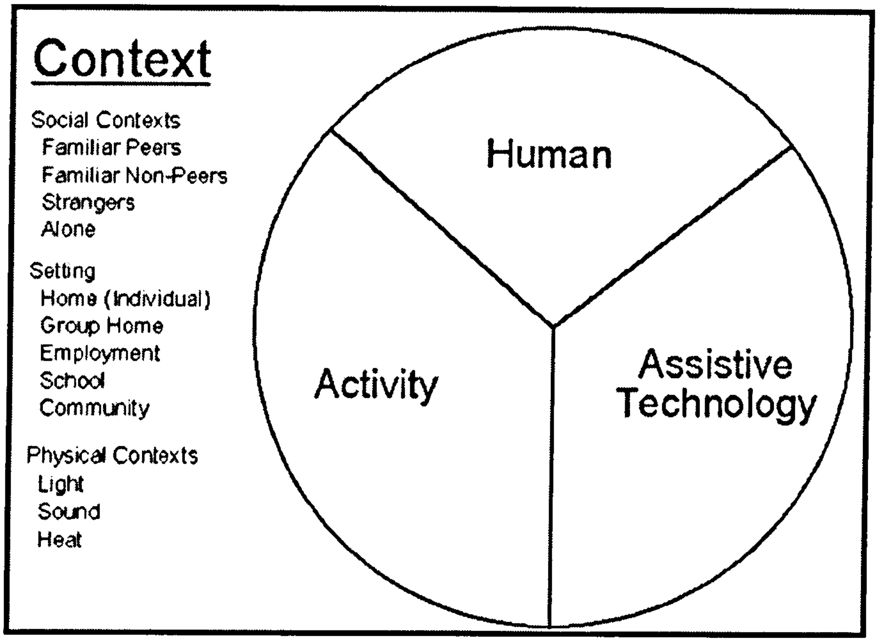


Figure 2-2 Human Activity Assistive Technology (HAAT) Model (Cook and Hussey 1995)(p.56).

Matching Person and Technology (MPT)

The Matching Person and Technology (MPT) model (Scherer 1998), first presented in 1989, has accounted for considerable influences on assessment instruments. Scherer's MPT model has suggested individual personality and social factors that influence a person's desire or ability to use technology (Galvin and Scherer 1996; Scherer 1990; Scherer 1991; Scherer and McKee 1991).

The MPT model is a multi-dimensional instrument target for adults with disability and has addressed three components in assessing an individual's predisposition to the use of technology involving milieu, person and technology, as seen in Figure 2-3. The '*milieu*' focuses on characteristics of environment and psychosocial setting in which the AT is to be used. Factors include, such things as, support from family, peers, employer, a setting that rewards the use of the device, and pressure from others. The '*person*' component provides information about the user's personality factors which refers to motivation, co-operation, optimism, good coping skills, patience, self-discipline, positive life experiences, skills, a perceived discrepancy between desired and current situation, and willingness to be challenged. In terms of the '*Technology*', it centralises specific characteristics of the technology itself, including functions and features, ability to be used without discomfort or stress, compatibility with other technologies, safe, reliable, easy to use and maintain, transportability , and best option currently available (Galvin and Scherer 1996; Scherer 2000c).

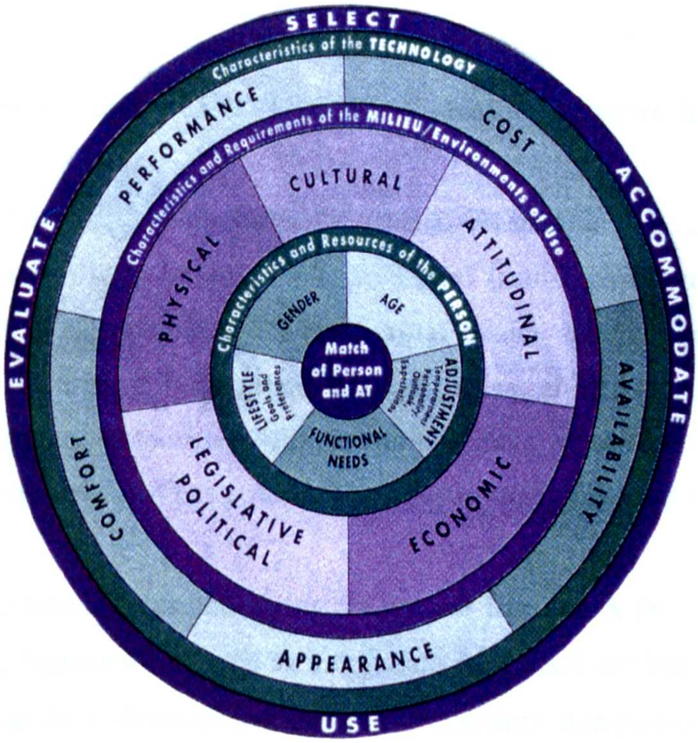


Figure 2-3 Matching Person & Technology Model (Scherer 1996).

The MPT model purposes to offer a more personal approach to matching persons with the most appropriate assistive technology for their use. The process consists of a series of instruments (self-report checklists about consumer predispositions to and outcomes of technology use) including (a) the survey of technology use (SOTU); (b) the technology-specific forms, i.e. Assistive Technology Device Predisposition Assessment (ATD PA), Educational Technology Predisposition Assessment (ET PA), Workplace Technology Predisposition Assessment (WT PA), Health Care Technology Predisposition Assessment (HCT PA). Each instrument consists of a pair of instruments (one for the clinician and one for the technology user) (Albaugh and Fayne 1996; Albaugh et al. 1997; Scherer and Cushman 2000; Scherer and Cushman 2001; Scherer and Cushman 2002; Scherer and Frisina 1998; Scherer and Glueckauf 2005; Scherer et al. 2005).

As a result, the MPT assessment process is one means of providing a more personal approach to matching person and technology and a range of technology assessment tools from a quick screen to a more detailed general AT evaluation to several more specialized evaluations.

Assistive Technology Device- (ATD-) Specific Outcome Framework

Due to many AT measures which narrowly focused on specific AT types and areas of user functioning which were incompletely developed from a psychometric viewpoint, Fuhrer et al. (2003) has formulated a conceptual device-specific framework which discriminates the features of ATD types, services, users, and their environments that include causal sequence associated with the procurement of device to ATD-specific outcomes. The framework also has potential to apply to many types of ATDs.

The following nine assumptions underlying the present framework are shown as follows: (a) an overarching framework as well as a template for causal models; (b) enclosing a view of device use in a developmental (time-dependent) framework which usually distinguishes an initial stage associated with procurement of a device from a subsequent stage associated with all the events thereafter; (c) accommodating both objective ('outsider') and subjective ('insider') perspectives; (d) the provision of multiple stakeholders' view of ATD outcomes; (e) an adoption of International Classification of Functioning, Disability and Health (ICF) for incorporating applicable concepts and terminology of the framework; (f) the depiction of 'Personal Factors' as those users being active and goal-oriented, not merely passively receiving services; (g) the highlight of the highest priority of the outcome measures should be assigned to individual users' needs and objectives in obtaining devices; (h) mediating or moderating factors involved in the framework. Mediating factors are concerned with antecedent and consequences, and key mediating events are the 'introductory' and 'longer-term use' of that device-type. In addition, the moderating factors play a co-factor role in the framework; finally, (i) the separation of continued use of a device in longer-term outcomes from discontinuation of its use as the endpoints of the framework (Fuhrer et al. 2003).

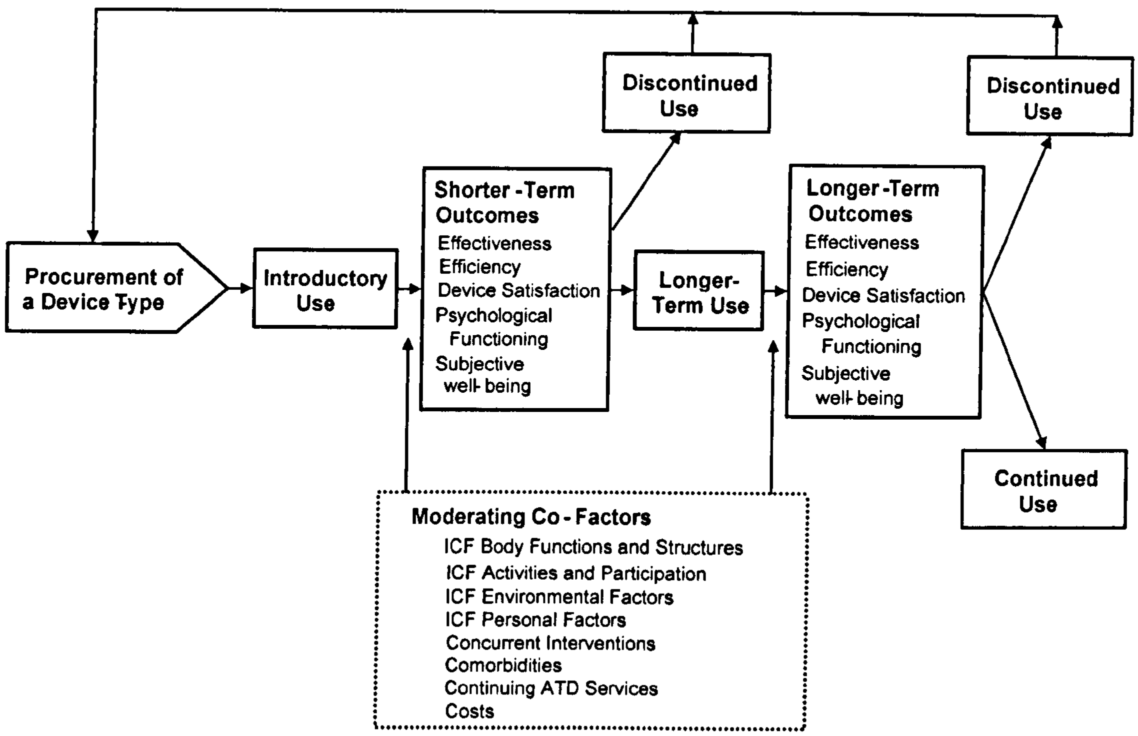


Figure 2-4 A framework for modelling the outcomes of assistive technology devices (Fuhrer et al. 2003)(p.1246).

The solid lines with arrows denote the principal directions of causal influences in Figure 2-4. The framework of device use should be viewed from the stage associated with the procurement of a device-type. Procurement of device-type could be grounding for the mediating events (introductory use and longer-term use) that follow. The device procurement relates to the inclusion of three considerations: those involving (a) needs for a device, (b) the type of device considered with both its intrinsic and extrinsic properties, and (c) the relevant services. The following period of introductory use results in shorter-term outcomes. The outcomes of effectives, efficiency, device satisfaction, psychological functioning, and subjective well-being are entailed in this period. As seen in Figure 2-4, the shorter-term outcomes not only bring on the interaction between introductory use and moderating co-factors but also incur longer-term use or discontinued use. The interaction of longer-term use and the specified moderating co-factors which act as the same as earlier generate an array of longer-term outcomes. Additionally, the longer-term outcomes result in either continued use or discontinued use. In some cases, discontinued use of a device might repeat the proceeding sequence, starting with procurement of another device or a different kind of support (Fuhrer et al. 2003).

Overall, this device-specific framework attempts to bring the consideration of particular device-type, user populations, and condition of device use into action, and intends to be a conceptual structure in facilitating the development of device-specific causal models.

To summarise, the three conceptual models all identified the strong association between individuals' needs and ATD use. ATD users are the centre of the assistive technology system. A user-centred assistive technology system places an emphasis on understanding human attributes and needs and involves device use that satisfies user requirements from a device.

2.5.2 Psychosocial Factors

Day et al. (2002) indicated that the AT field required a reliable and valid measure to discover the psychosocial impacts of assistive technology. Some non-functional criteria related to personal and psychosocial issues influence the shaping of individualized meanings assigned to assistive technology (Demers et al. 1996; Louise-Bender Pape et al. 2002; Scherer and McKee 1991; Stickel et al. 2002).

There are some assessments and measurements concerned with personal and psychosocial factors, such as the two standardized questionnaires: Psychosocial Impact of Assistive Devices Scale (PIADS) (Day and Jutai 1996) and Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) (Demers et al. 1996).

The Psychosocial Impact of Assistive Devices Scale

The Psychosocial Impact of Assistive Devices Scale (PIADS) is a 26-item, self-rating questionnaire developed to be a psychosocial measure; in particular, it measures user perceptions of how assistive devices affect quality of life (Day and Jutai 1996). The PIADS is also designed to be a generic measure, applicable to virtually all forms of AT.

Three dimensions of user perceptions described in PIADS were Adaptability (the enabling and liberating effects of a device), Competence (the impact of a device on functional independence, performance and productivity) and Self-esteem (the extent to which a device has affected self-confidence, self-esteem and emotional well-being). Scores range from -3 (maximum negative impact), zero (no perceived impact) to +3 (maximum positive impact). Accordingly, PIADS scores could be applied in evaluating assistive devices and services in combination with measures of health and functional outcomes, and service costs.

The PIADS was designed to be a generic, responsive and sensitive measure. The measure appears to be applicable to a wide range of AT devices, in populations of persons who have various forms of disability and medical conditions (Jutai 1999), can be completed within 5 to 10 minutes by a respondent or personal carer on behalf of a respondent, and be able to repeatedly provide respondents with a measure of impacts over time, and to compare impacts of devices for respondents who use more than one assistive device; in addition, it can be suitable for international comparisons of the impacts of assistive devices.

PIADS was developed to be a research tool for improving the design of AT devices, to better meet the needs of device users and professionals. However, Fuhrer (1999) suggested PIADS was more appropriate to consider as a measure of users' psychological well-being[9] (Ryff 1995) rather than of their perceived quality of life.

The Quebec User Evaluation of Satisfaction with Assistive Technology

The Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) is a structured and standardized measure aimed to reflect a consumer-responsive and client-centred approach via the evaluation of user satisfaction with a wide range of AT devices. The focus can be on the device itself, the service process surrounding it, or on both (Demers et al. 1996).

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[9] Ryff (1995) suggested that psychological well-being is comprised of six dimensions: self-acceptance, positive relationships with other people, autonomy, environmental mastery, purpose in life, and personal growth.

QUEST is an example of a dual-focus assessment instrument that has several possible applications. The items categorized the assistive device itself (e.g. the simplicity of use, durability, and effectiveness), associated services (e.g. acquirement and repair), its monetary costs, and the social context of using (e.g. support from other people when using it, and others' reactions to it); the instruments of QUEST had the compelling feature of distributing sovereignty to users' judgements, as opposed to the judgements of payers, clinicians, or researchers.

Furthermore, QUEST can be a self-administered or administered through a semi-structured interview. In the interview session, device users could rank their degree of satisfaction of each of 27 items bearing on a specific device; the importance of each item was also graded by the respondents (Demers et al. 2000). Nevertheless, Fuhrer (1999) pointed out two reservations of satisfaction judgement in QUEST evaluation. Firstly, the conceptual models of users' satisfaction judgements emphasize the conjoint role of individuals' perceptions on the one hand, and their expectations on the other; secondly, the satisfaction judgements would neglect the perspective of stakeholders who place greater value on other approaches to gauging outcomes.

The recognition of user satisfaction is a multidimensional phenomenon involving a wide range of variables which can influence the satisfaction of users with an assistive technology device. In brief, QUEST is an outcomes assessment tool which can certainly contribute to being simple to understand and easy to use when evaluating user satisfaction in a structured and standardized way.

Overall, each of the methods, PIADS and QUEST, has been developed and validated to focus on different aspects of assistive technology outcomes. Similarly, both methods have accepted that the psychosocial aspects and relevant crucial variables of assistive device utilisation could lead to successful AT measurements and assessments.

2.5.3 Usability Evaluation

An improvement or attainment of a certain level of functional capability was seen to be the critical key in AT use (Edyburn 2003; Fuhrer 1999; Jutai et al. 1996). Batavia and

Hammer (1990) identified some functional problems, such as the inadequate performance, failure in achieving improved function, and difficulty in operating, would affect AT users on their adoption and abandonment. The term usability is often used to refer to the capability of a product to be used easily and effectively. Hurst (2000), Yen (2001) and Gatti (2004) have addressed usability issues and implemented in assessments of devices/products performance, acceptance and suitability. Correspondingly, Lenker et al. (2005) designated the importance and imperative for applying usability evaluations in the field of AT measures.

In terms of measures of computer-based/-related system or devices, Lun (1995) indicated that usability factors are important considerations which continue to greatly influence the usage of any computer-based system and input/output devices. Three components of usability application were also specified: user-friendliness, user-acceptance, and user-competence. User-friendly, a system should be easy-to-use for users; user-acceptance is a measure of user perceptions which interacting with the system/device; and user-competence assesses the degree of confidence a user has in the use of the functions. The usability is also referred to the ISO (the International Organization for Standardization) standards, such as ISO 9241 [10]. Based on ISO 9241-11 [11] standard which defines usability and takes user performance and satisfaction into account when specifying or evaluating usability of a visual display terminal (VDT), usability has been identified as '*extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*' (ISO9241-11 1998). That is to say, in order to determine the level of usability achieved, it is necessary to measure the product performance in effectiveness, efficiency and user satisfaction.

ISO 9241-11 (1998) defined the effectiveness, efficiency, and satisfaction respectively as '*effectiveness: accuracy and completeness with which users achieve specified goals*', '*efficiency: resources expended in relation to the accuracy and completeness with which users achieve goals*' and '*satisfaction: freedom from discomfort, and positive*

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[10] ISO 9241 deals with several aspects of the use of visual display terminals (VDTs), takes considerations into the ergonomic design of direct manipulation dialogues where users perform operations by acting on displayed objects in ways analogous to manipulating physical entitles, and provides a number of recommendations.

[11] ISO 9241-11: Ergonomic requirements for office work with visual display terminals (VDTs)- Part 11: Guidance on usability

attitudes towards the use of the product' (ISO9241-11 1998). Many studies have approached the usability concepts in experimental assessments of alternative input devices, for instance, Kroemer (1992) demonstrated the usability of a ternary chorded keyboard by the experimental results of 97% accuracy and 70 characters/min in input speed on average and ability to memorize 59 chords, performed by the ten subjects who were trained in using the device for over three hours on average and requiring an additional 10-hour practice; Karl et al. (1993) assumed the results of accuracy, task performing time, and user positive attitude of the experiment which provided evidence for the utility of speech-activated commands. In this experiment, both keyboard and mouse were also used respectively for text entry and direct manipulation. The results showed an average 18.7% reduction of task time and 6.3 % error rate when completing tasks by using the speech-activated commands, and it also indicated that the performance of using speech to activate commands was faster as compared with mouse activation, and the error occurred on both keyboard and mouse text input resulted similar to speech-activated commands. The positive feedback and further suggestions were obtained from the sixteen participants; Coll et al. (1994) conducted four experiments associated with drawing tasks in assessing accuracy, speed and user preference on three cursor control devices, an electronic pen, keyboard and mouse. The accuracy results showed that the keyboard was the most error-free compared with the mouse and electronic pen; in contrast, the mouse operation was the fastest, followed by the electronic pen, and then the keyboard, in speed performance. In terms of user preference, subjects preferred the mouse usage in general work, but the keyboard was selected for tasks which required high accuracy; Mackenzie et al. (1994) implemented two empirical experiments of numeric and text entry with varied conditions on pen-based computers. The hand printing, soft keypad, pie pad, and moving pie menu were provided in performing numeric-entry tasks; in text-entry experiment, the hand printing and QWERTY layout soft keyboard, and ABC layout soft keyboard were adopted. The usability of soft keyboard operation was proved by accuracy and speed results. Accordingly, the soft keypad was displayed as the fastest and most accurate device (30 wpm, 1.2% errors) and the moving pie menu was the slowest and the least accurate in numeric-entry method; In text-entry method, similarly, the quickest performance was tapping on the QWERTY layout soft keyboard (23 wpm), and the ABC layout soft keyboard was the least prone to errors, but with slowest operation (0.6 % errors, 13 wpm); McMulkin and Kroemer (1994) addressed the utility of the one-hand ternary chord keyboard based on its short learning time (an average of 30 minutes learning time), high performance (an average peak keying speed of 170 characters/minute after an additional 60 hour practice), and low space requirement; The text-input speed and accuracy attained by a group of school pupils with reading ages from 8.3 to 12.9 years were highlighted to prove the usability of IBM VoiceType dictation package in O'Hare and McTear (1999); Young et al. (2001) investigated the use of a pen-based input device compared to a keyboard-based input device. Differences in scores of user preference, accuracy and speed during three simulated nursing-data-entry tasks were provided for determining whether nurses preferred pen-based or keyboard-based interfaces for nursing-data-entry tasks; in addition, Healy et al. (2004) employed the usability results (accuracy and speed rates) gathered from data-entry tasks to identify the interrelationship between the prolonged work and the component cognitive and motoric data-entry process.

Furthermore, habitual practice, such as keyboard and/or mouse operation, has been customarily applied to be a basis of comparison when assessing and evaluating an alternative input. For instance, Sears (1991) conducted the tasks in three phases. The development of the touchscreen was based on the findings of Phase One and Two. Phase Three focused on the use of the developed touchscreeen keyboard compared to the mouse and the standard QWERTY keyboard; a comparison study of input tasks of the developed touchscreen keyboard, a mouse-activation and the standard QWERTY keyboard in the Phase Three experiment; Coll et al. (1994) measured speed, accuracy and user preference for the pen tablet with the other two computer cursor control devices (mouse and keyboard); Wei et al. (1999) evaluated user performance, satisfaction and mental workload when operating the voice enhanced interfaces (VEI) and also compared the traditional keyboard and mouse interface (TI); Tyfa and Howes (2000) investigated the cognitive efficiency when using speech recognition for commands, in conjunction with the mouse and keyboard; moreover, Akamatsu and MacKenzie (2002) conducted measurements of applied force on the touchpad and mouse pointing devices. The mouse in this study was used as a baseline condition.

Moreover, training effects of alternative input devices were mentioned in some studies. Researchers such as a Lau and O'Leary (1993) conducted a descriptive case study designed to compare subjects' performance related to the use of three computer input devices, i.e. Tongue Touch Keypad, the HeadMaster, and the mouthstick. Four subjects (two with a C5 lesion spinal cord injury; two with muscular dystrophy), aged between 17 and 21 years, participated in and completed a twelve-week training course (three weeks spent on the mouthstick training; four weeks on the HeadMaster training; and five weeks on the Tongue Touch Keypad). Subjects' performance, such as input speed, accuracy, and level of perceived exertion were gathered from experiments following the training period. Results showed that the quickest in input speed was the mouthstick, followed by the HeadMaster and then the Tongue Touch Keypad. In contrast, the input accuracy showed no significant difference. Subjects' perceived exertion when using each interface device showed that the mouthstick gained the highest rate of perceived exertion, followed by the HeadMaster and then the Tongue Touch Keypad (the lowest perceived exertion). The study also suggested the considerations of selection of alternative inputs should not only focus on performing effectiveness, but also on users' acceptance; and, the latest study, by Fagarasanu et al. (2005), have demonstrated an advantage of short-period training on both ergonomic alternative keyboards, Maltron and Goldtouch. The participants were divided into two groups, one group which attended a related training session and the other remained untrained. Both typing accuracy and speed of both ergonomic keyboards were significantly improved by those trained subjects following the training period. The relationship between the training session, high muscle activity, and computer work-related injuries was also discussed.

The contrastive experiment design was usually adopted by many studies, such as, Jacobs et al. (1997) who evaluated an application of a chin-operated trackball on those people who cannot speak because of severe motor impairments. The experiments were implemented by eighteen students who had no physical dysfunction and who were required to simulate the chin-operated mode as used by the severely physically disabled with speaking difficulties. The contrastive experiment design was planned as one group completed typing tasks by using the chin with a fixed head, and the other contrast group were asked to perform chin-operations with free-head movement. Similarly, the typing performances of accuracy and speed were presented in comparison with usability of chin-controlled trackball operation with different head movement conditions.

2.6 Summary

Assistive technology presents a relatively new strategy and has the potential to break the cycle of functional limitation, poor fit of person and environment, and their psychological consequences; it offers appropriate support to the efforts of people and family carers. In this study, assistive technology even plays a significant role in assisting individuals who have sustained higher lesions of spinal cord injury and who suffer restricted computer access because of the physical impairments. It helps them regain their use of information and communication technologies and return to employment post-injury. In addition, the provision of an appropriate assistive technology device, such as an alternative input, not only enhances users' capabilities in computer skills, but also prevents work-related musculoskeletal injuries as secondary injuries post-SCI.

However, the field of assistive technology comprises a myriad categories and each has its specific characteristics. Most assistive technology devices, unlike other available conventional products, cannot be immediately used and may require induction and training for novices. Lenker and Paquet (2003) and Fuhrer (2001) have indicated that studies related to AT fields are inhibited by their numerous variables. The importance of measurements of ATD use has been identified as requiring a high level of attention. Similarly, Cook and Hussey (1995) have indicated that the effectiveness of assistive technology is determined by measuring performance linked to the person, the activity being performed, the environment in which it is performed, and the assistive technology being used; Scherer (1996; 2002) have stated that the fundamental focus of assessing and evaluating AT utilisation is to ensure that assistive devices/ prototypes meet user needs and become more widely acceptable and affordable in the marketplace; in addition, Lenker et al. (2005) have noted that typical ATD measures lack adequate information reducing their reliability and validity and suggested that the domain of usability should be included in the assistive technology assessment and measurements. Accordingly, both user-centred and scientific-data issues have been pointed out and require to be involved in AT assessment and evaluation.

- Three conceptual models

Three conceptual models, Human-Activity-Assistive Technology (HAAT) model, Matching Person and Technology (MPT) model and Assistive Technology Device-Specific Framework, have assisted in building rationales for the AT assessment and measurement in this study. Both HAAT and MPT models, describe the correlation between the environment/milieu, human operator/person, assistive technology and the given tasks/goals which must be accomplished. The Assistive Technology Device-Specific Framework's focus is on specific device-types and critical factors in the framework, such as the functional problems and particular features of device-type, user characteristics, elements and contingencies in the causal chain, and expected changes of users' status and environment. The human/person factor, certainly, is the core of the assistive technology system, and this has been highlighted by the three models. Besides, the importances of assistive technology itself and environment in which the device is to be used have to be taken into consideration.

Moreover, the device-specific framework has illustrated the correlation between procurement of a device and its subsequent events (i.e. from introductory use, shorter-term outcomes, followed by longer-term use and outcomes, and then continued/ discontinued use). The framework has noted that thee domains of shorter-term outcomes, effectiveness, efficiency, and device satisfaction (as the key components of 'usability')(ISO9241-11 1998), result in subsequent longer-term use. Similarly, the usability outcomes in the longer-term use could influence users' continued or discontinued use. It stands to reason that the usability results/outcomes play a decisive role in the field of AT assessment and measurement.

- Previous work focused on psychosocial aspects of ATD use

The PIADS and QUEST methods have been categorized as psychosocial-based measures. Both methods, firstly, were psychometrically similar in testing and evaluating principles, level of measures, referencing or comparison methods, reliability and validity; secondly, they had similar purposes in the domains of subject screening criteria, assessment progress, and data provision; thirdly, both employed ordinal measurement level for data collection and scoring criteria; then, their measures were based on a specified standard and focused on an individual performance; and finally, both had user-friendly administration procedures based on self-rating questionnaires and/or interviews.

However, user participation does not guarantee that the outcome of the work will be appropriate. A simple psychosocial-concerned assessment might be restricted by subjective outcomes and recommendations and give poor reliability and validity. These studies, which focus just on psychosocial aspects of ATD use, might provide user perceptions when measuring assistive technology use including user satisfaction and comfort, motivation, acceptability, functional performance, etc. However, the methods of self-rating and self-administered questionnaires and semi-structured interviews which are usually employed in this type of studies would result in overly-subjective or biased data, especially on the effectiveness and efficiency of ATD use. Humans, unlike objects, are able to sense, interact and be affected by any single changes happening in the surroundings and might cause unreliable outcomes. In other words, a user-issue only study would be insufficiently valid and reliable for the AT assessments and measurements.

- Research studies related with ATD functional performance and usability assessments

The usability assessments first addressed the definition of usability, based on ISO9241-11 (1998); second, it brought up many studies relevant to the usability concepts in experimental assessments of alternative input devices. Some studies have paid more attention to the usability results when evaluating devices' functional performance; some have focused on the comparison between the given alternative input and subjects' habitual practice (i.e. keyboard and/or mouse operation); some have illustrated the training effects of alternative input devices; and some researches have demonstrated the contrastive experiment design and outcomes.

For most studies related with ATD functional performance, the scientific evidence, i.e. quantitative data, is the distinguishing feature. Most experiments are conducted in the laboratory-based environments which attempt to eliminate all the variables during the procedure, together with a standard experiment procedure. In the specific fields of AT measurement and assessments, although the scientific data could provide the reliability and validation of users' performance measures, the types of experimental studies have missed a salient piece to the jig-saw - the user aspect. For instance, the interaction between a person, assistive technology use, and environmental arrangement based on personal habitual practice and preference would be scarcely perceptible in the laboratory. Accordingly, a scientific-evidence only study of AT measurement would demonstrate no significant difference as with many other assessments. Notwithstanding some experiment-based studies have involved user satisfaction in accordance with the promulgated usability concepts, the domain of user satisfaction has become an accessory and remained only nominal to the many experiments associated with AT measurements.

In summary, the performance for; and reactions to; assistive technologies are highly individual. Hence, the goal of AT assessments is to match an individual with the most appropriate assistive technology, based on his/her special needs. In terms of AT measures, the evaluations of assistive technology should shift from a more psychosocial-based measurement or a more scientific-focused assessment to focus on a user-centred usability evaluation which is closely linked to the concept of usability and people's requirements, and even to the environment in which the device is to be used.

2.7 Approaching Steps

It has been recognised that an appropriate alterative input device is able to provide useful support for individuals with SCI that limits their ability to operate conventional keyboards and mice. It can be said that the appropriateness of an input device is defined by the success of assistive technology utilisation by the users, and this is related to evaluation of levels of effectively using. Simply, more attention is now being paid to the usability of device when assessing the appropriateness for users. Measuring usability of an assistive technology device is particularly necessary in view of the complexity of the interaction between the users, device/prototype, the task, and relevant contextual elements of use.

To overcome the shortcomings described in the previous sections, a specific assistive technology measurement system focused on both user- and scientific-issues is proposed.

Firstly, the level of functional ability of SCI subjects when operating a keyboard and/or a mouse will be categorised. Secondly, a hierarchy of needs of SCI computer users will be formulated. Thirdly, the provision of an alternative input as the possible solution for those SCI users. Finally, the evaluation of the developed prototype among SCI users via usability assessments associated with their habitual practice and preference accustomed working environments, and training effects.

To achieve the aims and objectives of this research work, which have been set out in Section 1.3, several major steps are proposed as follows:

- generating the level of functional limitation and performance of SCI computer users related with level of lesion, part of body to operate a computer and present operating mode to explore the relationship between an ATD and disabled users when operating a computer, and to identify influential factors of adoption of an alternative input device;
- establishing a usability hierarchy of AT selection and utilisation for SCI computer users associated with the motivational needs when accessing an alternative device;
- suggesting a suitable alternative input device for SCI subjects as the possible solution in accordance with the functional classification of computer operation and the usability hierarchy;
- overcoming the shortcomings of insufficient AT measurements and assessments and providing a assistive technology assessment system which integrates both user-centred and scientific-based factors into the usability assessments;
- validating and evaluating suitability and usability of the developed prototype on both people-issue consideration and scientific-data demonstration through single-subject case studies;
- identifying further research.

CHAPTER 3 METHODOLOGY

3.1 Introduction

The purpose of the research work aims to investigate the special needs for computer utilisation in real-life situations among persons with spinal cord injuries; in addition, it provides useful support, such as an alternative input device, to facilitate their computer access and increase productivity and satisfaction. To achieve the aims of the objectives of this research, which have been set out in Section 1.3, the research consists of a series of five integrated experimental, correlational and qualitative studies. In this methodology chapter, an overview of the following for each of the studies is provided: purposes and research plan, overall research framework, research method used, participants, environments, instruments, procedure, ethical concerns, and research limitations. Subsequent studies in this thesis will elaborate further on each chapter.

The chapter begins with a general overview of research framework as shown in Section 3.2. The choice of the research approaches, including documentary research, single-case study design, laboratory and field experiments, observation and interview methods is detailed in Section 3.3. In Section 3.4, the research components such as the subject and screening criteria, choice of instruments, environmental issues, and standard operating procedure are described, followed by the ethical concerns associated with this study shown in Section 3.5. Finally, in the Sections 3.6 and 3.7, the rationales of reliability and validity, and the methodological limitations are outlined.

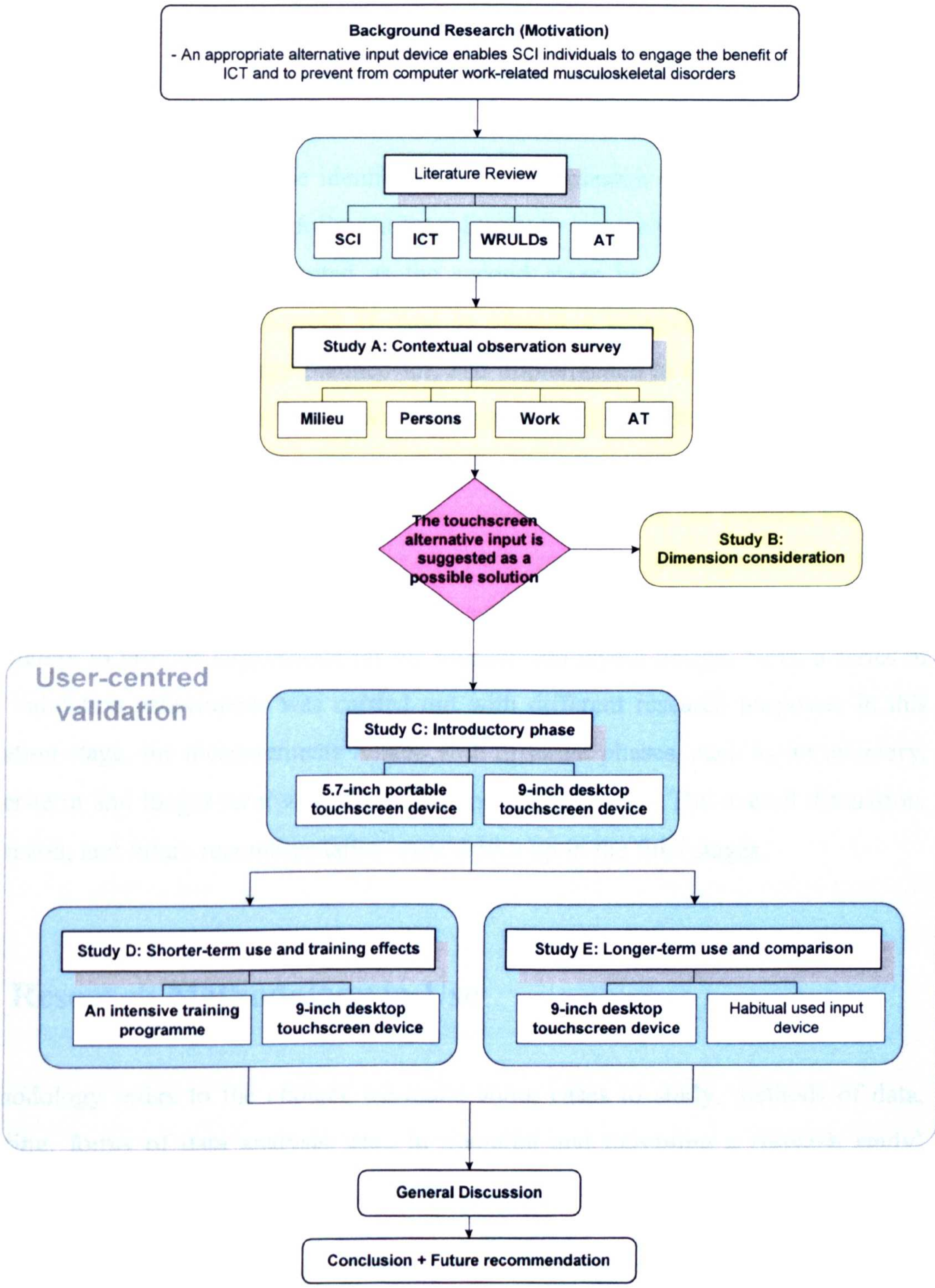


Figure 3-1 Framework overview.

3.2 Overall Research Framework

The research framework in this study is provided as the general plan of how the researcher goes about answering the set research questions as illustrated in Figure 3-1. The first stage started with the identification of the research problem and setting out research objectives. This was followed by a literature survey which is associated with the research factors and presented as the second stage in the research framework. Briefly, the developed framework is used to present a schematic illustration of the details of the research strategy planned for, and implemented in the study. At the third stage, an in-depth contextual survey was conducted for obtain a better understanding of special needs of SCI computer users. Following the observational survey, the touchscreen input device was suggested as a possible solution for persons who have hand movement impairments, such as SCI, when accessing a computer. The further stage was to investigate the size issue of the newly developed alternative input device and attempt to provide suggestions for the touchscreen layout design. Next, a series of three validation assessments was carried out with different research purposes. In this validation stage, the measurements related with different phases, such as introductory, shorter-term and longer-term were identified and implemented. The overall discussion, conclusion, and future recommendation were drawn up in the final stages.

3.3 Research Methodology in Use

'Methodology refers to the choices we make about cases to study, methods of data, gathering, forms of data analysis, etc., in planning and executing a research study' (Silverman 2005). Accordingly, the choice of approach is decisive for a research project and necessitates being affected by the problem found. As presented earlier, the studies conducted in this research project are multidisciplinary. The field of AT assessments and measurements is evidently a part of engineering science, but what is crucial to the point at issue is that this particular research deals not only with the technology itself but also with the human operator concerned with psychosocial aspects. In terms of technology, it deals with the functional status, performance and utility; in terms of persons with disability, such as spinal cord injury, both physical limitations and psychological issues need to be considered in depth; in addition, when dealing with the collaboration between technology and its users, the milieu issue arises. To summarise, research methods in the field of AT outcome measures are not simply neutral tools: they are closely tied to user issues, technology status and the nature of social reality. The methodological foundation of this research is therefore multi-faceted and concerned with the integration of quantitative and qualitative strategy research and bringing research designs and methods together.

The issues of quantitative and qualitative approaches are very much consistent with 'one of scientific objectivity versus phenomenological subjectivity'(Clarke and Dawson 1999b). The quantitative and qualitative paradigms involved different ontological positions when approaching the question of the nature of reality which is objective and exists independently of human perception. The terms of quantitative research, as well known as the conventional paradigm, assume the researcher adopts a stance of scientific detachment. Simply, it limits the interaction that take place between the researcher and the researched from the phenomenon under the study. Conversely, the qualitative research is used to elicit the point of view of research participants without burdening it with pre-existing expectation, hence, to obtain an insight into the search of truth (Clarke and Dawson 1999b). Combining quantitative and qualitative approaches in a research practice can accomplish that: the merits of one method can be featured and expected to redeem the demerits of the other; the measurement errors and the problems of bias can be reduced and controlled, and enhancing the overall research quality further (Clarke and Dawson 1999a). In addition, this mixed research strategy entails making choices between research designs and research methods. Bryman (2004) indicated that research methods are tied up with different types of research design. The former gives a framework for guiding the implementation of research methods and the analysis of the subsequent data; and, the latter represents simply a technique for data collection. According to the view, the mixed-strategy research, i.e. the combination of quantitative research and qualitative research, the research designs employed, i.e. experimental design and case study design, and the research methods used, i.e. documentary analysis, observation and interviews, has been presented in this study and elaborated in the following sessions.

Study A (Section 4.2), the single-case study design incorporated with the systematic contextual observation was presented as a direct method of collecting qualitative data. In Study B (Section 4.3), a laboratory-based experiment was conducted. The mixed-method research strategy, as combining the single-case study design, experiment, observation, and interview, was applied in Study C, D and E. (Sections 5.2, 5.3 and 5.4). The overview of research methods adopted is listed in Table 3-1 and Table 3-2. The following sessions elaborate on the research methods selected in this study.

Table 3-1 Outline of sequence of studies.

Study	Title	Aim of study	Research methods
Study A	Contextual observation survey: How assistive technology impacts the computer use among individuals with spinal cord injury	- To observe the present selection and utilisation of input devices among SCI operators and identify their special needs when activating an alternative input.	- Documentary research - Single-case study design - Observation
Study B	Dimension consideration of a portable touchscreen device for SCI individuals	- To assess the effectiveness of the newly developed 5.7-inch touchscreen prototype and suggest the dimensional design improvement for SCI users who have upper-limb impairments.	- Documentary research - Laboratory experiments
Study C	User-centred validation: usability assessments at introductory phase	- To measure the appropriateness of the newly developed touchscreen alternative inputs among persons who suffer high lesion of spinal cord injury via usability evaluations	- Documentary research - Single-case study design - Field experiments - Observation - Unstructured interviews
Study D	User-centred validation: shorter-term use and training effects	- To investigate the improvements in usability when involving CSI individuals with the touchscreen alternative input prototype during a short-term training programme.	- Documentary research - Single-case study design - Field experiments - Observation - Unstructured interviews
Study E	User-centred validation: longer-term use outcome and comparison with habitual practice	- To investigate the longer-term use of the touchscreen alternative input prototype, in addition, to compare usability outcomes between the provided touchscreen and the currently adopted input device of CSI subject.	- Documentary research - Single-case study design - Field experiments - Observation - Unstructured interviews

Table 3-2 Outline of sequence of studies (Continued).

Study	Subject distribution	Instruments	Environment	Location
Study A	- 20 CSI subjects - 12 TSI subjects - 2 LSI subjects	N/A	- Home - Workplace	Chapter 4-2
Study B	- 20 non-disabled subjects	- The 5.7-inch touchscreen alternative input prototype	- Laboratory	Chapter 4-3
Study C	- 14 CSI subjects	- The 5.7-inch touchscreen alternative input prototype - The 9-inch touchscreen alternative input prototype	- Home - Workplace	Chapter 5-2
Study D	- 2 CSI subjects	- The 9-inch touchscreen alternative input prototype	- Workplace	Chapter 5-3
Study E	- 1 CSI subjects	- The 9-inch touchscreen alternative input prototype - Subject's accustomed input device	- Home	Chapter 5-4

3.3.1 Documentary Research

The literature review is to issue command of the subject area, to understand the problems, and to rationalise the research topic, design and methodology via the selection and evaluation of available documents in relation to the proposed research (Hart 1998). That is to say, the activity of reviewing previous research work helps the researcher broaden and modify the structure of the knowledge domain, explore assumptions underlying the problem of the study, and investigate theories and findings relevant to the phenomena of the study (see Chapter 2).

Moreover, the researcher's experiential knowledge guided her to locate and review the appropriate documentation in the major areas related to this research. The key limitations of the previous work were established in Section 2.6; the rationale and scope of this research work were addressed in Section 1.3.

3.3.2 Single-Case Study Design

Every spinal cord injury is unique. Even if the patients suffer the same level of lesion, they often experience dissimilar losses of physical function and sensation. In addition, various ways have been selected and different lengths of time have being taken in the issue of SCI sufferers adapting to their injuries (Krause and Crewe 1987; Trieschmann 1988). For this reason, the single-case study design, which has the potential for gathering data with more apparent applicability in situations in which it might be difficult and focuses on the impact on individuals, is employed in this research (Barlow and Hersen 1984; Yin 2003a).

'*A single-case study can be the basis for significant explanations and generalisation*' (Yin 2003d), and, '*the single-case study is analogous to a single experiment*' (Yin 2003c). A single-case study can be used to test a well-formulated theory, to represent an extreme or unique case, a typical or representative case, a longitudinal case, and a pilot case. Also, the single-case study is likely for the revelatory case into the situation in which a researcher may observe and analyse a phenomenon that was previously inaccessible. For the design of a single-case study, it can be the holistic or embedded design. The holistic design occurs in a single-unit of analysis, and the embedded design involves more than one unit (multiple) of analysis in a case study (Yin 2003c).

Overall, single-case study designs demonstrate one of several strategies applying in practice-based research. The method intends to provide empirical data directly related to the research practice, designs for a single subject at a time, and can be adaptable to the needs of the individual subject and the clinical approach of the researcher. In addition, the single-case design is ideal for the development and validation of research hypotheses in single subjects.

3.3.3 Laboratory Experiments and Field Experiments

The experiment '*as the only available route to cumulative progress*' (Campbell and Stanley 1963) has become a classic text for experimental research designs. The principle purpose of the experimental design is to establish causality (Clarke and Dawson 1999b). An experiment, in accord with the scientific method, can manipulate a set of actions and observations directly, precisely and systematically for a specific research purpose. In addition, the design of experiments is concerned with balancing the requirements and limitation of the scientific works for furnishing the advisable conclusion concerning the hypothesis being tested. In other words, the experiments play a role of either supporting or opposing a hypothesis/hypotheses or reason concerning phenomena.

Laboratory experiments

Laboratory experiments allow the researcher to precisely control a small number of variables that are studied intensively in a designed laboratory situation. In addition, they use quantitative analytical techniques with a view to making generalisable statements applicable to real-life situations. However, the key weakness of laboratory experiments is the '*limited extent to which identified relationships exist in the real world due to oversimplification of the experimental situation and the isolation of such situations from most of the variables that are found in the real world*' (Galliers 1992). In other words, laboratory experiments may not be typical of real-life situations, and the laboratory may narrow the ranges of behaviour because of its precise control of the situation. In addition, most laboratories are set up in the contrived environments in which participants perform required tasks. The artificial laboratory environment, together with unfamiliar tasks, might result in the distortion of behaviour from participants. It is therefore difficult to infer a conclusion from the experimental findings.

Field experiments

Although laboratory experiments allow the control of variants in a sterile environment (i.e. laboratories), such controls might be viewed as artificialities affecting both the subjects or contexts of the task (Harrison and List 2004). Because of this, Harrison and List (2004) indicated that field experiments which are designed in order to draw a contrast with laboratory experiments could bridge the gap between a laboratory experiment and naturally-occurring data. The field experiments apply the scientific methods to investigate the intervention in real-life situations, rather than in contrived laboratories, thereby achieving greater realism and lessening the gauge to which situations can be criticised in laboratory experiments. Six criteria which are proposed by Harrison and List (2004) are used to define a field experiment. That is, the field context of an experiment should meet the natural of *subject pool*, *information that the subjects bring to the task*, *commodity*, *task or trading rules applied*, *stakes*, and *environment that the subject operates in.* The significant strength of field experiments, strictly speaking, is to conduct experiments in the natural settings and obtain data as true as possible to real-life situations. In the field experiment, the independent variables can be deliberately controlled; however, it has to be noted that it is difficult to have as much control over variables as that in the laboratory experiment.

Concerning the motor limitation of SCI subjects and the expectancy of gathering data associated with subjects' behaviour in actual situations, a field experiment is selected in this research as the scientific method to measure the use of assistive technology (i.e. the novel touchscreen input devices)

3.3.4 Observation

Observation is a direct method of collecting primary qualitative data (Clarke and Dawson 1999a). In addition, the distinct value of the observation evidence is to provide information about the topic being studied (Yin 2003b). Direct observation, that is, a mode of observation in which the observer only watches and records events on the spot but does not predicate in the activity being observed, was employed in this research project.

The one-by-one direct observation was performed as either the main strategy of the study (e.g. Study A) or a complementary method as part of the study (e.g. Study C, D, and E) as seen in Table 3-1 and Table 3-2. In Section 4.2, the in-depth survey study, the observational technique is the principal research method and provides a means of accessing determined behaviour and situations in the 34 subjects' real-life practices from an insider's perspective and the gathering of the desired information and factual data. In contrast, the observation method transforms into the random assignment of participants in the experimental conditions in the serial studies of Chapter 5. This technique not only offers assistance in reducing problems of data analysis caused by individual differences between subjects, but also elicits additional or unanticipated findings from the research process. Note that, in order to avoid the potential biases produced by the observer, the researcher is merely an 'observer' and not allowed to interact with the selected subjects or the environment in this study. Moreover, all observations were recorded with note-taking and visual data (photographs) and then transcribed into a computer.

3.3.5 Unstructured Interviews

'Interviews are an essential source of case study evidence because most case studies are about human affairs' (Yin 2003b). Interview provides a means of acquiring empirical data in respect of social world and real lives from people via special kinds of conversation (Holstein and Gubrium 1997). Similarly, Lofland and Lofland (1995) refer to 'interview' as '*a guided conversation*'. The natural course of interview is to allow the interviewer to ask specific questions to the interviewee through the form of

interviews, such as structured interview questions, semi-structured interviews, and unstructured interviews (Clarke and Dawson 1999a).

The unstructured or unstandardised interview is also known as the informal conversational interview and refers to a purely qualitative interviewing strategy (Patton 1987). The unstructured interview is open-ended in character and allows the interviewee to give the definition of a situation, and thereby obtains a better understanding of the interviewees' viewpoints (May 1997). Patton (1987) also indicated that this qualitative interviewing aims to recognize the participants' point of view, their terminology and judgements, and individual perceptions and experiences. Thus, the unstructured interview is applied in the research study to obtain information that provides valuable insights especially associated with subjective perception, e.g. satisfaction and comfort.

3.4 Research Design and Procedure

The components which are indispensable to research design and procedure, i.e. subject, environment, instrument, and standard operating procedure, are discussed in the section.

3.4.1 Subject Selection and Sample Size

The research studies were carried out in Taiwan and in the UK. The volunteer participants in all studies of this thesis were invited from Graduate centre, Art and Design, De Montfort University (DMU), and three Taiwan associations, i.e. Taiwan Assistive Technology and Vocational Rehabilitation Association (TATA), Taipei Spinal Cord Injury Association (TPESCI), and Taoyuan County Spinal Cord Injury Rehabilitation Centre (SCSRC).

Characterising the nature of the causal relationship between users' feedback and the usability of an AT device is by no means a straightforward matter. In terms of user issues, the sample size of subjects needs to be considered. In recent studies, Wu et al. (2004b) aimed to investigate the effectiveness of the alternative input devices, involving accuracy and speed, on 3 subjects with cervical spinal cord injury. In this research project, each subject was provided with a different device based on their different levels of function and sensation losses. In Gips et al. (2004), the alternative input devices, EagleEyes was evaluated by a subject who sustained cerebral palsy; the other device, Camera Mouse, was tested by a subject who had a severe, undiagnosed neurological condition that leaves her without speech and with very limited muscle control respectively. Furthermore, Oyama et al (2004) conducted a usability evaluation associated with CoBIT (Compact Battery-less Information Terminals) and involved 3 visual impaired participants. The findings of the above 3 studies related to usability evaluations of the specific AT devices demonstrated that rich information can be obtained by a small number of subjects, i.e. one or two subjects.

In this research study, a conceptual model, including the specific research methodology and a systematic user-centred measuring procedure, has been proposed and suggested for evaluating suitability of an assistive technology device. In order to validate the capability and pilot the proposed conceptual model, the 5 studies, i.e. Study A, B, C, D and E, were conducted and performed as case studies in this thesis. In terms of subject selection, the participants of each study had to meet the planned screening criteria connected to the research proposal. In terms of the sample size, 34 SCI subjects participated in Study A, 20 people took part in Study B, and in Study C that a total number of 14 CSI subjects were involved. Unlike the previous case studies, there are only 2 CSI subjects enlisted in Study D and a single CSI subject joined in Study E. From the above point of view, it is believed that the low number of subjects in Studies C and D could still provide meaningful information and reliable data, and also the findings from the two studies can be extended to the relevant research.

More importantly, for ethical reasons, consent for participation and photographs being taken was given by each participant; in addition, participants had been informed in detail of the purpose of the study, procedures and relevant consequence, and time period following participation prior to obtaining the required informed consent. In order to keep these subjects more clearly in mind as they emerge in the narrative, the author summarised their situations in Table 3-3, Table 3-4 and Table 3-5.

Table 3-3 Comparison of subject selection between studies.

Study	Screening criteria	Reference
Study A	- having a diagnosis of spinal cord injury; - with a stable medical status as indicated by the onset of SCI over a 6 month period; - without significant cognitive, visual, or hearing impairments; - having experience of computer utilisation for one year or more post-injury.	TATA TPESCI SCSRC
Study B	- without any physical, cognitive, visual, or hearing impairments; - aged between twenty and forty-five years	DMU
Study C	- having a diagnosis of cervical spinal cord injury; - with a stable medical status as indicated by the onset of SCI over a 6 month period; - without significant cognitive, visual, or hearing impairments; - having computer working experience of at least one year post-injury.	TATA TPESCI
Study D	- having a diagnosis of cervical spinal cord injury; - with a stable medical status as indicated by the onset of SCI over a 6 month period; - with sufficient physical tolerance for sitting upright in a wheelchair for more than 1 hour; - without significant cognitive, visual, or hearing impairments.	TPESCI
Study E	- having a diagnosis of cervical spinal cord injury; - with a stable medical status as indicated by the onset of SCI over a 6 month period; - without significant cognitive, visual, or hearing impairments; - having computer working experience for at least one year post-injury	TATA

Table 3-4 Brief biographical summary of the subjects in this thesis and the participation distribution.

no.	Gender	Age	Disability category	Level of lesion	Participation distribution				
					Study A (2003)	Study B (2003)	Study C (2004)	Study D (2005)	Study E (2005)
1	Female	44	SCI	C 5.6.7	◆		◆		◆
2	Male	43	SCI	C 3.4.5	◆				
3	Male	44	SCI+ CP	C 3. 4	◆		◆		
4	Male	35	SCI	C 5	◆		◆		
5	Male	42	SCI	C 3.4.5	◆		◆		
6	Male	30	SCI	C 5. 6	◆		◆		
7	Male	33	SCI	C 5. 6	◆		◆		
8	Male	48	SCI	C 3. 4	◆				
9	Male	37	SCI	C 5. 6	◆		◆		
10	Male	49	SCI	C 6.7	◆		◆		
11	Male	31	SCI	C 5. 6	◆		◆		
12	Female	39	SCI	C 3.4.5	◆		◆		
13	Male	46	SCI	C 4.5	◆		◆		
14	Male	27	SCI	C 4	◆		◆		
15	Male	23	SCI	C 4. 5	◆		◆		
16	Female	24	SCI	C 2. 3. 4	◆				
17	Male	32	SCI	C 5. 6	◆				
18	Male	19	SCI	C 6. 7	◆				
19	Male	35	SCI	C 4. 5. 6	◆				
20	Male	38	SCI	C 4. 5	◆		◆		
21	Male	30	SCI	C 4				◆	
22	Male	32	SCI	C 5.6				◆	

* Ages given are those at which the subject firstly participated.

Table 3-5 Brief biographical summary of the subjects in this thesis and the participation distribution (continued).

no.	Gender	Age	Disability category	Level of lesion	Participation distribution				
					Study A (2003)	Study B (2003)	Study C (2004)	Study D (2005)	Study E (2005)
23	Male	18	SCI	T 5	◆				
24	Male	38	SCI	T 5-7	◆				
25	Male	33	SCI	T 4	◆				
26	Male	40	SCI	T 10	◆				
27	Male	43	SCI	T 11.12	◆				
28	Male	28	SCI	T 12	◆				
29	Female	22	SCI	T 12	◆				
30	Male	35	SCI	T 12	◆				
31	Male	40	SCI	T 7-12	◆				
32	Male	32	SCI	T 12	◆				
33	Female	42	SCI+ SLE	T 4-7	◆				
34	Male	32	SCI+ Loss of left eye	T 12	◆				
35	Male	21	SCI	L 2-3	◆				
36	Male	23	SCI	L3	◆				
37	Female	24	None	None		◆			
38	Female	28	None	None		◆			
39	Male	28	None	None		◆			
40	Male	32	None	None		◆			
41	Female	33	None	None		◆			
42	Female	29	None	None		◆			
43	Female	31	None	None		◆			
44	Male	25	None	None		◆			
45	Male	37	None	None		◆			
46	Male	28	None	None		◆			
47	Female	32	None	None		◆			
48	Female	28	None	None		◆			
49	Male	24	None	None		◆			
50	Female	26	None	None		◆			
51	Female	21	None	None		◆			
52	Female	45	None	None		◆			
53	Female	38	None	None		◆			
54	Female	27	None	None		◆			
55	Male	30	None	None		◆			
56	Female	23	None	None		◆			

3.4.2 Specific Touchscreen Devices

Following a comprehensive review of this literature (in Chapter 2), there is a strong demand for an appropriately designed assistive input device from computer users with spinal cord injuries. In the search of existing alternative inputs for the disabled, the findings showed there are many varied assistive devices which aim to provide assistance for disabled computer users and which were developed highlighting specific functionalities. However, there are no proper inputs for spinal cord injuries in particular. Furthermore, it is indicated that most of the in-the-market alternate inputs target the group with mild or moderate physical disability, or the group with extremely severe physical limitations (as referred to Table 2-1, Table 2-2, and Table 2-3). As previously stated, even although each spinal cord injury is individual and performs a variety of levels of physical functions, individuals with high lesion of spinal injury, such as CSI tetraplegias, have partial or very limited upper limb movements and are confronted with the hardship of computer access without exception. For this reason, the touchscreen alternative input device is suggested to be an ideal solution for those computer users who suffer SCI tetraplegia (Chang 2004; Tseng 2003).

The two-year research project (2003-2004) was funded by the Department of Labour, Taipei City Government in collaboration with the Department of Information and Computer Education, National Taiwan Normal University, Taiwan and Design Innovation, De Montfort University, U.K., aimed to develop an integrated touchscreen alternative input device for users with severe hand movement disorders. The 5.7-inch and 9-inch touchscreen alternative devices were developed in 2003 and 2004 respectively (Chang 2004; Tseng 2003). Whereas the majority of SCI sufferers use a wheelchair (manual or powered) at some point in their lives as a mode of personal mobility, the 5.7-inch touchscreen alternative input was designed and developed for the purpose of portable use for SCI wheelchair users (Tseng 2003). In addition to the portable 5.7-inch touchscreen input device, the 9-inch touchscreen input device was designed for desktop utilisation, as seen in Figure 3-2.

The touchscreen devices propose to provide SCI computer users with a more user-friendly interface, lessen tiredness incurred by long-term and intensive operation and to prevent computer work-related upper-limb disorders. The touch panel, which is controlled by an 8051 single chip microprocessor, has receiving inputs from the user and displays information. In terms of function status and performance, firstly, the conventional keyboard and mouse functions are integrated into the touchscreen device with a view of offering users multiple functions simultaneously. Secondly, in terms of operating mode, the touchscreen devices offer users three choices of different operating modes, i.e. touch, scan and Morse code inputs. Finally, the function of a personal digital assistant (PDA), which includes diary and address book, has been attached to this system for additional practical value. Different layouts are presented on the 5.7-inch and 9-inch touchscreen devices in accordance with their different purpose (portable or desktop use). That is to say, the ABC layout is displayed on the 5.7-inch portable device consisting of most of the PDA products; on the other hand, the QWERTY standard keyboard layout was selected to be on the 9-inch desktop use device.

The validation of the newly developed touchscreen integrated devices are discussed at length in subsequent chapters. In Section 4.3 (Study B), the dimension issue, which is related to the appropriate touchscreen size, is discussed; in Sections 5.2 (Study C), 5.3 (Study D) and 5.4 (Study E), a sequence of usability assessments was carried out, including introductory use, shorter-term training and outcome, and longer-term use and observation (Table 3-1 and Table 3-2).

Figure 3-2 5.7 inch dimension (the left-hand side) and 9 inch dimension (the right-hand side) touchscreen input prototypes.

3.4.3 Environment

The choices and denotation of research methods are crucial to the attribution of the environments. Following the research framework, both laboratory and field experiments are presented in this study. In terms of laboratory experiments, a laboratory is a place where scientific research and experiments are conducted and ought to be properly designed and arranged by the researcher. In contrast, the environmental choice of field experiments is oriented towards the natural surroundings. In other words, the laboratory-based experiment (Study B) had been carried out in the specially arranged environment, located in the graduate centre, Design and Manufacture, De Montfort University in this research project; the real-life workplaces of SCI subjects, such as homes, offices, or computer labs, were selected for the field experiments (Study C, D, and E). The experiment categorisation is shown in Table 3-1 and Table 3-2.

3.4.4 Standard Operating Procedure

A Standard Operating Procedure (SOP) is a set of written instructions presenting documents in sufficient detail, the routine procedure or repetitive activity followed by a specific operation, analysis, or action. An SOP plays an integral part in successful quality assurance and management system; it details the work process to individuals for performing a job properly, therefore, consistent use of an SOP facilitates consistency of organizational practices, reduces work effort and error occurrences, and, ensures data quality (EPA 2001). Moreover, a standard operating procedure with accurate process documentation and proper construction is generally agreed to assist individuals to perform their tasks with higher productivity (De Treville et al. 2005). On the contrary, Yu et al. (1999) addressed that the inappropriate design of standard operating procedure would be an essential and latent reason incurring unexpected results or limited value during human operation.

In terms of SOP application, Stauffer (1999) indicated that SOPs can ensure that laboratory experiments are more accurate and effective. Isaman and Thelin (1995) also suggested that a written standard operating procedure should be set forth in a testing facility. Hence, the standard operating procedures were implemented in each experiment with a view to minimising the errors and bias during the research procedure, as well as assuring reliability and validity.

The standard operating procedures were attached to each experiment in the research study. This is discussed at length in subsequent chapters. The SOPs focus on processes to accomplish a task and provide step-by-step procedures to follow, including the roles of the participant and researcher.

3.4.5 Data Analysis

It is critical to identify the evidence to support the research assertions; therefore, the data analysis provides a means to identity the evidence via dissecting varied sources of data collection. In terms of the process of data analysis, three activities are outlined: data reduction, data display, and conclusion drawing and verification (Miles and Huberman 1994b). In this research, there were different methods used for collecting research data and different ways of analysing data then. The varied patterns and themes of data and analytical methods are detailed in the following.

Observation and Interview data analysis

Note-taking is efficient in eliciting sufficient data for the observations and interviews (Cheetham et al. 1992a) and photographs taken can be most valuable for helping to transfer important characteristics to outside observers (Dabbs 1982). The evidence gathered from observations and interview led to qualitative information in this research project.

In the observations, copious filed notes and visual data (i.e. photographs) taken by the researcher were used to describe the focused domain, such as workplace space, workplace set-up and arrangement, devices used in the workplace, devices adjusted, actions and interactions between subjects, input devices, activities, and environment. Data analysis of observation consisted of entering field notes into Microsoft Word software, transferring images from the digital camera to the computer, reading and re-reading observational notes, and completing domain analysis and comparison. The unstructured interviews were conducted at the end of observation. The notes were taken during interviewing to assist the interviewer to keep track of the interview contents and facilitate analysis.

Upon completing observation and interview data collection and data reduction, the analysis of many data into categories for labelling was begun. All data collected from individual subjects were analysed into categories of contextual factors and practices specified in the primary research question. The contextual factors were intrinsic and extrinsic. Practices were labelled from the observation tool: subjects' use of technology, subjects' level of technical skills, and the researcher role.

Experimental data analysis

The experimental technique was adopted for providing the best way of testing hypotheses and arriving at the scientific explanations. The experiments involve measuring or characterising some variables whose values can be used to measure effects of research treatments or inherent attributes of research materials. Data obtained from the designed experiments are expressed in a numerically ordered fashion, and first scrutinised to ensure their accuracy and appropriateness prior to the analysis. Data analysis is subsequently carried out, involving displaying, breaking down, inspecting, re-arranging, and statistical analysis. Furthermore, Microsoft Excel was employed as the most relevant tool to analyse the experimental data in detail.

3.5 Ethical Considerations

Ethics are a major issue in a research project, especially one concerned with participants with disability. In this study these were based on the revised ethical principles of the British Psychological Society (BPS 2005). The ethical considerations involved in the conduct of the research are listed as the following;

- A research proposal was submitted to the Human Research Ethics Committee (HREC), De Montfort University. Approval was granted.

- Consent was required from each participant, prior to any involvement in the research studies. In addition, the objectives of the research necessitated informing and explaining to all participants before obtaining the required consent.
- The participants should be protected from both physical and mental harm during the research.
- Individual participants were not named or identified in any recognisable way in order to guarantee the anonymity and confidentiality of the data and protection of the participants' right to privacy.

3.6 Reliability and Validity

Yin (2003c) stated that a research design should be presented as a logical set of statements, and the quality of any given design could be judged to hinge on certain logical tests. As Bryman (2004) observed, the quality of research design is determined by two criteria, reliability and validity. The reliability and validity of this research work are constructed by adopting the logic and rules of scientific methods elicited from the research process. The following characterise the tactics for establishing the trustworthiness of the research.

3.6.1 Reliability

Reliability is '*the degree to which the finding is independent of accidental circumstances of the research*' (Kirk and Miller 1985). Further, the term 'reliability' is '*the degree of constancy with which instances are assigned to the same category by different observers or by the same observer on different occasions*' (Hammersley, 1992). Simply, Yin (2003c) pointed out '*the goal of reliability is to minimize the errors and biases in a study*'. Accordingly, the tactic of using the research protocol for shielding 'reliability' in a case study is advised (Yin 2003c).

In order to ensure the later research procedures are conducted in the same manner as the earlier ones, and to allow replication, the research protocol is represented as one prerequisite in each case study in the research project. Case study research procedures have remained insufficiently documented and elicited suspicions of the reliability of the study in the past (Yin 2003c). As a specific tactic to overcome the shortcomings and approaching the reliability problem, the standard operating procedures are documented and enclosed in each study protocol. The standard operating procedures have been calculated as many steps as possible in an operation and attempts made to conduct research activities just as someone were always looking over one's shoulder.

Generally, the study protocols and standard operating procedures provide a guideline in this research project and, therefore, repeat the same quality of procedures in each study and assume the quality of data collected.

3.6.2 Validity

The issue of 'validity' is 'another word for truth' (Silverman, D., 2005). Many forms of validity are mentioned in the research literature. The mixed-method research design (or Triangulation[12]) is one of common response to validity (Clarke and Dawson 1999a; Miles and Huberman 1994a). Clarke and Dawson emphasized that 'methodological triangulation is presented as a way of guarding against threats to both reliability and validity' (Clarke and Dawson 1999a). Also, Smith (1986) distinctly addressed that combining qualitative and quantitative approaches offers the possibility of enhancing validity.

Triangulation is the use of multiple sources of data, investigators, theory and methods to enhance the probability that interpretations are credible (Clarke and Dawson 1999a; Denzin 1970b; Miles and Huberman 1994a). The purpose of triangulation is to reduce the likelihood of misinterpretation by employing various procedures (Stake 2000). Even if qualitative research is not associated with the intention of generalization, Shaw (1999) highlighted that triangulation possesses stronger potential for researchers to generalize implications to their personal context for practical settings as well as future study. According to the literature survey, each research approach has its own strengths and weaknesses. Employing multiple approaches effectively (or methodological

[12] *'The term "triangulation" is borrowed from surveying or navigation, where it refers to the practice of establishing the exact position of a given object by taking readings or measurements from multiple viewpoints'* (Clarke and Dawson 1999a)(p.87).

triangulation), as mentioned in Section 3.3, enables the strengths of one method to compensate for the weaknesses of another method; the errors and bias can possibly be reduced and overcome, therefore, the quality of research data can be improved. It also stands to reason that the researcher would have greater confidence when using triangulation as part of a mixed-method design than a single method (Clarke and Dawson 1999a). With the purpose of expanding the research content and depth, and establishing validity, different types of evidence need to be gathered by using multiple sources of data and multiple methods, which combine both quantitative and qualitative approaches. Either quantitative or qualitative approaches are associated with different research methods and have relative merits and demerits. Thus, care needs to be taken to choose between the research methods when conducting a research. Based on the research purpose which is stated as a focus of both scientific and people issues, the work essentially involves mixed research methods, integrating objective qualitative and subjective qualitative approaches and emphasising the relative advantages of two types of research method. Triangulation methods of documentary review, case study design, experiments, observations, and interviews were applied in this study (as discussed in Section 3.3) with a view to controlling research bias and maintaining an objective stance, and obtaining a complete understanding of the beliefs, context factors, and real-life practices. In terms of research evidence, both quantitative and qualitative data were examined and analysed. Integrating data supports the view that not only can qualitative findings enrich the conclusions drawn from the statistical analysis of quantitative data, but also quantitative results provide depth to the understanding of qualitative results.

To summarise, triangulation, including multiple methods applied and multiple sources of data collected, ensures validity of the study. In other words, the researcher adopted several techniques to ensure reliable results.

3.7 Methodological Considerations

This research has its limitations. Firstly, as stated in Section 1.2, this research study, associated with disability and human ethics, encountered great difficulties in participant recruitment in the UK. The disability community has been well-protected under the umbrella of the UK's social welfare and services, and consequently research related to human resource ethics faces a certain level of limitation; to reiterate persons with spinal cord injury are the core of this research. However, the research would descend into meaninglessness or remain on the surface of research problems if the part of users' perceptions is sacrificed. Because of the subject issue, the author had been attempting to overcome the legislation boundary and procrastinating for a favourable turn in the UK, but this resulted only in an unfortunate delay in the research work. The research finally enlisted help in subject participation from the three Taiwanese associations, and had a total of thirty-six SCI subjects who participated in the research project. As a result, the research was carried out in the UK and in Taiwan.

Secondly, the situations and settings covered by the research are also limited by the subject's age. Because of ethical and practical complexities, parents or specific protectors necessitate to involve in the research activities when the minors are selected as research participants. This might increase a number of uncontrolled variables for a study. Because of this, this research work involved only adult subjects.

A third consideration was the environment. Because of the limited motion of participants with spinal cord injuries and the need for investigation in subjects' real-life situations, the research was conducted in the subjects' actual workplaces located in homes or offices. Also, the inconvenience of travelling for the researcher made it more difficult to take all the variables into account when conducting an experiment in the place where the subject belonged and performed usual computer activities.

The final consideration was time. As described in Section 3.3, the single-case study strategy, which can be analogous to a single experiment, was employed. However, to measure, observe, and interview one subject at a time was a laborious, time-consuming and a costly undertaking. For instance, a total number of 34 SCI subjects participated in Study A related to an in-depth observational survey. It can be anticipated that considerable time and labour could be taken for accomplishing this study. In the other case study, sixty-five days (Study E, the longer-term usability assessment) were spent on assessing and observing only one participant. It stands to reason that there is only a single subject presented in that study. From this point of view, the single-case study design resulted in time-consuming activity; this brought about the methodological limitation.

3.8 Summary

The salient point of the research is presenting a series of integrated quantitative, correlational and qualitative case studies. Furthermore, this research is placed in both the positivist and the descriptive camps, utilizing a mixture of research approaches. In this chapter, the overall research design encompasses techniques employed for data collection and analysis, participants and instruments, challenges and limitation, as well as the means incorporated in a methodological foundation in order to enhance the quality of this study.

To summarise, both scientific evidence and people issues, which attempt to acquire insight into the existing real-world situation with systematical approaches, are constantly accentuated and accomplished by triangulation research strategy, and consequently illustrate the distinct nature of this research study when compared to other published work.

CHAPTER 4 CONTEXTUAL OBSERVATION SURVEY: HOW ASSISTIVE TECHNOLOGY IMPACTS COMPUTER USE AMONG INDIVIDUALS WITH SPINAL CORD INJURIES

4.1 Introduction

This chapter presents an in-depth investigation into the real-life situations among computer operators with spinal cord injuries in order to gain an insight into the special needs of these users when activating a computer. The survey involves the observation of the physical limitations of SCI users, utilisation of input devices, workplaces, and their habitual practices and activities. This is followed by the experimental assessments aimed to explore the dimension issue of a touchscreen alternative input for these disabled persons.

Based on the documentary search, the primary cause of spinal cord injuries originates from trauma (due to injury), e.g. falls, road traffic accidents, and sports injuries. Imagine that an able-bodied person is suddenly unable to perform daily activity with both lower extremities (i.e. paraplegia); or even worse, has limitations in function from the shoulder down (i.e. tetrapleta). Then imagine that an able-bodied person is unexpectedly confined to a wheelchair for life. Spinal-cord-injured patients not only encounter physiological limitations, but also confront great difficulties in psychological and social issues. For instance, the first case was, a 'despairing eight years' described by one of the participants. This participant was 28 years old when he had a sport injury (when diving) that resulted in his C4 and C5 spinal cord injuries. From moment of the accident, he was paralysed from the shoulders down and was no longer an independent person. He lay on a bed watching either the TV or the ceiling and was in a depressed state for eight years. The second example was a man and his 'grey ten years'. This subject sustained a C3-C5 spinal cord injury in a 1990 car accident, when he was 30 years old. He has no voluntary control over the movements of all his extremities and cannot live an independent life as can the former case. After four months staying in hospital, the subject was transferred to a nursing home which was particularly designed for the elderly, and stayed there for more than ten years. He was pushed outdoors by the carer in the morning, and pushed back indoors only in the evening, and this was true for every single day of his stay in the nursing home. Ten years passed by in a continuous motiveless struggle to survive. Eventually, both overcame their difficulties and attempted to regain their strength, especially psychologically. These are only two instances of the thirty four SCI participants in this study. Every SCI sufferer has his/her different story. Every different patient experiences a different level of function and sensation losses, and adapts him-/herself to the new conditions (many SCI people called it 'the second life') in a variety of ways with different lengths of time being taken. It stands to reason that each spinal-cord-injured person ought to be treated as an individual case.

In Section 2.5, the Human Activity Assistive Technology (HAAT) model (1995) and Matching Person and Technology (MPT) model (Scherer 1996; Scherer 1998) have identified that a human operator/ person is the core of the assistive technology system, and, necessitates obtaining individual needs for the utilisation of assistive technology devices. Cook's (1995) HAAP model has emphasized the importance of 'human', 'activity', 'assistive technology' and the relevant 'context'. Similarly, Scherer's (1996; 1998) MPT model has addressed three components, involving 'milieu', 'person' and 'technology', when measuring an individual's predisposition of the use of technology. On the other hand, both methods, Day and Jutai (1996)'s Psychosocial Impacts of Assistive Devices Scales (PIADS) and Demers et al (1996)'s Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST), have addressed the psychosocial aspects as being the crucial factor for assistive-technology-device measurements. Furthermore, the methods of observation and contextual analysis are used to read the experiences, characteristics and behaviours for the measurements of assistive device utilisation (Teng and Chen 2003; Yeh 2001). In Section 4.2, what should be said about an individual spinal-cord-injured subject is quite different from what should be said about all subjects. Each SCI subject has important atypical features, happenings, and situations; therefore, the generalisation should not be emphasized among those SCI individuals. For the reasons above the author intended to obtain better physical and psychological understanding of specific difficulties and requirements of each SCI computer operator in real-life situations. Every subject was regarded as an individual case during this survey. Contextual observation and an unstructured interview were selected as the leading approaches in this study.

Moreover, many researches have believed that individuals with upper-limb impairments, such as spinal cord injury, would encounter great difficulties in activating conventional input devices which are designed for the majority of two-handed computer users, but could regain benefits from an appropriate alternative input device (Hawking and ATAccess 2000b; Loy 2005). Alternative inputs are made in many designs, shapes, and sizes in order to match a variety of limitations and requirements among different users. When discussing these design issues of alternative inputs, Karlqvist et al. (1999) indicated that the size factor would affect joint positions that are strongly associated with levels of muscular load in neck/shoulder and hand/forearm muscles when operating an input device; Sears and Zha (2003) pointed out the importance of keyboard size of the mobile and handheld touch-screen devices. Further, Lin and Kreifeldt (1993) focused on the designs of the key size and key shape of the input device; Colle and Hiszem (2004) explored suitable key sizes of touch-screen input device and found that a 20 mm square key size was sufficiently large for land-on key entry. Correspondingly, in the section of the observation survey, an appropriately designed alternative input device figured as the strong demand and support of individuals with spinal cord injuries for lessening difficulties in computer operations, reducing tiredness caused by repetitive and intensive computer use, and even improving the productivity. The findings also brought up the dimensional consideration as a priority before offering an alternative input to SCI persons. From this point of view, integrated touchscreen prototypes are suggested as a possible solution for SCI individuals, and the size issue of the touchscreen input devices should be explored

As previously addressed in Chapters 2 and 3, the touchscreen prototypes are designed for two purposes: portable use (5.7-inch width) and desktop use (9-inch width). In terms of portable electronics products, Japanese industries represent high-quality, high-performance and low-price qualities, and have outsold their European and American competitors and brought success in the global market (Boulton 1995). Reflecting on the successes of the Japanese electronics business, the downsizing technologies (also called miniaturization) for portable electronics products were pointed out as the direction of electronic packaging technology roadmap of Japanese industries. That is to say, the development of portable electronic equipment requires lighter, thinner, smaller, and shorter dimensions (or called LTSS concept) (Boulton 1995). However, could the LTSS design concept apply to the electronic devices which are specially designed for the disabled? Wu (2003) provided a universal Personal Digital Assistant prototype with a 5.7-inch width, for wide range of users including patients with hand movement disorders, e.g. spinal cord injury and muscular dystrophy. Based on his findings of anthropometry and observation, a 5.7-inch width should be considered as the suitable dimension for designing portable touch-screen products for those users with hand movement disorders. Computer users with a high level of spinal lesion (e.g. cervical spinal injury) can operate an input device only by a single finger and/or another part of their body (e.g. head, mouth, forearm, and so forth). Due to the limitation of movements, it is very important to consider an appropriate dimension of input devices for these CSI persons. The question is- could the touchscreen alternative input with the 5.7-inch dimension be applicable to those CSI users? Correspondingly, the dimension issue of the touchscreen input prototype was considered, measured and discussed in Section 4.3.

An overall architecture for this proposed study begins with the contextual observation survey between SCI persons, assistive devices, workplaces, and activity/work, as presented in Section 4.2. Following the findings of the survey, the touchscreen input device has been suggested as a possible solution for persons with spinal cord injuries, also, the size factor was highlighted as it leads to differences in users' operating performance and productivity. Section 4.3 is therefore devoted to exploring the dimension issue and design improvements for the touchscreen prototype as the initial phase of user-centred assessments.

4.2 Study A: Contextual Observation Survey: How Assistive Technology Impacts Computer Use among Individuals with Spinal Cord Injuries

4.2.1 Introduction

Since computer technology has flooded into the world, its widespread use changes many aspects of everyday life and brings a certain level of benefit to people. For people with severe physical disabilities, computer technological advances fuel dreams of the possibility of freedom and of communicating outside their isolated world. However, how could those people with disability fill the gap between their function limitations and the actual computer use? The answer is an 'assistive technology'. Assistive technologies provide assistance with critical tasks (e.g. computer use) and influence the lives of individuals who use them. In actuality, the use of assistive technologies does not always provide users' wishes, especially individuals with disability. Persons with disability are too often regarded as passive and incompetent, and excluded from decisions concerning assistive technologies and other matters affecting their lives (Scherer 2000d). As assistive technologies are very intimately involved with most persons with disability, it is critical to understand people's experiences and look at the influences on the use of assistive technologies in real-life situations. In addition, there needs to be increased attention paid to people's perspectives and to ensuring that technologies match their expectations.

In this contextual survey, the ascertaining and gathering of people's perspectives and expectations of input device utilisation could encourage the identifying of a SCI user's needs hierarchy for an alternative input. The formulation of hierarchy would be expected to be a pyramid as in Maslow (1987) and Scherer (2000d), as illustrated in Figure 4-1 and Figure 4-2. Maslow (1987) theorized a hierarchy of needs, ranking these needs in the order and beginning with the most basic at the bottom of the hierarchy and working upwards. In Maslow's hierarchy of human needs as seen in Figure 4-1, he laid out five broader layers and depicted them as a pyramid with the *physiological* needs as the base of the hierarchy, then *safety and security*. The third layer is the need for *love* *and belonging*, followed by the need for *esteem*, and *self-actualization* at the top as the highest of those needs. That is, there must be a satisfaction of lower needs before being motivating to move up the pyramid. In response to Maslow's theory, persons with spinal cord injuries, particularly those with recent injuries, often meet the first criterion for rehabilitation, and then achieve smaller goals. Once the lower-level tasks are met and successfully achieved, they would expect and want more. In general, the post-injury life situation of SCI individuals is greatly altered by assistive technologies so that they are possibly capable of performing usual activities and tasks. However, as '*the desire for-and reactions to-assistive technologies are highly individual*' (Scherer 2000c), a usability hierarchy of assistive technology selection and use was diagrammed by Scherer (2000d) in Figure 4-2. In Scherer's usability hierarchy, people choose an assistive technology based, firstly, on the satisfaction of functional need for the device, then its attractive and appeal, and finally meeting people's expectations of performance and usability. It can be said that Scherer's hierarchy diagrams provide a direction of matching a person with an appropriate assistive technology. Following the findings of observational survey and Maslow's and Scherer's hierarchies, a SCI user's needs hierarchy of an alternative input would be illustrated as one of the outcomes in this study.

This study aims to observe the present selection and utilisation of input devices among SCI operators and identify their special needs when activating an alternative input. The protocol of this survey is:

- To select the appropriate subjects, contact them and arrange the date and time for observation and interviews;
- To investigate the present practice and special needs of computer use among computer users who suffer CSI;
- To analyse the observed findings and formulate a needs hierarchy;
- To recommend possible solutions.

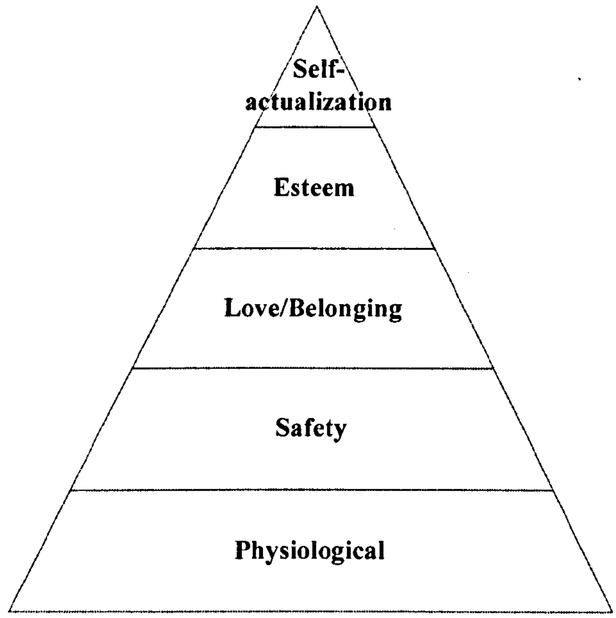


Figure 4-1 Maslow's hierarchy of needs (Maslow 1987).

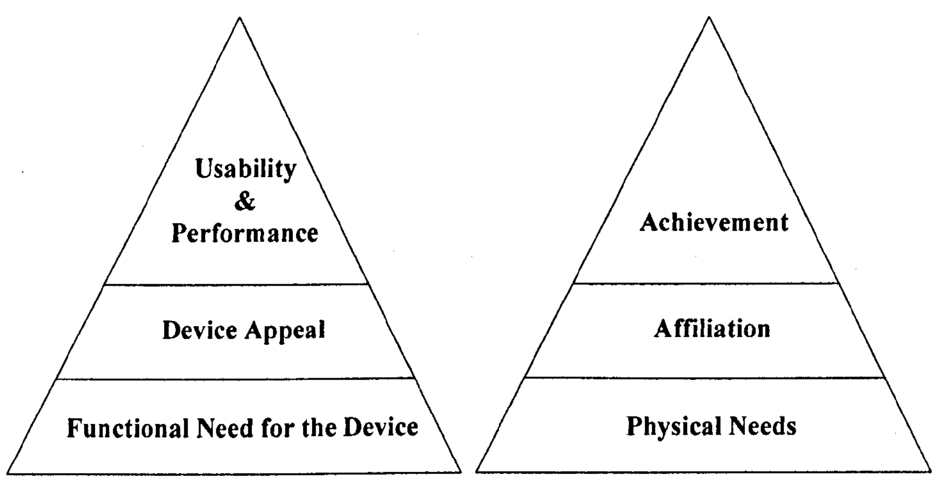


Figure 4-2 Scherer's usability hierarch of technology selection and use (Scherer 2000d)(p.181).

4.2.2 Method

The case study is used as the research strategy for contributing to the knowledge of individual, group, organisational, social, political and related phenomena in many situations, such as psychology, sociology, political science, social work, business, community planning, and economics (Yin 2003d). In brief, the case study method aims to retain the holistic and meaningful characteristics of real-life event (Yin 2003d), and could be the choice when the phenomenon under study, that may be a project or program in an evaluation study, is not readily distinguishable from its context (Yin 2003e). Firstly the case study can be established as a single-case study which focuses on a single case only, and multiple-case studies that includes two or more cases within the same study; secondly, the case study can be used for all three purposes: exploratory, descriptive or explanatory (causal), whether a single or multiple case study (Yin 2003e). Yin(2003c) has defined four types of design of case studies: single-case (holistic) designs (Type1), single-case (embedded) designs (Type 2), multi-case (holistic) designs (Type 3), and multiple-case (embedded) designs (Type 4). There are five rationales for selecting a single-case design (Type 1 and 2) rather than a multiple-case design (Type 3 and 4). Besides, the holistic and embedded case studies can be defined by the unit of analysis in the same case study. The holistic case study occurs when, within the case study, attention is given only to a subunit of analysis; in contrast, the embedded-case study design is incorporated into multiple subunits of analyses. Furthermore, there are five rationales serving as major reasons for selecting a single-case study design, that is, when the case represents (a) the critical case or the critical experiment in testing existing theory, (b) an extreme case or a unique case, (c) the representative or typical case with the objective of seizing the circumstances and conditions of an everyday or commonplace situation, (d) the revelatory case based on the situation of having an opportunity of observing and analysing a phenomenon previously inaccessible to scientific investigation, and (e) the longitudinal case which purposes to study the same single case at two or more different points in time (Yin 2003c). Within this study, each person with spinal cord injury represents a single and unique case which is worth analysing. Thus, the adoption of the single-case study design in this survey would document an SCI person's ability and disability, not only to determine the precise difficulties when accessing a computer in real-life situations, but also ascertain the specific requirements. Four embedded units of analysis are involved in this survey, i.e.

functional limitations, workplace setup and arrangement, habitual practice and preference, and the input device selection, as illustrated in Figure 4-3.

Research techniques, direct observation and the unstructured interview were used in this survey. In the practice of observation, the role in which a researcher acts in the fieldwork would affect the type of data subsequently produced. Gold (1969) identified the four roles of fieldwork researchers as follows: the *complete participants*, *participant as observer*, *observer as participant* and the *complete observer*. Depending upon the aim of this study, the research employing this role of the *complete observer* attempts to engage purely an observer (or non-participatory) in the activities under investigation. In order to avoid the potential biases generated by the observer, there is no social interaction between the researcher and the subject during the course of data collection. The unstructured (unstandardized or informal) interview was undertaken following the observation. This form of interviewing allows the participants more freedom to answer questions in terms of their own frames of reference, thereby, squarely obtaining a better understanding of the subjects' opinions. In this study, observation, field notes and visual information, together with any relevant interview data, provide a rich insight into research relations, events and processes. It was noted that the time on observation and interview that the researcher spent with a subject varied with a range of between eight and sixteen hours.

The subject is the most important component in this proposed survey study and is described in the following Section 4.2.3. Data collection and analysis are explained and detailed in Section 4.2.4.

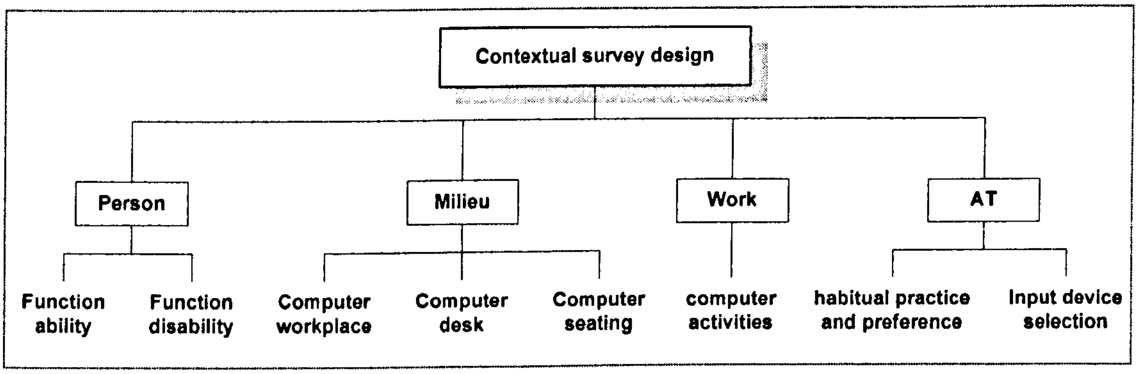


Figure 4-3 Design framework of contextual survey.

4.2.3 Subject Selection

Thirty-four subjects aged between 18 and 50 participated in this study. TATA, TPESCI and SCSRC provided thirty-four volunteer spinal-cord-injured subjects who met the screening criteria, such as (a) having a diagnosis of spinal cord injury; (b) with a stable medical status as indicated by the onset of SCI over a 6 month period; (c) without significant cognitive, visual, or hearing impairments; (d) having experience of computer utilisation for one year or more required. Consent for participation and photographs being taken was obtained from the subjects prior to this study.

The twenty subjects who sustained cervical spinal injuries can access a computer only by single input operation e.g. single hand, head, mouth, forearm, or assistive input devices. The other fourteen participants who have either thoracic or lumbar spinal injuries are capable of operating a computer with both hands. In terms of the work status of the subjects, 28 out of the total 34 participants were engaged in computer-related work, including 14 computer vocational trainees, 8 computer employees, 2 IT technicians with website design, 2 computer game professionals, 1 free-lance graphic designer, and 1 computer science student; the other 8 participants were occupied as counsellors in Taiwanese SCI associations. Furthermore, more than half of the CSI subjects (15 out of the 22 cervical-spinal-injured participants) worked with computers at least 8 hours a day, however, each CSI subject had no computer operating experience prior to their injury. It can be acknowledged that the computer revolution had improved the quality of post-injury life and expanded employment opportunities by the participants, especially those with CSI. The brief situation of the total thirty-four participants is summarised in Table 4-1, Table 4-2 and Table 4-3.

Table 4-1 The brief biographical summary of 34 subjects.

	GENDER	AGE IN 2003	TYPE OF INJURY	CAUSE OF SCI	TIME AFTER ONSET	OTHER DISABILITY
01	Female	44	C 5.6.7	Fall	8 - 9 yrs	None
02	Male	43	C 3.4.5	Car accident	12 -13 yrs	None
03	Male	44	C 3. 4	CP	19 -20 yrs	CP
04	Male	35	C 5	Fall	10 -11yrs	None
05	Male	42	C 3.4.5	Car accident	11 -12 yrs	None
06	Male	30	C 5. 6	Fall	15 -16 yrs	None
07	Male	33	C 5. 6	Car accident	9 -10 yrs	None
08	Male	48	C 3. 4	Fall	20 -21 yrs	None
09	Male	37	C 5. 6	Motorcycle accident	13 -14 yrs	None
10	Male	50	C 6.7	Fall	16 -17 yrs	None
11	Male	32	C 5. 6	Motorcycle accident	11 -12 yrs	None
12	Female	40	C 3. 4.5	Failed operations	17 ½ yrs	None
13	Male	47	C 4.5	Fall	23 -24 yrs	None
14	Male	28	C 4	Motorcycle accident	5 - 6 yrs	None
15	Male	24	C 4. 5	Car accident	7½ yrs	None
16	Female	24	C 2. 3. 4	Car accident	6 - 7 yrs	None
17	Male	32	C 5. 6	Sport injury	5 - 6 yrs	None
18	Male	19	C 6. 7	Motorcycle accident	3 - 4 yrs	None
19	Male	35	C 4. 5. 6	Sport injury	2 - 3 yrs	None
20	Male	38	C 4. 5	Sport injury	10 -12 yrs	None
23	Male	18	T 5	Fall	17 yrs	None
24	Male	38	T 5-7	Car accident	16 -17 yrs	None
25	Male	33	T 4	Car accident	12 -13 yrs	None
26	Male	40	T 10	Car accident	13 -14 yrs	None
27	Male	43	T 11.12	Car accident	14 -15 yrs	None
28	Male	28	T 12	Failed operation	9 -10 yrs	None
29	Female	22	T 12	Fall	2 - 3 yrs	None
30	Male	35	T 12	Fall	2 - 3 yrs	None
31	Male	40	T 7-12	Car accident	3 - 4 yrs	None
32	Male	32	T 12	Fall	2 - 3 yrs	None
33	Female	42	T 4-7	SLE	10 -11yrs	SLE
34	Male	32	T 12	Motorcycle accident	6 - 7 yrs	Loss of left eye
35	Male	21	L 2-3	Motorcycle accident	1½ yrs	None
36	Male	23	L 3	Car accident	2 yrs	None

C: Cervical spinal cord injury
T: Thoracic spinal cord injury
L: Lumbar spinal cord injury
CP: Cerebral palsy
SLE: Systemic lupus erythematosus

Table 4-2 The brief biographical summary of 34 SCI subjects.

	EDUCATION STATUS	DEVICE USED (INDOORS)	DEVICE USED (OUTDOORS)	DOMESTIC STATUS	WORK STATUS
01	Senior high school	Manual wheelchair	Powered wheelchair	Apartment with family	Computer employee
02	College	Powered wheelchair	Powered wheelchair	Apartment with family	Computer employee
03	University student	Walker and computer chair	Powered wheelchair	Apartment with family	Computer employee
04	University	Manual wheelchair	Powered wheelchair	Apartment with family	Computer employee
05	College	Manual wheelchair	Manual wheelchair	Apartment with carer	Computer employee
06	Senior high school	Powered wheelchair	Powered wheelchair	Apartment with family	President of TPESCI
07	College	Powered wheelchair	Powered wheelchair	Apartment with family	Counsellor for TPESCI
08	College	Manual wheelchair	Manual wheelchair	Apartment with family	Computer employee
09	College	Lying on bed	Powered wheelchair	Apartment with family	Computer Employee
10	Junior high school	Powered wheelchair	Powered wheelchair	Apartment with family	Counsellor for TPESCI
11	Senior high school	Manual wheelchair	Powered wheelchair	Apartment with family	Computer game tester
12	College	Powered wheelchair	Powered wheelchair	Apartment with family	Free-lance graphic designer
13	Senior high school	Powered wheelchair	Powered wheelchair	Apartment with carer	Counsellor for TPESCI
14	Junior high school	Powered wheelchair	Powered wheelchair	Apartment with family	Counsellor for TPESCI
15	Senior high school	Manual wheelchair	Powered wheelchair	Apartment with family	Computer Employee
16	Senior high school	Manual wheelchair	Manual wheelchair	SCSRC with carer	Computer skills trainee (graphic+ website design)
17	Senior high school	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (graphic+ website design)
18	Junior high school	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (graphic+ website design)
19	Senior high school	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (graphic+ website design)
20	Senior high school	Manual wheelchair	Manual wheelchair	SCSRC with carer	Computer skills trainee (graphic+ website design); Mouth & Foot painting artist

Table 4-3 The brief biographical summary of 34 SCI subjects (continued).

	EDUCATION STATUS	DEVICE USED (INDOORS)	DEVICE USED (OUTDOORS)	DOMESTIC STATUS	WORK STATUS
23	College student	Manual wheelchair	Powered wheelchair	Apartment with family	Computer science student
24	College	Manual wheelchair	Manual wheelchair	Apartment with family	Previous President of TPESCI; Counsellor for TPESCI
25	College	Manual wheelchair	Manual wheelchair	Apartment with family	Computer game tester
26	University	Manual wheelchair	Manual wheelchair	Apartment with family	IT technician and website designer
27	College	Manual wheelchair	Manual wheelchair	Apartment	IT technician and website designer
28	College	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (graphic+ website design)
29	University student	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (graphic+ website design)
30	Junior high school	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (office System)
31	Senior high school	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (office System)
32	Senior high school	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (office System)
33	College	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (office System)
34	Senior high school	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (office System)
35	College	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (office System)
36	Junior high school	Manual wheelchair	Manual wheelchair	SCSRC	Computer skills trainee (office System)

Table 4-4 The range of motion of SCI subjects.

	RANGE of MOTION																
	LEFT HAND								RIGHT HAND								
	Elbow	Forearm	wrist	Thumb	Index finger	Middle finger	Third finger	Little finger	Elbow	Forearm	wrist	Thumb	Index finger	Middle finger	Third finger	Little finger	CATEGORY
01	◐	◐	◐	○	○	○	○	○	◐	◐	◐	◐	◐	○	○	◐	C 5.6.7
02	◐	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○	○	C 3.4.5
03	◐	◐	◐	○	○	◐	○	○	◐	◐	◐	○	◐	○	○	○	C 3. 4
04	◐	◐	◐	○	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 5
05	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	C 3.4.5
06	◐	◐	◐	○	◐	○	○	○	◐	◐	◐	○	○	○	○	◐	C 5. 6
07	◐	◐	◐	○	○	◐	○	○	◐	◐	◐	○	◐	○	○	○	C 5. 6
08	◐	◐	◐	◐	○	○	○	○	◐	◐	◐	○	◐	○	○	○	C 3. 4
09	◐	◐	◐	○	◐	○	○	◐	◐	◐	◐	○	○	○	○	○	C 5. 6
10	○	○	○	○	○	○	○	○	◐	◐	◐	○	◐	○	○	○	C 6.7
11	◐	◐	◐	◐	○	◐	○	○	◐	◐	◐	○	○	○	○	○	C 5. 6
12	◐	◐	◐	○	○	○	○	◐	◐	◐	◐	○	○	○	○	◐	C 3. 4.5
13	◐	◐	◐	○	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 4.5
14	◐	◐	◐	○	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 4
15	◐	◐	◐	○	○	○	○	○	◐	◐	◐	○	◐	◐	○	○	C 4. 5
16	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	C 2. 3. 4
17	◐	◐	◐	○	○	○	○	○	◐	◐	◐	◐	○	○	○	◐	C 5. 6
18	◐	◐	◐	○	◐	○	○	○	◐	◐	◐	○	○	○	○	○	C 6. 7
19	◐	◐	◐	◐	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 4. 5. 6
20	○	○	○	○	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 4. 5
23	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 5
24	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 5-7
25	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 4
26	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 10
27	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 11.12
28	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 12
29	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 12
30	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 12
31	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 7-12
32	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 12
33	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 4-7
34	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	T 12
35	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	S 2-3
36	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	S 3

○ No or minimal contraction or movement
◐ Partial movement
● Normal or near normal movement

4.2.4 Results

The majority of information collected from observations and interviews is field notes and visual data. The first stages of data analysis were the selection and definition of concepts and indices. At this stage, four focused domains followed the design framework depicted in Figure 4-3 was labelled, involving (a) workplace set-up and arrangement, (b) the function ability and disability of SCI subjects, (c) assistive technology utilisation, including input device used and adjusted, based on habitual practices and preferences, and (d) computer activities and practices. The second stage was the entering of field notes and transferring photographs into a computer. Then, the need to generate subjective findings to formal theory in this contextual survey was the particular task at the final stage of analysis. In other words, the researcher attempted to move particular findings from observed experiences of individual cases to the more general concept via data reading, re-reading and comparison between individual subjects.

In brief, this survey aims to explore and theorise the relationship between alternative input devices and users with spinal cord injuries. Four embedded units of analysis, which are the functional limitations inherited from spinal cord injuries, the environments in which the subjects performed computer activities and used a device, the representative types of assistive input devices adopted by the SCI users, and the habitual practices and preferences, are involved and elaborated in the following sections.

4.2.4.1 Function Limitation of Spinal Cord Injury

As previously noted, each person with spinal cord injury is unique and experiences different levels of function and sensation losses. Individual levels of spinal lesion do not result in the same level of functional disabilities, as demonstrated in Table 4-4. Spinal cord injuries at the thoracic or lumbar level result in paraplegia and give voluntary motor control and muscle strength to the upper body. Conversely, those subjects with cervical spinal cord injures generally suffer from the condition of tetraplegia, with little or no sensation or motor function of their hands. The presence or absence of voluntary motor control of upper limbs is a critical determinant for performing independent computer operation. This indicates that persons with severe high level of spinal lesion, i.e. cervical spinal cord injury, would have difficulties to access an input device and require a good deal of assistance.

4.2.4.2 Workplace Set-up and Arrangement

Thirty-four SCI subjects were powered and/or manual wheelchair users as seen in Table 4-2 and Table 4-3, and it was difficult to gather them together in the laboratory-based environment. Because of their transport difficulties and the purpose of delving into the real-life practices, the subjects' habitual workplaces were chosen for the research environment.

The set-up and arrangement of subjects' actual computer workplaces, including the location, habitual computer seating and desks with/without adjustments, as detailed in Appendix A and Appendix B. The locations of subjects' working places are homes, offices, or computer laboratories placed in the vocational training centre. Home is the place of choice for all subjects compared with their current working milieu in the office/computer laboratories. In terms of computer seating, all subjects' wheelchairs became their desk chair except Subject 03 who used a computer chair and Subject 09 who was used to lying on a bed, as seen in Figure 4-4. Other subjects, like Subject 05 (Figure 4-5), used the general computer desk but with special adjustments. The monitor, the keyboard, and the assisted input mouthstick were supported by a specially made metal frame; also, the desk was extended to enlarge the working area (refer to Appendix A and Appendix C). On account of financial considerations, all subjects chose conventional tables (computer desks/ office tables) excluding Subject 04. Figure 4-6 shows that Subject 04's workstation, which was specially designed and manufactured for his special needs, such as height, width and depth, allowed his wheelchair to slide under it. Unlike Subject 04's special workstation, the general computer desk adopted by Subject 02 was adjustable by an extended table which could be set up on the wheelchair and improved the situation when the wheelchair could not be pulled up to the desk. The findings of the workplace set-ups and arrangements indicated that the situation when the wheelchair could not be pulled up to the desk caused many of the subjects a problem over the distance between themselves and the computer monitor (refer to Appendix A and Appendix B).

Figure 4-4 The computer seating of Subject 03 (left) and Subject 09 (right).

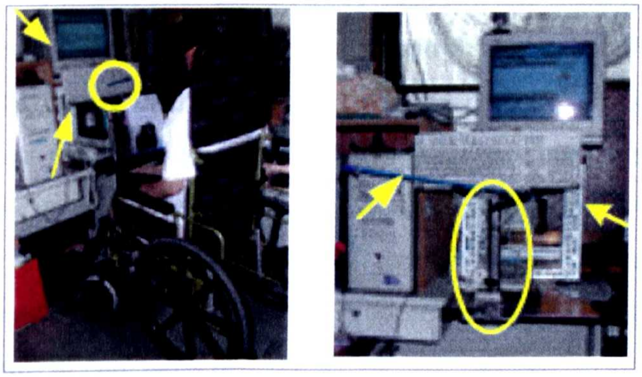


Figure 4-5 The workplace set-up and arrangement of Subject 05.

Figure 4-6 The computer desks adopted by Subject 02 (left) and Subject 04(right).

4.2.4.3 Subjects' Adopted Input Devices, Habitual Practices and Preferences

Appendix C and Appendix D show how the subjects accessed a computer with/without the use of assistive devices in their daily practice. Twenty CSI subjects performed individual and dissimilar operating modes and used computer input devices. Some subjects required additional assistive devices, such as the finger/wrist orthoses, handstrips, the input pens, or a mouthstick (as seen in Figure 4-7, Figure 4-8 and Figure 4-9); some made changes/adjustments to their used input device, for instance, non-slip material or foam tapes stuck on the surface of the input devices (Figure 4-10); some used special keyboards (a smaller dimension keyboard or an on-screen keyboard which should be operated by a mouse) or the specially designed and manufactured mouse such as a trackball mouse, or a breath and mouth controlled mouse (Figure 4-11); some worked only with a mouse or a keyboard; and some users accessed a computer by a single finger without assistance (Figure 4-12). Subjects' performances are discussed on an individual basis in Appendix C. Unlike CSI subjects, people who suffer TSI/LSI have normal movement functions and performance when accessing a computer; therefore, the conventional mouse and keyboards were adopted by all TSI/LSI participants as shown in Appendix D.

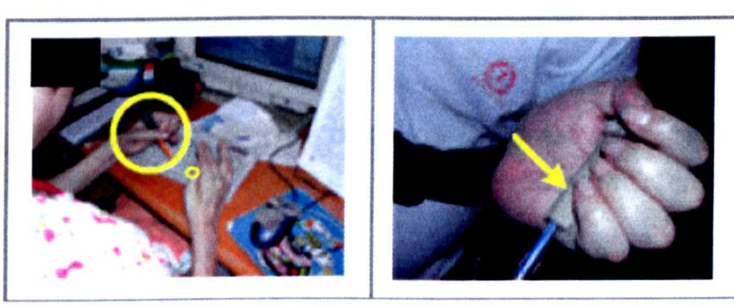


Figure 4-7 Subjects use the handstrips on the left hands for supporting an input pen.

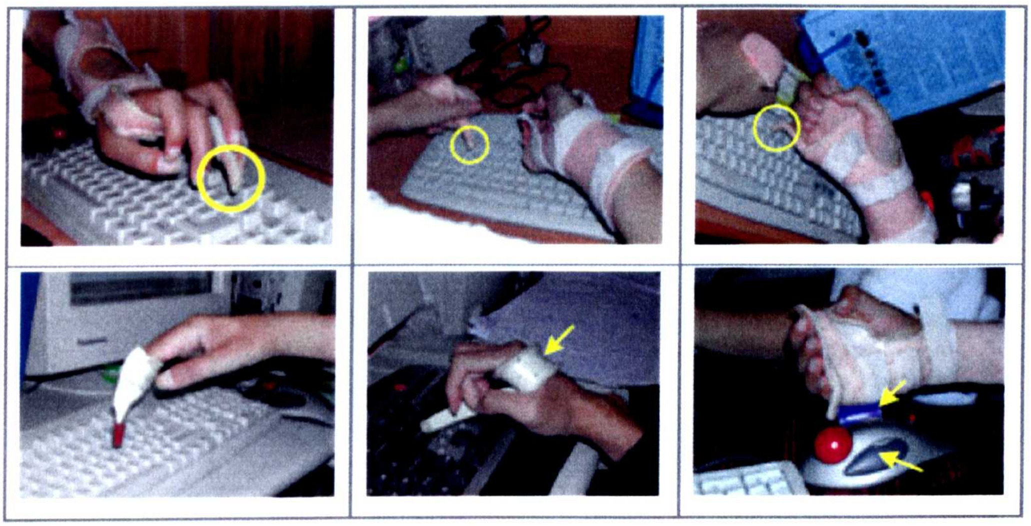


Figure 4-8 The finger or/ and wrist and finger wrist orthoses are worn as a substitute finger to assist the subjects to operate a computer.

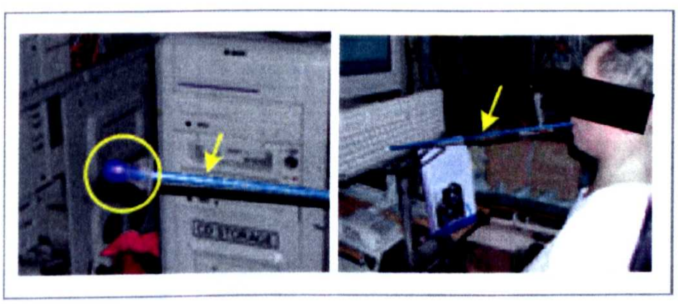


Figure 4-9 The mouthstick, which is made from an arrow shaft in which are bored many holes in order to reduce its weight, is used as an input pointer.

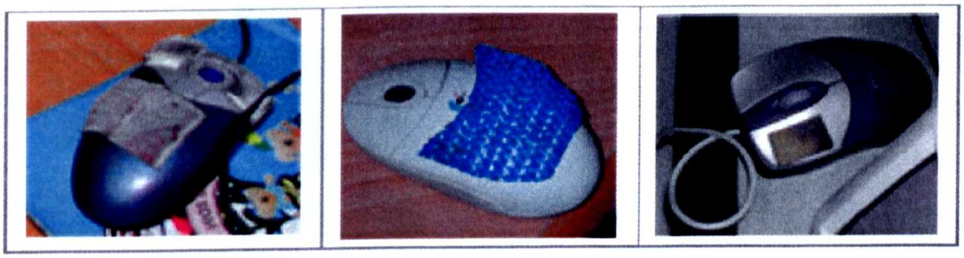


Figure 4-10 Non-slip material or foam tapes are stuck on the surface of the mice in order to assist operations and separate the right button from the left button on a mouse.

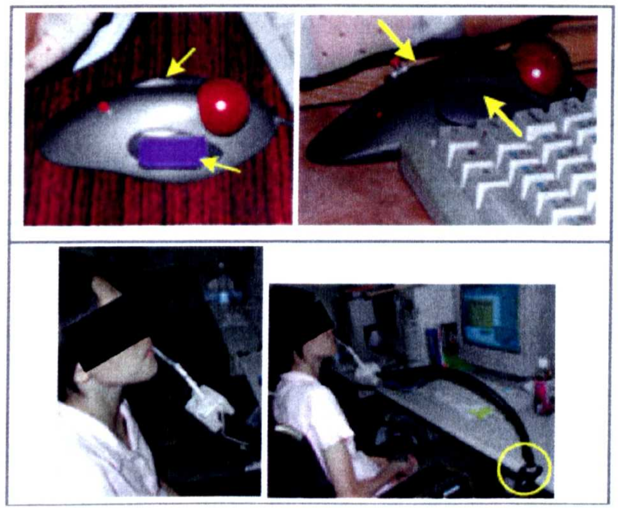


Figure 4-11 The special designed trackball mice (rows above); the specially designed breath and mouth control mouse (rows below).

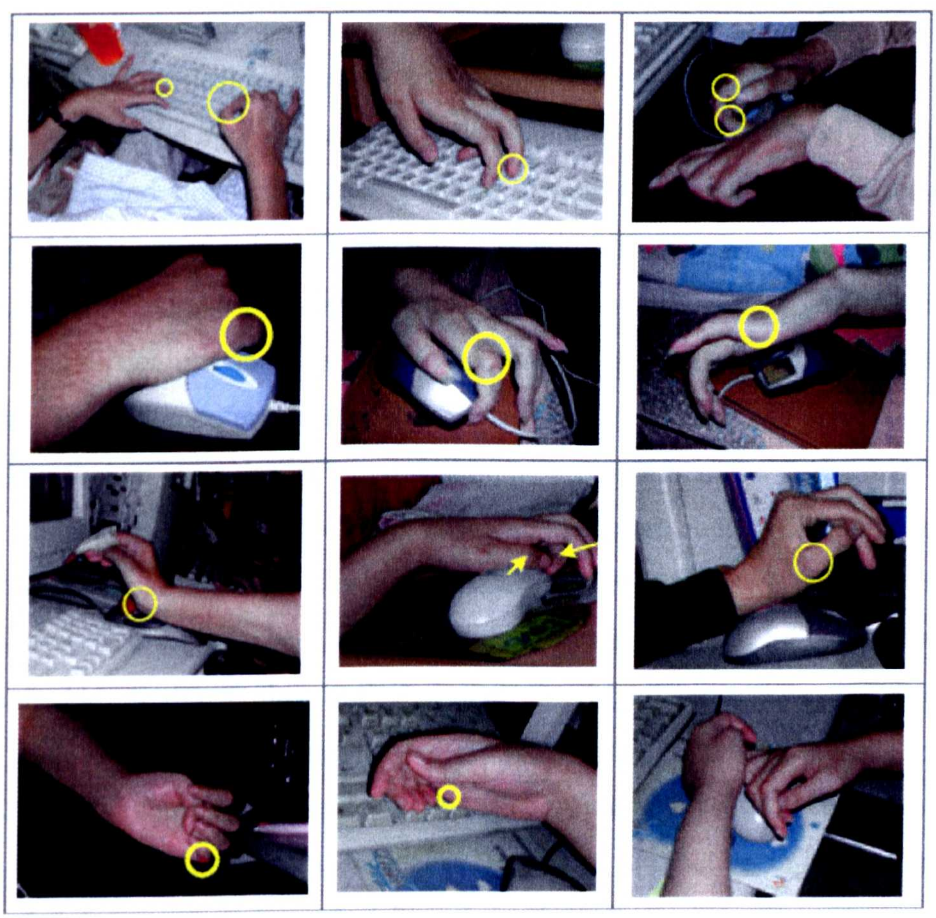


Figure 4-12 The subjects operate a keyboard and/or mouse with a fingertip, metacarpophalangeal joint, interphalangeal joint, or the wrist.

4.2.4.4 Computer Work and Activities

In terms of computer use, it was found that the SCI subjects were highly engaged with the data input, graphic drawing, programming, internet use (including information search, online meeting, emailing and chatting), and game playing. Computer use has become a major part in the life of SCI persons. Many SCI subjects, who have upper-limb disorders in particular, devoted a great deal of time to computer practices. Because of the partial or very limited function (as discussed on an individual basis), the SCI subjects would rather stay at home (or travel only between home and the workplace), that is to say, the computer work which permits home-based use is a part of routine, and occupied SCI subjects most of time. It can be seen that the time taken in computer use by the subjects with cervical spinal cord injuries with a range of between 8 and 12 hours a day, is higher than the others with thoracic or lumbar spinal cord injures on average. However, there are some operating difficulties found among those subjects with spinal cord injuries. Many SCI computer users, especially those with higher level of spinal lesion, may hit the computer keys or move a pointer only by single key-in operation by a single finger or/and another part of their body. In addition, repetitive strain and tiredness leads to lower accuracy of input performance mainly caused by hitting wrong keys and slow operation speed. Assistive technologies, therefore, are used in the first place to help such persons to successfully overcome more basic physical difficulties and develop certain abilities in computer operation. Once the difficult tasks, e.g. computer access, can be performed, the desire and drive run deeper. SCI people select an input device based first on how well it benefits functional needs in operating. Secondly, if the lower level physical needs are met, SCI computer users would require an assistive input device for matching their further needs, such as easier and comfortable use, reducing more operating tiredness, and better performance expectation. The findings also indicated that the highly repetitive and long-time computer work has incurred some potential adverse effects, such as musculoskeletal disorders. The SCI subjects seemed to work with considerable postural stress from neck, shoulder, arms, hands, backs, and buttocks. Hence, an alternative input device is not only provided for easier and comfortable use and reducing operating stress, but also presented as a possible solution for those users with spinal cord injuries.

Table 4-5 The comparison of personal preference and habitual practice.

	Part of body used to access a computer						Operating mode		Computer input devices						Problems caused		
									Keyboard			Mouse					
	One hand	One hand with AT support	Two hands	Two hands with AT support	Other part of body	Other part of body with AT support	Single input operation	Bimanual input operation	General keyboard	General Keyboard with adjustment	Specially designed keyboard	General Mouse	General Mouse with adjustment	Specially designed mouse	Easy to hit the wrong keys	Much time spent on data keying	Easily becomes tired
01				☆			●				●		●		●	●	●
02		☆					●		●					●	●	●	●
03			☆				●		●			●			●	●	●
04				☆			●		●				●		●	●	●
05						☆	●			●					●	●	●
06			☆				●			●			●		●	●	●
07			☆				●		●			●			●	●	●
08			☆				●					●			●	●	●
09	☆						●						●		●	●	●
10		☆					●		●					●	●	●	●
11	☆						●		●			●			●	●	●
12			☆				●		◑			●			●	●	●
13		☆					●		●						●	●	●
14		☆					●		●						●	●	●
15	☆						●		●			●			●	●	●
16						☆	●							●	●	●	●
17	☆						●					●			●	●	●
18	☆						●		●			●			●	●	●
19			☆				●		●			●			●	●	●
20		☆					●		●					●	●	●	●
23			★					●	●			●					●
24			★					●		●		●					●
25			★					●		●		●					●
26			★					●	●			●					
27			★					●	●			●					
28			★					●	●			●					
29			★					●	●			●					
30			★					●	●			●					
31			★					●	●			●					
32			★					●	●			●					●
33			★					●	●			●					●
34			★					●	●			●			●		●
35			★					●	●			●					
36			★					●	●			●					

★ Normal or near normal function or performance.
☆ Partial or very limited function or performance. May require to be discussed on an individual basis.
◑ Infrequent use in daily practice.
● Habitual performance or adopted device.

4.2.5 Interview and Observation Studies

Observations and interviews were held by arrangement in the subjects' workplaces on their computer operating modes and the assistive devices used, on the ease, comfort and effectiveness of use, and on the conditions and circumstances under which they experienced difficulties when accessing a computer.

In terms of the adopted input devices, habitual practices and preference, the findings indicated that TSI/LSI users had less or no difficulty in operating a conventional keyboard and mouse. However, many difficulties in computer use arose for CSI sufferers. It was discovered that the common characteristic of CSI subjects is to operate a computer only by single key-in operation by a single finger, mouth, or their adopted assistive devices, such as a hand strip for holding the input pen tightly, wrist and finger orthoses as substitute fingers, or a mouthstick. The findings also signified a keyboard presents more required functions than a mouse for those CSI users, especially when drawing computer graphics and inputting data to a computer. Table 4-5 shows the comparison of personal preference and habitual practice between CSI and TSI/LSI users.

Based on regular, intensive, and long-time computer use of all SCI subjects (in particular with individuals with cervical spinal cord injuries), many problems arose, such as the difficulties found when accessing a computer and the musculoskeletal pains caused by long-term computer operation. In brief, participants who sustained cervical spinal lesions who have limited or no voluntary control of hand movements and muscle strength regularly confront difficulties during computer use as follows: perform single key-in operation only, easily feel tired when operating a computer, repeatedly hit wrong keys, much time spent on data input, as well the musculoskeletal disorders present in the neck, shoulder, arms and hands, back, and even buttocks, as shown in Figure 4-13. As a result, every SCI subject assumed there needs to be more improvement and alterations to their current devices for facilitating computing operations and matching their needs. That is to say, there is a strong demand from persons with spinal cord injuries for seeking an appropriately designed assistive computer input technology, especially a keyboard. Following the findings of contextual survey, a five-layer SCI users' needs hierarchy of an alterative input was formulated, especially for persons who have hand movement disorders and meet difficulties in accessing a conventional input. These needs are ranked in the order; beginning with the most basic criterion at the bottom of the pyramid; lower-level criteria must be met before one moves on to the higher levels. The need of *single key-in operation* is laid out as the base of the hierarchy, then *easy-to-use*, *lessening operating tiredness* presented as the third layer, followed by the expectation of increasing *input accuracy*, and enhancing *input speed* at the top as the highest layer of the pyramid as pictured in Figure 4-14. As a result, the integrated alternative touchscreen input devices (5.7 inch and 9 inch) (Chang 2004; Tseng 2003), designed to assist persons with severe physical impairments and match the criteria set up in the SCI needs hierarchy are suggested in this study as a possible solution.

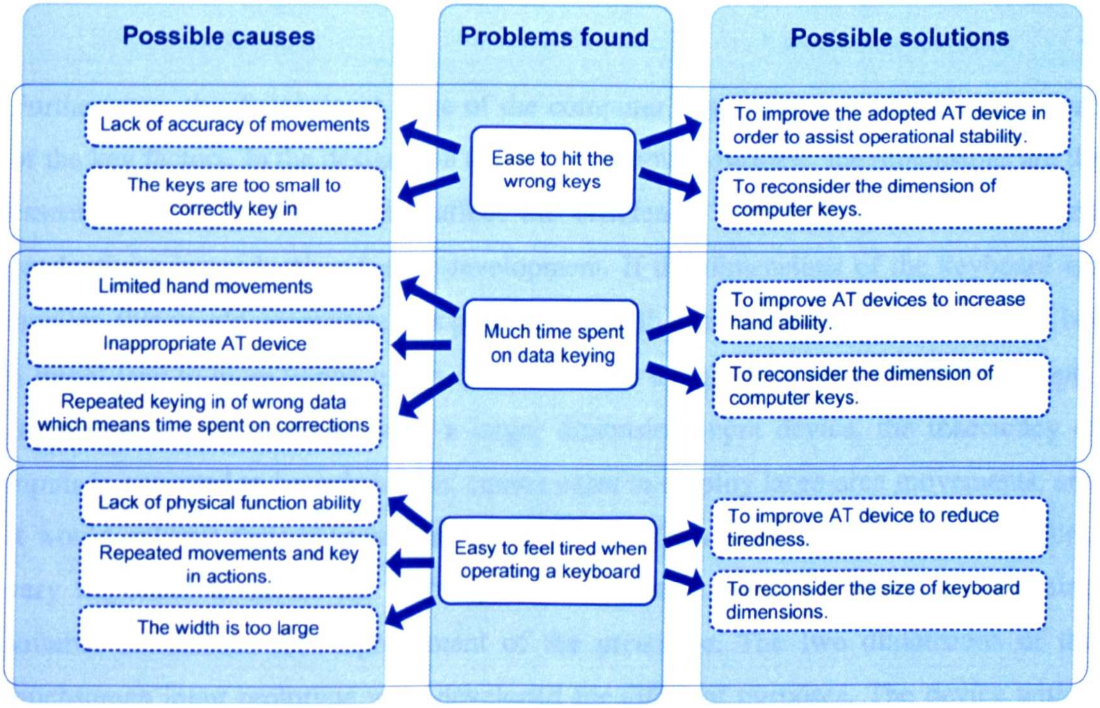


Figure 4-13 Problems caused by keyboard use and their solutions.

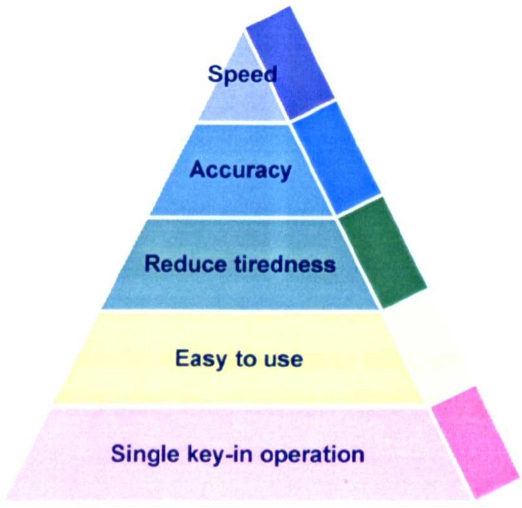


Figure 4-14 SCI users' needs hierarchy for alternative input selection.

Furthermore, the dimensional issue of the computer input device is pointed out as one of the key factors. In the design of a touchscreen input prototype, the dimensions are the essential factors which directly affect the efficiency, accuracy, cost, mobility, and productivity in product/marketing development. If the dimensions of the keyboard are smaller, this would necessitate less physical strength needed for the computer users, but it might lead to more wrong inputs or result in the wrong order over repeated attempts. In contrast, if users operate with a larger dimension input device, the inaccuracy of inputs is expected to be reduced but causes users to employ large-area movements, and it would exhaust their physical strength with long-term computer use. It is, therefore, very important to assess the usability from the target users' viewpoint by choosing suitable dimensions for improvement of the prototype. The two dimensions of the touchscreen input prototype were developed for different purposes. The device with a 5.7-inch dimension as seen on the left-hand side in Figure 4-15 is designed to be a portable input device for those wheelchair users with severe upper-limb disabilities, and the newly developed 9-inch dimension prototype on the right-hand side of Figure 4-15 aims to take the place of subjects' inappropriate desktop input devices. Hence, the evaluation of the appropriateness of this touch screen input device is suggested and conducted in subsequent assessments.

Figure 4-15 5.7 inch dimension (the left-hand side) and 9 inch dimension (the right-hand side) touchscreen input prototypes.

4.3 Study B: Dimensional Consideration of a Portable Touchscreen Device for Individuals with Spinal Cord Injuries

4.3.1 Introduction

The findings of the contextual survey indicated that the subjects with spinal cord injuries - even the similar level of spinal cord lesion - have different limitations and capabilities. However, they encountered great difficulties in operating a conventional keyboard and a mouse. These participants, who activate a computer as a major part of routine, exhausted their physical strength due to their limited scope of movements, highly stressful and repetitive operation, extensive length of time being taken, and the inappropriate input device used. As a result, a hierarchy of five levels of SCI users' needs for input device selection was developed in the previous contextual survey (as illustrated in Figure 4-14). The view of input device selection and use was diagrammed in a pyramid form similar to Maslow's motivation needs hierarchy (1987) and Scherer's usability hierarchy of technology selection which focused on the course of rehabilitation (2000d) (discussed in Section 4.2). This diagram can be thought of as a hierarchy and guidance of matching of SCI persons (those with severe upper-limb impairments in particular) and assistive input devices – the needs of SCI users were ranked in the order; beginning with the most basic, single key-in operation, then easy to use, reduce tiredness, and finally to improve input accuracy and speed. Moreover, the hierarchy has brought the rationale to this experimental work.

In a sense, the consideration of the usability and of the device's dimensions is an essential factor for selecting a computer input device among those SCI users. The novel touchscreen devices (5.7 inch and 9 inch dimensions) are pointed out and suggested to be a possible solution for those users with hand motion impairments. The 5.7 inch device was designed for portable use and the interface layout followed an alphabetical arrangement (as with the interfaces on conventional IT products); and the 9 inch device, which the interface arrangement is as similar to conventional computer keyboards, was developed to take the place of subjects' existing inappropriate input devices. There is the question of the appropriateness of the touchscreen dimension - an issue foremost in the mind of the researcher. In other words, this requires the researcher to be aware of and sensitive to a particular consideration of dimensions, especially with the smaller 5.7-inch device. At this research stage, the researcher assumed an idea – if the 5.7-inch dimension is suitable for those SCI persons, the larger size, such as 9-inch, could be similarly applicable. From this idea this study aims to assess the appropriateness of the dimension of the portable 5.7-inch touchscreen device through the simulation of function movements of those SCI subjects.

Generally speaking, input accuracy and speed present the most viable methods to test the usability of computer-based systems or devices (as addressed in Section 2.5.3). With this in mind, the outcomes of usability enable probing the range of dimensional suitability. Correspondingly, the aims of this study are to assess the usability of CSI subjects using the novel 5.7-inch touchscreen input prototype for its dimensional appropriateness; in addition, this study is conducted as a pilot study prior to the subsequent user-centred validation studies. The stages in this trial assessment can be identified as:

- To contact the selected participants and arrange the assessment;
- To set up the location of assessment and the related ergonomic practices;
- To collect and analyse data with the experimental assessments;
- To draw up conclusions.

4.3.2 Method

The experiment represents the most rigorous approach to answer questions of causal inference (Clarke and Dawson 1999b; Denzin 1970a). A characteristic feature behind the experiment is found as a successionist conceptualization of causality (Harr'e 1985). In the generic form the experiment stands for a situation in which the three features of the causal proposition: time order between variables, covariance, and the exclusion of rival causal factors can be directly controlled by the researcher (Denzin 1970a). The experimental approach, providing a realistic scientific strategy, was employed in this study in order to measure the dimensional appropriateness of the novel touchscreen input device. Based on the findings of an earlier contextual survey, it was found that there was a variety of operating modes performed by SCI subjects; even so, the two main accessing mehods, offering arms and elbows *with* or *without* assistance when operating an input device, were identified. That is, in order to simulate the true practices of SCI computer users, the experimental design involved two sets of measurements: one group exposed to operate the touchscreen input *with* arm and elbow support, the other assigned to complete the given tasks *without* arm and elbow support.

The purpose of the experiments is to probe into the dimensional suitability of the newly developed touchscreen device for SCI persons, especially those with cervical spinal cord injuries, via the usability measurements of a touchscreen alternative input. Designs in this experiment included a situation in which each participant was requested to operate the touchscreen device only by single key-in ability. As noted earlier, the measure of input accuracy, which is frequently used to test the usability of computer-based instruments, was adopted in this experimental work. The idea of experiments was one in which the participants were asked to key-in required vocabularies, then, the results gathered were used to make a usability rating. Of course, the key-in vocabularies were randomly selected prior to the experiments.

In this experimental study, the participants were asked to act out their designed roles and respond to the demand characteristics of the experiment. Denzin (1970a) suggested there needs to be an appreciation of the aims and objectives of experiment and to determine the various meanings subjects attribute to the situation. Thus another strategy in this work was to present participants with the instruments of an experiment before they responded to the actual experiment. The participant instructions were explicitly set out in order to direct participants' demand characteristics and behaviour in the experiment. These involved:

- Single key-in operation

Participants are requested to complete requested key-in operations by using an assisted input pen in order to simulate the operating behaviour of CSI computer users and demonstrate the difficulties when data inputting.

- Ignore the mistakes

With the purpose of obtaining data on key-in errors, participants should ignore any mistakes made in the process of the experiment.

- Clean up the remaining memory

With the aim of reducing a coefficient of variation and error function, the same key-in vocabularies were used twice but data was inputted by different operating modes. Besides, in order to avoid participants retaining memory of the former key-in words, there was an interval of one week between the two experiments. Participants were unlikely to be able to remember the former vocabularies on the second occasion.

Furthermore, the relevant components of the experiment design, involving participants, instruments, and environment, are detailed as follows.

4.3.2.1 Participant Selection

The twenty volunteer participants were randomly selected from the Graduate Centre, Art and Design, De Montfort University, and ranged in age from twenty to forty-five years. It was essential to gain the consent to participation from each principal prior to the experiment. Every participant was requested to simulate the restricted hand movements of computer users with cervical spinal cord injury by way of completing research tasks under two different situations in which one was requested to perform key-in operation with supported arms and elbows (Assessment I), and the other conducted required actions with non-supported arms and elbows (Assessment II). The Basic information on participants is shown below in Table 4-6.

Table 4-6 Basic information on participants.

NO.	GENDER	AGE IN 2003	WORK STATUS	NO.	GENDER	AGE IN 2003	WORK STATUS
01	Female	24	MA student	11	Female	32	MA student
02	Female	28	MA student	12	Female	28	PhD student
03	Male	28	MA student	13	Male	24	MA student
04	Male	32	Staff	14	Female	26	PhD student
05	Female	33	MA student	15	Female	21	MA student
06	Female	29	Staff	16	Female	45	PhD student
07	Female	31	MA student	17	Female	38	PhD student
08	Male	25	PhD student	18	Female	27	PhD student
09	Male	37	PhD student	19	Male	30	PhD student
10	Male	28	MA student	20	Female	23	MA student

4.3.2.2 Instruments

The experimental instruments, including the 5.7-inch touchscreen alternative device, an assisted input pen, a wheelchair, as well the documented standard operating procedure, were required.

- The novel touchscreen alternative input device

The touch screen input device with a 5.7 inch width with alphabetically arranged layout was provided. Details are shown in Section 3.4.2.

- An assisted input pen

Following the findings of previous survey, a substitute finger (the finger and/or wrist ortheses) or an assisted input pen, provided CSI subjects with great assistance in computer operation. Hence, the input pen was used for simulating the key-in operation of users with cervical spinal cord injuries in this experiment.

- A wheelchair

A manual wheelchair. The survey indicated that all SCI subjects are wheelchair users except for one bed-ridden participant (No. 9). To simulate real-life computing practices for SCI users, a manual wheelchair was provided in this experiment.

- Standard operating procedure

In order to ensure reliability of the experiment, the standard operating procedure was provided. In its generic form, the standard operating procedure represents a guidance of replication of the experimental processes. Moreover, the job of the standard operating procedure is to assist the researcher to ensure to create consensus quality of every single experiment in this research work. That is to say, given the standard operating procedure which conceived step-by-step processes, the actual execution of every experiment follows. The standard operating procedure in this study had to be made as the step-by-step instruction of the experimental processes, involving the settings selected for the experiment and a series of encounters considered between the researcher and subject. In addition, the twenty experiments conducted by the researcher and twenty different participants should correspond exactly to the SOP. The standard operating procedure for the experimental work is shown in Figure 4-16.

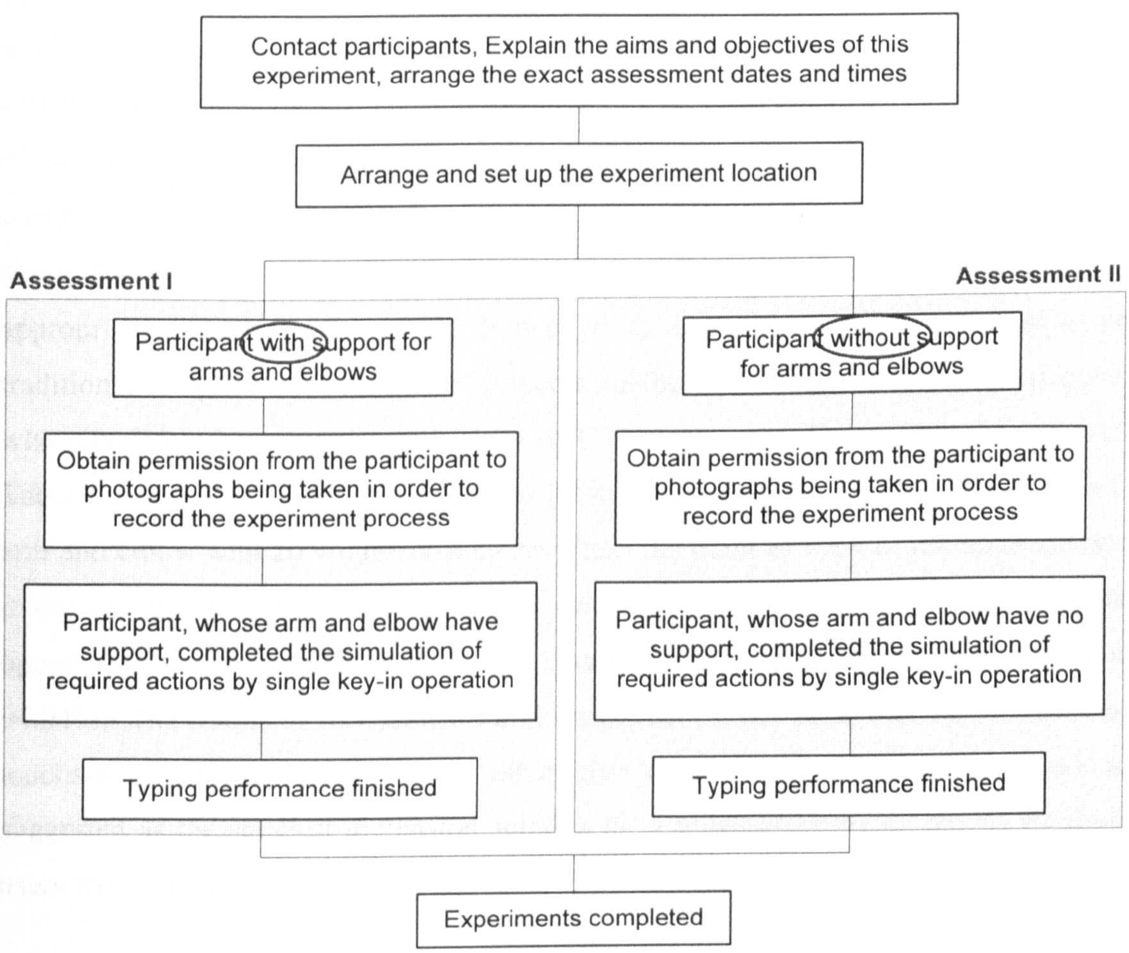


Figure 4-16 The standard operating procedure of usability assessments.

4.3.2.3 Location of the Experiments

In order to ensure reliability and validity controls, scientific meaning and effectives, this study had staged the experiments in the laboratory. Denzin (1970a) phrased the laboratory as '*an interactional theatre*', '*a behaviour setting with its own rules and props for conduct*' and '*a small stage on and in which the drama of interaction is presented*'. The laboratory, located at the Digital Media Centre of De Montfort University, was engaged in a performance close to the actual situations of SCI subjects and followed ergonomic practices.

4.3.3 Results and Analysis

Following the findings of the previous interview and observation survey (Section 4.2), it can be seen that computer users who suffer CSI/SCI require the special support of input devices which are easy to use, that avoid too many key-in mistakes and increase key-in efficacy i.e. accuracy and speed and lessen tiredness when inputting. Additionally, ease of use and accuracy are, for subjects, more important than speed when accessing a computer. Consequently, the key-in speed was not considered in this study. The assessments were conducted with the aim of providing a touch screen input device of appropriate dimensions for people with physical disabilities who are unsuited to the traditional computer keyboard. The hit records gathered from the 20 normal participants, who simulated the computer operations of CSI users, were illustrated in Figure 4-17, Table 4-7 and Table 4-8 showed the two different assessed results of on/off support of arm and elbow with 20 volunteer subjects. From the point of view of the accuracy rate, it showed that both assessments equally demonstrated the efficacy of subjects when operating a touch screen input device (i.e. Assessment I of 96.81% and Assessment II of 94.04%). The results of Assessment I and Assessment II indicated that the 5.7-inch size touchscreen was appropriate as an alternative input device. In addition, it can be suggested as the smallest dimension suitable for a touchscreen-based device for those users with severe upper-limb impairments.

Table 4-7 The rate of accuracy from usability assessments (Assessment I).

ASSESSMENT I			
No.	**Accuracy Rate**	**No.**	**Accuracy Rate**
01	97.87 %	11	100.00 %
02	100.00 %	12	95.74 %
03	93.62 %	13	97.87 %
04	100.00 %	14	95.74 %
05	100.00 %	15	91.49 %
06	95.74 %	16	95.74 %
07	97.87 %	17	100.00 %
08	97.87 %	18	100.00 %
09	100.00 %	19	85.11 %
10	93.62 %	20	97.87 %
AVERAGE:	**96.81 %**		

Table 4-8 The rate of accuracy from usability assessments (Assessment II).

ASSESSMENT II			
No.	**Accuracy Rate**	**No.**	**Accuracy Rate**
01	100.00 %	11	87.23 %
02	100.00 %	12	100.00 %
03	87.23 %	13	85.11 %
04	97.87 %	14	87.23 %
05	93.62 %	15	91.49 %
06	87.23 %	16	97.87 %
07	100.00 %	17	97.87 %
08	91.49 %	18	100.00 %
09	85.11 %	19	93.62 %
10	97.87 %	20	87.23 %
AVERAGE:	**94.04 %**		

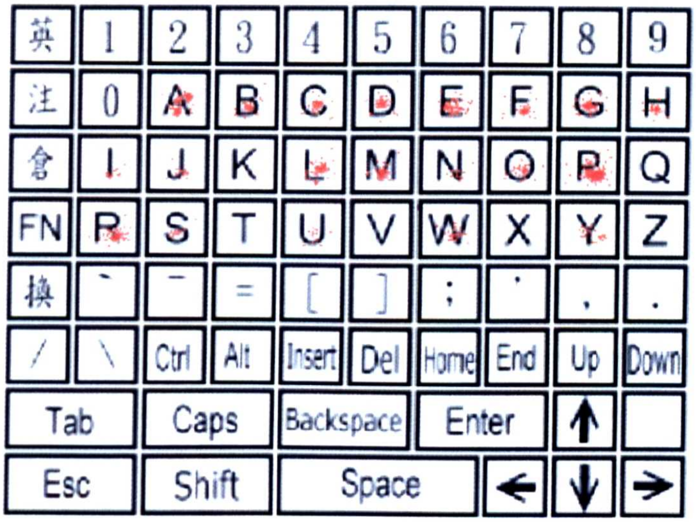


Figure 4-17 5.7-inch simulated touch-screen key-in test result.

4.4 Summary

This chapter began with the in-depth contextual survey presented in Section 4.2. To gain an insight into the real-life situations from the thirty-four participants with spinal cord injuries through observation in their homes, workplace, or the vocational training centre. In addition, every participant was discussed on an individual basis. The survey was conducted to help to address such needs of people with spinal cord injuries when accessing a computer; it describes the function abilities and limitations of SCI subjects, the choices and utilisation of input device, the habitual computing practices and preference; it concerns the environment in which the subject uses a device and performs regular computer practices and its set-up and arrangement; further, it outlines the operating difficulties and musculoskeletal disorders caused by intensive computer work. Eventually, the novel hierarchy, which ranked the needs of SCI computer users for input device selection, is firstly described in details in this chapter, meets the objectives set out in Section 1.3 and embodies the rationales for the sequent studies. Secondly, the newly developed touchscreen input devices are pointed out as the possible solution for persons with hand movement impairments, such as a cervical spinal cord injury. In Section 4.3, this simulation study was conducted as a pilot study prior to the following user-centred evaluation studies, and focused on the dimensional appropriateness of the newly developed touchscreen device. The results showed that the 5.7-inch size touchscreen was acceptable as an alternative input. In addition, it was proposed as the smallest dimension for a touchscreen-based device for those users with severe upper-limb impairments.

In summary, this chapter, firstly, theorises a unique hierarchy, which had not been applied by previous research work and which has established a rationale of the sequence of studies in this thesis; then, the 5.7-inch dimension has been suggested as the smallest size for touchscreen-based device for people with spinal cord injuries; there, finally, needs to continue to measure the usability of the novel touchscreen input devices on SCI individuals, on real-life situations, and on the different evolution phases.

CHAPTER 5 USER-CENTRED VALIDATION

5.1 Introduction

Chapter 4 described real-situations for computer operation among persons with spinal cord injuries, characterised as individual cases. It addressed a hierarchy of SCI users' needs for input selection, and presented a novel touchscreen input device which was deemed acceptable to those SCI users. In addition, a 5.7-inch sized screen was examined and suggested as a smallest size of the touchscreen-based device for those users with hand movement disorders. Following the former outcomes, the research turns to a different stage of evaluation of the process in this chapter. Attention is still paid to the user-centred requirements as the core for the sequence of evaluative system. This is, three sets of user-centred outcome measures are outlined in this chapter. The studies, which can be defined by different evaluative stages, focus on both user-issue consideration and scientific-based validation.

5.1.1 Fuhrer's ATD-Specific Outcome Framework

Following the needs hierarchy for input device selection for SCI users, set out in Chapter 4, the novel touchscreen input device has been suggested as a solution for those users who sustained upper-limb impairments and who encounter difficulties in operating conventional input devices. Once an assistive technology device is designed for specific users, it is essential to measure its performance and functional effectiveness (Cook and Hussey 1995). That is to say, the suitability of the newly developed touchscreen device is determined by whether it can improve or attain a certain level of functional capability on its target users (i.e. the spinal cord injury). Correspondingly, the term usability described in Section 2.5.3 is frequently referred to the capability of a product. The key components for evaluating the usability of a computer-based system or device usability, addressed in ISO9241-11(1998), involve effectiveness, efficiency and user satisfaction in a specific context. Similarly, the outcomes of a device's effectiveness, efficiency, satisfactions, psychological functioning, and subjective well-being, have been observed in Fuhrer's ATD-Specific Outcome Framework (2003).

Fuhrer's ATD-Specific Outcome Framework, reviewed in Section 2.5.1, has formulated the causal influence between the features of device types, users, their environments and condition of device use into action. The framework begins with the procurement of a device-type, followed by introductory use, shorter-term outcomes, longer-term use and outcome, and then continued/discontinued use. This conceptual framework has not only depicted the principal directions of causal sequence for assistive device use, but also provided a theoretical basis for the studies in this chapter. Merging the above points, the purpose of this chapter is to present serious user-centred usability assessments which measure a device's effectives, efficiency and satisfaction in three stages of device utilisation (i.e. industry, shorter-term and longer-term uses and outcomes).

5.1.2 Triangulation Method

As earlier noted in Chapter 2, the studies, which only focus on psychosocial or qualitative aspects of AT outcome measures, enable the researchers to directly acquire user perception. However, there could arise overly-subjective or biased data that risks the validation and reliability of AT assessments and measurements. Conversely, many experimental assessments in the field of AT outcome measures are conducted in a laboratory-based environment and attempt to offer scientific reliability and validation. Although the types of experimental studies can precisely control the variables during the procedure and apply scientific or quantitative analytical technique with a view to making generalisable statements, the interaction between a person, assistive technology, and the normal working place would scarcely be recognised and observed in a laboratory.

When linking up people issue with scientific evidence, the use of one method alone to collect a wider range of issues and perspectives cannot satisfy an overall research strategy in this study. It stands to reason that the research work requires drawing upon mixed research techniques, combining quantitative and qualitative approaches. The triangulation method is most often referred to a systematic combination of several different approaches to data collection in a single study. On the other hand, the use of triangulation cannot only validate information obtained from different sources, show merits and demerits of different techniques, but also enlarge the theoretical relevance and strength the conclusion arising from the research (Cheetham et al. 1992a).

'Qualitative' and 'quantitative' are represented '*fundamentally opposed approaches*' to the study of the social word (Hammersley 1992). Distinguishing qualitative from quantitative is characterised by the use of words rather than numbers (Miles and Huberman 1994a). Hammersley (1992) has identified the distinction between 'qualitative' and 'quantitative'; the former represents (a) qualitative data, (b) the investigation of natural phenomenon, (c) a focus on both perspectives and behaviour, (d) the inductive approach, (e) identifying cultural patterns and (f) idealism; conversely, the latter represents (a) quantitative data, (b) the investigation of artificial setting, (c) the attitude research, (d) the deductive, or hypothetico-deductive approach, (e) the discovery of scientific laws and (f) realism. Hence, a number of different qualitative and quantitative approaches are employed to document or measure the research activities and obtain information. Some approaches, such as single-case study design, direct observation, unstructured interviews, and field experiments, are employed to achieve the research's purposes and objectives.

The research's theoretical orientation, specific research questions, purposes and objectives, concerns of participants, and even the research environment may impose constraints and influence to a considerable degree the choice of methodologies and data collection techniques. Chapter 4 provided the picture of many adjustments and changes that have occurred in accessing an input device via the in-depth survey of the SCI persons. Each person with spinal cord injury has his or her unique experiences of being as a *person with disability (PWD)* (Scherer 2000e). Each participant in Study A (Section 4.2), except Subject 03 who sustained cerebral palsy, resulting in brain injuries during birth – was an able-bodied and healthy person prior to the injuries, as seen in Table 4-1. Life itself suddenly turns to reliance on assistance from other people or assistive devices (e.g. a wheelchair); in addition, even the personal privacy is nonexistent after spinal cord injury. In the previous investigation survey, many subjects require help from others (either family members or hired personal carers) for eating, bathing, toileting, dressing, grooming, getting into a wheelchair, pressing on a power button of a computer, etc. A spinal cord injury brings not only lifelong physical impairments but results in a varied level of psychological barriers. It can be said that the most critical and complicated part in the research work is to penetrate into the SCI subjects, team up with them and hence understand their actual perspectives and special needs.

Three evaluation studies in this chapter, namely Studies C (Section 5.2), D (Section 5.3) and E (Section 5.4), are concerned principally with user-centred issues and are aimed at scientifically measuring the usability of the novel touchscreen input devices in SCI users' real-life situations. Therefore, caution had to be exercised in respect of different levels of physical and psychological difficulties of the individual SCI participants. Care had also to be taken in their varied surroundings and habitual practices. Attention had to be given as well to a wide range of responses derived from each individual SCI subject. In terms of research techniques, first, as the specific participants who suffer spinal cord injuries and who have upper-limb motion disorders were required and as each subject needed to be studied as an individual case. The single-case study design was applied in the three evaluation studies in this chapter (Section 5.2, 5.3, and 5.4). Second, as described in Section 3.3.3, as field experiments, have the virtue of conducting experiments in the natural settings and therefore acquiring data as true as possible to real-life situations, they were adopted instead of laboratory experiments. Some qualitative approaches, observational and interviewing techniques, are attached to each field experiment as complementary methods. Observational techniques which present the most direct method for data collection should firstly assume the subjects' awareness that they are being observed for ethical considerations, and secondly identify the role of the researcher in the research activities. In order to avoid the over-identification with the subjects in the study and potential biases produced by the observer, the role of the researcher is more likely to be an overt but detached observer rather than a participant observer in each observation. Further, the use of unstructured interviewing methods in each study has potential to elicit personal interpretations and perspectives on subjects.

From the above points of view, multiple methods (triangulation of method), such as single-case study design, field experiments, observation and unstructured interviews, combining qualitative and quantitative approaches, were employed for generating both user-issue and scientific-issue outcomes in a series of evaluation studies in this chapter.

5.1.3 Hypotheses

In Chapter 4, a novel needs hierarchy for the selection of an input device was formulated as a guidance of SCI users' readiness for the use of technology. Accordingly, the newly developed touchscreen alternative inputs were suggested as a possible solution to persons who have sustained a high level of spinal lesions (i.e. cervical spinal cord injury) and who cannot operate a conventional keyboard and mouse easily. Would the touchscreen alternative devices match the needs hierarchy (as seen in Figure 4-14) and be acceptable for people with cervical spinal cord injuries? As a result, three hypotheses grounded on the needs hierarchy of SCI users are proposed:

- The novel touchscreen alternative input was easy to use and applicable to persons with cervical spinal cord injuries;
- The touchscreen input device was identified as being able to improve users' effectiveness and efficiency;
- The developed touchscreen device would reduce time spent on adjustment and adaptation compared with subjects' current adopted input devices.

With the view to validating the proposed hypotheses, there is required a codified and sequence of user-centred validation, as illustrated in Figure 5-1. A series of systematic evaluation studies began with the usability assessments at the introductory phase of the touchscreen device utilisation, among those persons with cervical spinal cord injuries (Study C, located in Section 5.2). Then the outcome measurements at the shorter-term training and use presented as Study D in Section 5.3. An intensive training programme was planned and the training effects of subjects were investigated at this stage of device utilisation. As in Study E in Section 5.4, the outcomes of the longer-term use of the touschscreen prototype are measured via the continuous usability assessments. In addition, comparison between the provided touchscreen prototype and the subject's existing used input device is examined. Further, the proposed hypotheses are validated by evidence derived from the three contextual user-centred evaluation studies in Section 5.5.

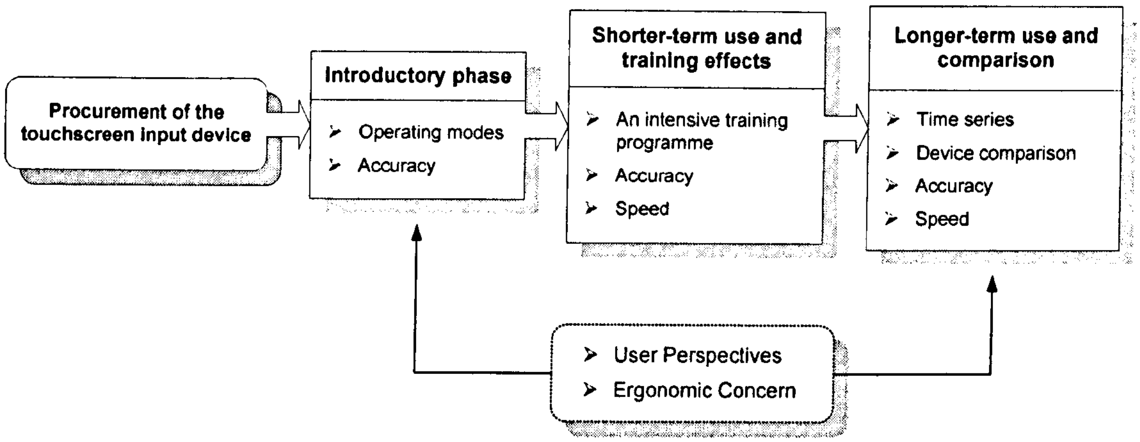


Figure 5-1 A framework for measuring usability of the novel touchscreen devices.

5.2 Study C: User-Centred Validation: Usability Assessments at the Introductory Phase

5.2.1 Introduction

According to Fuhrer et al (2003)'s framework for assistive technology device outcomes, the measurements of the outcomes from assistive-devices should be continuous. Based on the framework, the initial stage of a series of assistive-device outcome measurements is to assess device utilisation at the introductory phase after a technology is procured and selected.

Chapter 4 indicated that people with severe spinal cord injury, especially those with high level of spinal lesion (i.e. cervical spinal cord injury), have desires to operate computers as efficiently as able-bodied users, but have difficulties coping with most conventional computer input devices in real-life operations. The previous contextual observational survey discussed in Section 4.2 found that people suffering cervical spinal cord injuries could hit computer keys or move the cursor only by using their fingers singly or/and other parts of their bodies. Nevertheless, an appropriate alternative input device can equip those users with severe upper-limb impairments to deal with computer operations and improve their productivity. Moreover, the novel integrated touchscreen input devices were suggested as a solution for SCI users. Thus there is required an advanced demonstration of the device use and outcomes via a codified and sequence of usability assessments.

Muhlehner and Miesenberger (2004) indicated that the lack of usability assessments is the significant problem for uses of the alternative input devices. The usability evaluation of the novel touchscreen input device is crucial. Further, the specific users, persons with spinal cord injuries, are the core of the validation study. Every person with a spinal cord injury not only has varied levels of function limitations and psychosocial barriers but also is unique and deserves to be treated individually. Therefore, this study focuses on usability measurements of the specific assistive device (the novel touchscreen alternative input) and the specific users (those with cervical spinal cord injuries).

Moreover, in the previous contextual survey presented in Section 4.2, the findings indicated the dissimilar operating modes among the thirty-four SCI subjects. Most of the subjects with cervical spinal cord injuries activated their input devices with only a single finger with or without additional support except two subjects, Subjects 05 and 16, who performed mouth-operations. In terms of the subjects' additional supports, these included the handstrip, finger/ wrist and finger ortheses, assisted input pens, and the mouthstick. As a result, the CSI participants in this study were divided into three groups based on their varied level of motor function and their habitual operating modes. In Section 4.3, the newly developed 5.7-inch touchscreen device was demonstrated and suggested as the smallest size for a touchscreen-based device for those users with upper-limb motion limitation via the laboratory-based experimental simulation. In parallel, the larger size, 9-inch, could be expected to be suitable for the touchscreen device for its specific users. Hence, this study involved both 5.7-inch and 9-inch touchscreen prototypes and intended to determine their usability.

The purpose of this study is to measure the adoptability of the newly developed 5.7-inch and 9-inch touchscreen prototypes among users who suffer high lesions from spinal cord injuries through usability evaluations at the introductory phase of device utilisation. In addition, this study is the first step of a series of user-centred validation studies. The objectives of this study are as follows:

- to identify the physical limitation of CSI computer users and select the appropriate subjects based on the set-up criteria;
- to formulate usability evaluations and install the instruments;
- to generate the contextual survey and interviews;
- to collect and analyse data;
- to draw conclusions.

5.2.2 Method

Cook's HAAT model (1995) and Scherer's MPT model (1996) are presented for conceptual guidance in this study. To be precise, a better understanding of users' characteristics and their workplaces must be obtained prior to a technology selection and procurement. It can also be said that the user (i.e. persons with cervical spinal cord injury) was the heart of this validation study. On the other hand, the usability of an input device which was mentioned in the above section is the key to sway device users from their choices of an assistive technology. In terms of usability assessments (or assistive-technology-device outcome measures), both in the ISO standard 9241-11(1998) and Fuhrer (2003) designated three principles – 'effectiveness', 'efficiency' and 'satisfaction' – to determine the level of usability achieved. 'Effectiveness' involves accuracy and completeness of the specific goals achieved by users; 'efficiency' can be expected as resources regarding the accuracy and completeness with which users achieve specific tasks; and 'satisfaction' signifies comfort and positive attitudes gathered from users who use the device (ISO9241-11 1998). For that reason, a user-centred usability assessment involves concerns for accuracy and users' perspectives. This was conducted at the introductory phase for the use of the novel touchscreen devices.

Evaluative strategies, such as the single-case study, field experiments, observation and unstructured interviews, were applied in this study for collecting both scientific data (to access the accuracy rate) and people concern (to understand the users' characteristics and perspectives). Thus, the distinguishing characteristics of this study are firstly to retain the uniqueness of the individual subject and secondly to accomplish the experimental studies in the naturally occurring environments (i.e. the subjects' real-life workplaces). Each subject was given full information associated with the purpose, expected outcomes and procedure, in advance of consenting to participation and allowing photographs to be taken. As frequently noted, the users' positions are the core of a series of validation studies. The fourteen subjects who sustained cervical spinal cord injuries and who participated in the previous contextual survey (Section 4.2) again took part in this validation study. Description of the participants' characteristics associated with the criteria for selection, their range of motion, workplaces and arrangement, habitual practices follows in Section 5.2.2.1. Besides, a similar level of spinal lesion results people in dissimilar physical impairments and performs different function abilities, it stands to reason that every CSI subject activates an input device with a variety of operating modes. This study categorized the fourteen participants into three groups as follows:

- Group 1 participants operated both the 5.7-inch and 9-inch devices with their normal adopted assistive supports;
- Group 2, an assistive input pointer was provided to standardize the operational mode when users operated the touch screen input devices;
- Group 3 subjects completed tasks without any assistive technology support.

In the field of experimental work, the experiments, that aimed to assess the input accuracy during the first use of the novel touchscreen input devices, began with the device instructions on the use of the devices, that lasted approximately 45 minutes and included a demonstration by the researcher and practice by the subject. Subjects were asked to operate both the portable (5.7-inch) and desktop (9-inch) touchscreen input devices and measure the usability among the 14 CSI subjects. The instruments employed and the experimental procedure designed are detailed in Sections 5.2.2.2 and 5.2.2.3.

5.2.2.1 Subject Selection, Workplaces, and Habitual Practices

The subjects were selected from the Taiwan Assistive Technology and Vocational Rehabilitation Association (TATA) and the Association of Spinal Cord Injury Taipei (TPESCI). The 14 volunteers, aged from 25 to 51 years, participated in this evaluation procedure. The subjects all met the following criteria: (a) were diagnosed to have cervical spinal cord injuries; (b) had a stable medical status as indicated by the onset of spinal cord injury over a 6 month period; (c) without significant cognitive, visual, or hearing impairments; (d) having had computer working experience of at least one year post-injury. Identical problems, such as hand movement disorder, are the main difficulties for persons with cervical spinal cord injuries when they use computers. The 14 subjects operated a computer using different parts of their bodies (e.g. mouth, finger, wrist, etc) in a single key-in operation. It was noted, that all the subjects had participated in the previous observational survey in Section 4.2, and they joined in this study. Information on the 14 participants and their motor function of upper limbs are summarised in Table 5-1 and Table 5-2.

Table 5-1 Brief biographical summary of the 14 CSI subjects.

No.	GENDER	AGE IN 2004	TYPE OF INJURY	CAUSE OF SCI	TIME AFTER ONSET	OTHER DISABILITY
01	Female	45	C 5.6.7	Fall	9 -10 yrs	None
03	Male	45	C 3. 4	CP	20 -21 yrs	Cerebral Palsy
04	Male	36	C 5	Fall	11 -12 yrs	None
05	Male	43	C 3.4.5	Car accident	12 -13 yrs	None
06	Male	31	C 5. 6	Fall	16 -17 yrs	None
07	Male	34	C 5. 6	Car accident	10 -11 yrs	None
09	Male	38	C 5. 6	Motorcycle accident	14 yrs + 3 m.	None
10	Male	51	C 6.7	Fall	17 -18 yrs	None
11	Male	33	C 5. 6	Motorcycle accident	12 -13 yrs	None
12	Female	41	C 3. 4.5	Failed operations	18 yrs + 6 m.	None
13	Male	48	C 4.5	Fall	24 -25 yrs	None
14	Male	29	C 4	Motorcycle accident	6 - 7 yrs	None
15	Male	25	C 4. 5	Car accident	8 yrs + 8 m.	None
20	Male	39	C 4. 5	Sport injury	11 yrs+ 2 m.	None

Table 5-2 The range of motion performed by the 14 CSI subjects.

	RANGE of MOTION																
	LEFT HAND								RIGHT HAND								
	Elbow	Forearm	wrist	Thumb	Index finger	Middle finger	Third finger	Little finger	Elbow	Forearm	wrist	Thumb	Index finger	Middle finger	Third finger	Little finger	CATEGORY
01	◐	◐	◐	○	○	○	○	○	◐	◐	◐	◐	◐	○	○	◐	C 5.6.7
03	◐	◐	◐	○	○	◐	○	○	◐	◐	◐	○	◐	○	○	○	C 3. 4
04	◐	◐	◐	○	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 5
05	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	C 3.4.5
06	◐	◐	◐	○	◐	○	○	○	◐	◐	◐	○	○	○	○	◐	C 5. 6
07	◐	◐	◐	○	○	◐	○	○	◐	◐	◐	○	◐	○	○	○	C 5. 6
09	◐	◐	◐	○	◐	○	○	◐	◐	◐	◐	○	○	○	○	○	C 5. 6
10	○	○	○	○	○	○	○	○	◐	◐	◐	○	◐	○	○	○	C 6.7
11	◐	◐	◐	◐	○	◐	○	○	◐	◐	◐	○	○	○	○	○	C 5. 6
12	◐	◐	◐	○	○	○	○	◐	◐	◐	◐	○	○	○	○	◐	C 3. 4.5
13	◐	◐	◐	○	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 4.5
14	◐	◐	◐	○	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 4
15	◐	◐	◐	○	○	○	○	○	◐	◐	◐	○	◐	◐	○	○	C 4. 5
20	○	○	○	○	○	○	○	○	◐	◐	◐	○	○	○	○	○	C 4. 5

○ None or minimal movement;
◐ Partial movement;
● Normal or near normal movement.

Prior to the experimental studies, the researcher visited the 14 CSI subjects, firstly to obtain their consent to participate, and secondly to observe their actual situation when using a computer. Most of the subjects maintained their operating modes as observed in 2003 as described in Section 4.2 except Subject 05 and Subject 20. In Appendix E and Appendix F, the set-up and arrangement in their workplaces, together with their normal operating modes are described. The two subjects who took part in the earlier survey have changed either their workplace or normal practice. Subject 05 used to perform his computer activities seating in a manual wheelchair. Because of the onset of a decubitus ulcer, which involves slow recovery, Subject 5 switched his workplace to the bed from early 2004. As a result, the keyboard and his input mouthstick were moved to his bed and held by a specially designed metal frame in front of the subject. In addition, the monitor that was raised by the metal frame was placed next to his bed. Subject 20, who attended a one-year computer vocational training programme and used to operate a computer in the computer laboratory of the vocational centre, returned home at the end of 2003. After completing the training programme, the subject works at home but has maintained his normal operating mode.

The 14 subjects were divided into 3 groups according to their normal operating modes, as detailed in Appendix F. In Group 1, the subjects were expected to operate both 5.7-inch and 9-inch touchscreen devices with their normal adopted assistive supports (e.g. the mouthstick or finger / wrist and finger orthosis). This involved Subjects 05, 04, 10 and 20. In Group 2, the touchscreen alternative inputs were operated by an input pointer by Subjects 01, 06, 07, 09, 11, 13, 14 and 15. The normal operating modes of Subject 01 and 14 were to wear a handstrip to hold an assisted input pen tightly. Subjects 06, 07, 09, 11, 13 and 15, who used to access a computer with a single finger and who are able to grasp a pen, were provided an input pointer when using a touchscreen input device. Besides, Subjects 03 and 12, who could not grip a pointer and only key-in data by a single finger without any assistive support, belonged to Group 3.

5.2.2.2 Touchscreen Input Prototypes

Two integrated diagonal touch screen input prototypes, the 5.7-inch and 9-inch devices, were used in this study, as detailed in Section 3.4.2. In addition, an assisted input pen was provided for Group 2 participants who were able to grasp a pen. In order to facilitate the touchscreen-device utilisation, the placing of a skidproof cover on one end allows the user to stabilise their operations.

Based on the proposed research methodology, the research environments were arranged at the subjects' real-life workplaces, either their homes or offices. The set-up of the touchscreen input devices needed to follow the subject's original workplace arrangement and their preference. However, as earlier described, each subject has his/her own operating mode, practice and preferences in computer use, that crucially influences the device set-up and working place arrangements. For instance, the conventional keyboard, that belonged to Subject 03, was usually placed on a keyboard tray. However, because the subject's keyboard tray was not large enough to accommodate the 9-inch touchscreen prototype, the device needed to be set up on Subject 03's thigh and tilted against the computer desk (Figure 5-2). Subject 05 transferred his computer working place to his bed. The subject's keyboard was fixed on to a metal frame on his bed, and the mouthstick could rest on the specially designed mouthstick rest on the frame. It stands to reason therefore that the novel touchscreen input devices should be installed on the subject's special frame and taped for stability (Figure 5-3). Also, according to some subjects' normal practice (Subjects 06, 13 and 14), performed keyboard operations on their thighs, therefore, the set-up of the touchscreen input devices followed their habitual arrangements of an input device (Figure 5-4). Moreover, due to the height of the subjects' wheelchairs (e.g. Subjects 11 and 12), their operating of the touchscreen prototypes would lead to awkward wrist, arm and shoulder postures to the subjects if the touchscreen devices were set on the desk (Figure 5-5). More importantly, in order to enable the subjects to use the touchscreen prototypes, the devices might require to be raised by some rigid material to avoid light reflection caused by the flat-panel and adjust the angle for fitting the users' line-of-sight. Following the normal practices and preferences of the CSI subjects, the instruments were set-up and adjusted as described in Appendix G.

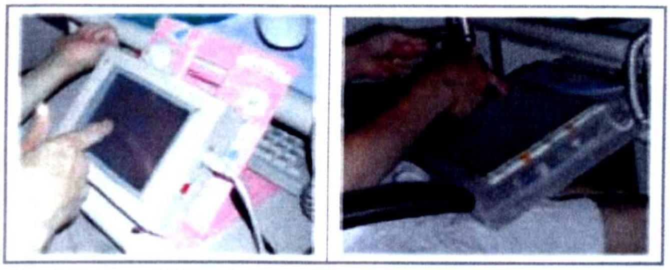


Figure 5-2 The device set-up and adjustment of Subject 03.

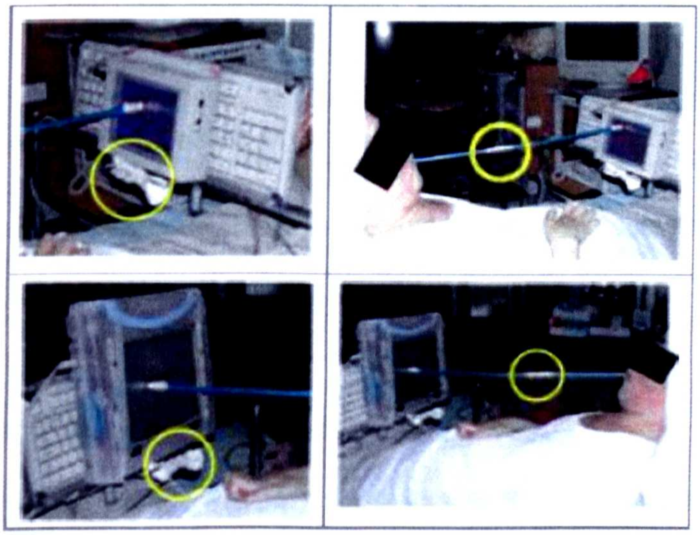


Figure 5-3 The touchscreen prototypes are installed on Subject 05's special frame.

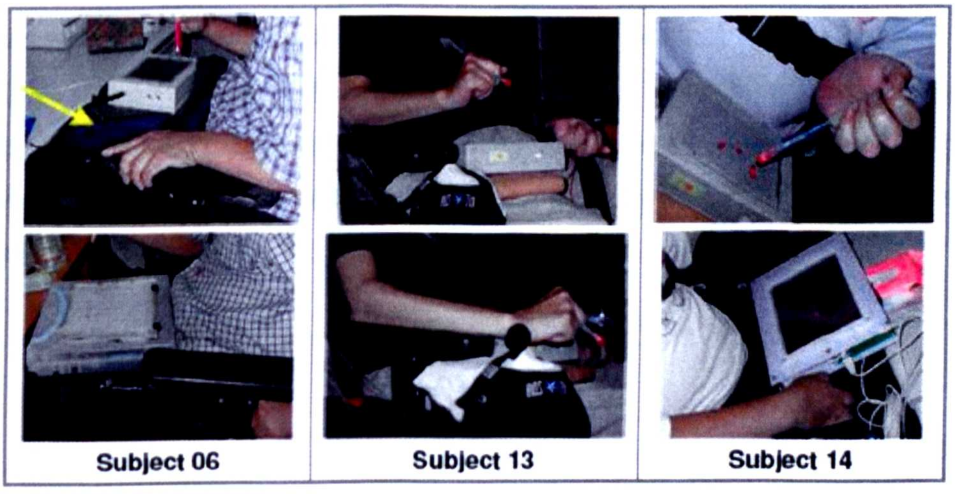


Figure 5-4 The devices were put on the subjects' thighs.

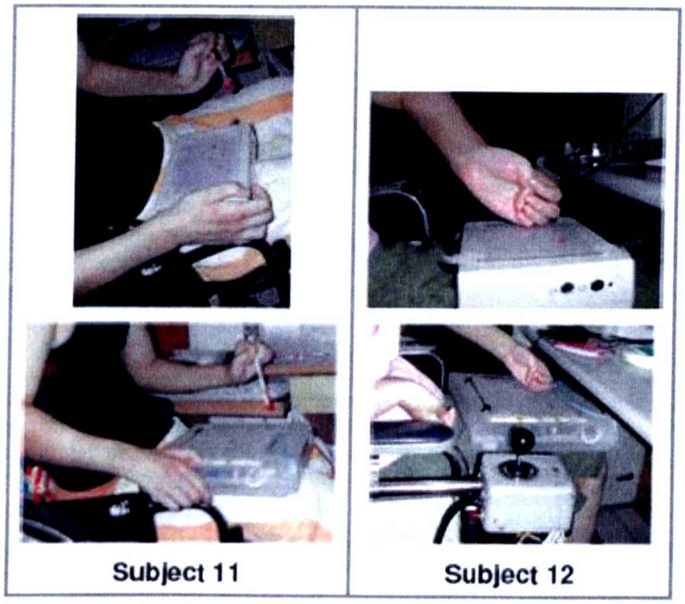


Figure 5-5 The device set-ups and adjustments of Subjects 11 and 12.

5.2.2.3 Standard Operating Procedure

A standard operating procedure was provided to lead to standardised procedures and the repetitive research activities. An instruction period lasted approximately one hour, including demonstration by the researcher and spontaneous practice by the subject, was carried out prior the experimental study. The design of usability evaluation at the introductory phase was comprised of two parts. In the first part (Assessment 1), the subjects were asked to key in the requested data into Microsoft Word with the 5.7-inch prototype. In parallel, the subjects had to complete the task with a 9-inch touchscreen device in the second part (Assessment 2). Any input mistakes were ignored during the experimental evaluation. The standard operating procedure of this usability assessment is described in Figure 5-6.

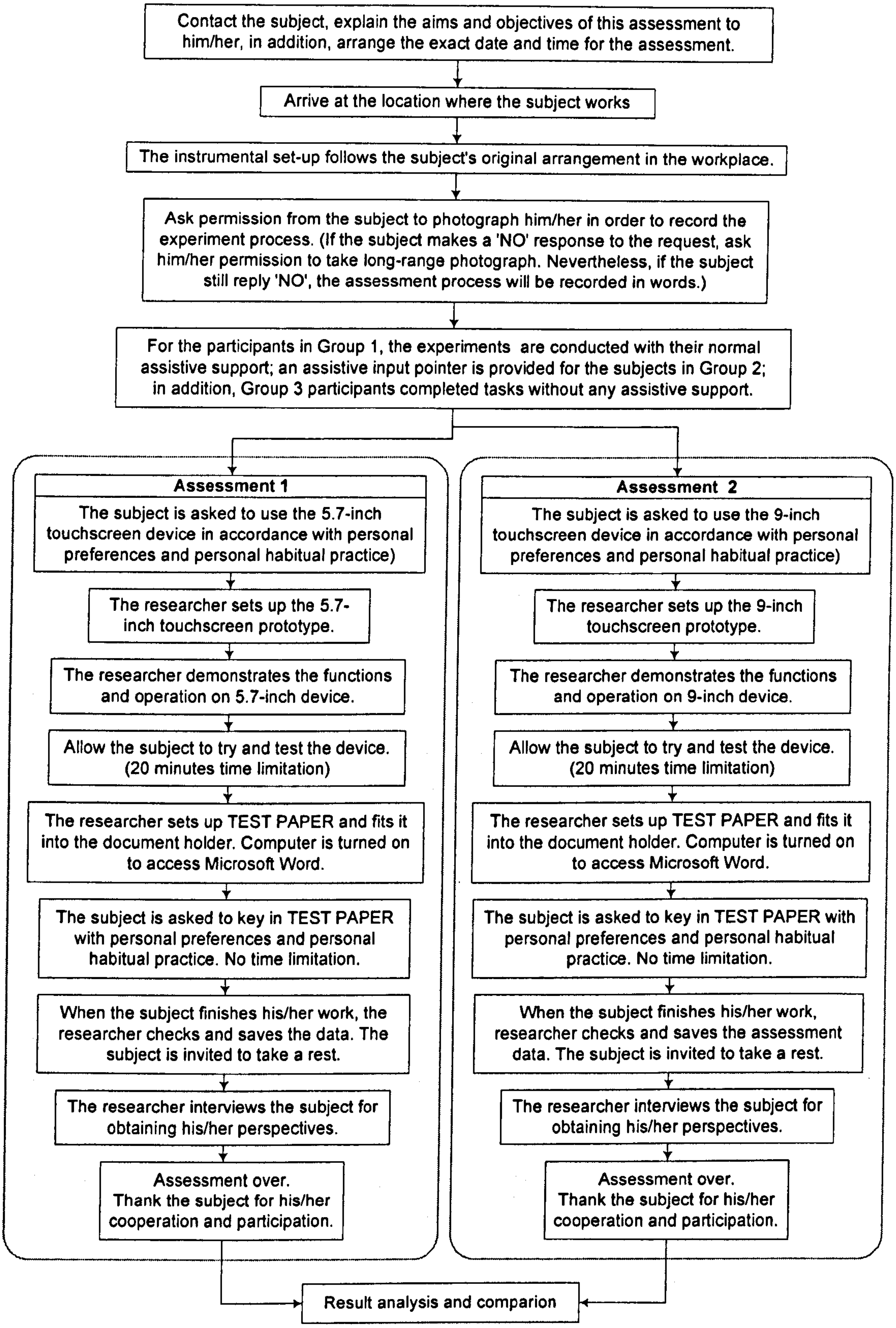


Figure 5-6 Standard operating procedure of usability assessments.

5.2.3 Results and Analysis

This section, describes the quantitative data, presented numerically and subjected to statistical analysis, and the qualitative data that deals in words and sets out the concerns of the individual users.

It was previously noted that each person with spinal cord injury has his/her unique and dissimilar functional abilities and motion limitations. Therefore, a variety of operating modes are performed among those CSI users when accessing a computer. Because of this, this study placed the 14 CSI subjects into three groups as (a) Group 1, participants operated the touchscreen input devices with their normal adopted assistive supports; (b) Group 2, an assistive input pointer (i.e. an input pen) was provided to standardise the operation mode when users operated the touchscreen devices; (c) Group 3 participants completed tasks without any assistive technology support. The overall results are given in Table 5-3 show the accuracy outcomes among the 14 CSI subject from their initial use of both the 5.7-inch and 9-inch touchscreen input devices. The range of accuracy of the 5.7-inch device was from 10.34% (Subject 01 in Group 1) to 98.28% (Subject 06 in Group 2), for the 9-inch device was between 56.90% (Subject 03 in Group 3) and 100% (Subject 10 of Group 1; Subjects 06, 09 and 15 in Group 2). The experimental outcomes of the three groups are described in Sections 5.2.3.1 (Group 1), 5.2.3.2 (Group 2) and 5.2.3.3 (Group 3), and observational and interviewed results are described in 5.2.3.4.

5.2.3.1 Group 1: Subjects used their current adopted assistive supports

Figure 5-7 shows, firstly the two types of operating modes, the mouthstick and hand orthosis operation, which are currently adopted by Subjects 04, 05, 10, and 20 when operating both the 5.7-inch and 9-inch touchscreen devices; secondly, the comparative key-in outcomes. As noted earlier, participants with cervical spinal cord injuries have their unique functional limitations even if they have identical level of spinal lesions. Correspondingly, the experimental outcomes were influenced by the subjects' motion abilities. As Subject 05 had to stay in bed because of illness, he operated the touchscreen prototypes only by his mouth using a mouthstick, as shown in Figure 5-3 or seen in Appendix F and Appendix G. Due to his bedridden state and mouthstick practice, more attention needed to be paid to lessening keying strain caused by repetitive access and prolonged work. The 5.7-inch touchscreen device is designed to reduce the subject's repetitive keying fatigue when sliding a pointer across its smaller work surface. However, the lowest level of accuracy with the 5.7-inch device was obtained from Subject 05 at only 10.34%. In contrast, it can be seen that with the larger 9-inch device it was easier to target the keys on its stationary surface reducing errors; hence, his accuracy improved to 89.66% when using the 9-inch device. In addition to the experimental results, the unstable operation performed by this bedridden subject was found when accessing the touchscreen devices during the experimental process. As a result, it required an additional support of the mouthstick in order to improve the stability and efficiency when operating the touchscreen input devices. The other lower accuracy rate with the 5.7-inch device was achieved by Subject 04. Subject 04 accessed the touchscreen device only by his substitute fingers (i.e. the hand orthoses on both hands) as seen in Appendix F and Appendix G. The sizes of keys and surface of the 5.7-inch device are far smaller than his currently used conventional keyboard. It stands to reason that the subject performed a disappointing 22.41% accuracy on the 5.7-inch device operation. Unlike the 5.7-inch device, the key size on the 9-inch touchscreen is similar to the conventional keyboard; the QWERTY standard keyboard layout is preferred for those experienced computer users; then, the sliding and tapping operating mode is labour-saving. Consequently, an accuracy of 91.38% was achieved when Subject 04 operated with the 9-inch device. From the above results, this showed that the larger area of the computer keys provided by the 9-inch touchscreen device was better suited to Subjects 04 and 05.

As seen in Figure 5-7, in terms of input accuracy performance, Subject 10 achieved an 81.03 % accuracy rate on the 5.7-inch prototype and an optimum 100 % accuracy with the 9-inch touchscreen device. Similarly, Subject 20 achieved good results on both touchscreen devices – a 72.42 % on the 5.7-inch portable device and a 91.38 % on the 9-inch desktop prototype. Based on the experimental results at the first use of the touchscreen input devices, it can be said that the novel devices, including 5.7-inch and 9-inch prototypes, were well suited to Subjects 10 and 20.

Table 5-3 The comparative outcomes between 5.7-inch and 9-inch prototypes.

SUBJECT NO.	OPERATING MODE	5.7-INCH ACCURACY	9-INCH ACCURACY
01	Hand strip + Input pen	27.59%	82.76%
03	None	27.59%	56.90%
04	Wrist and finger orthosis	22.41%	91.38%
05	Monthstick	10.34%	89.66%
06	Input pen	98.28%	100.00%
07	Input pen	82.76%	94.83%
09	Input pen	84.48%	100.00%
10	Finger orthosis	81.03%	100.00%
11	Input pen	96.55%	91.38%
12	None	25.86%	67.24%
13	Input pen	46.55%	72.41%
14	Hand strip + Input pen	58.62%	82.76%
15	Input pen	94.83%	100.00%
20	Wrist and finger orthosis	72.41%	91.38%

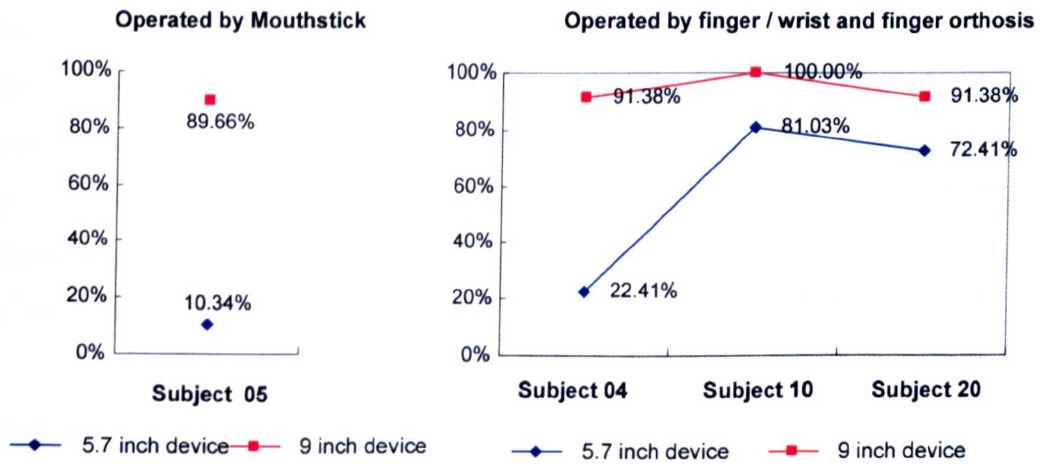


Figure 5-7 The accuracy rates performed by those subjects who operated the touchscreen prototypes with their adopted assistive supports (Group 1).

5.2.3.2 Group 2: Subject used the provided assisting input pointer

In Group 2, eight participants, Subjects 01, 06, 07, 09, 11, 13, 14, and 15, provided experimental outcomes for their initial use of the novel touchscreen integrated input devices, as shown in Figure 5-8. Excluding Subjects 01 and 14 whose computer habitual practices were to wear a handstrip to hold an input pen tightly as seen in Appendix F and Appendix G, the other group members (i.e. Subject 06, 07, 09, 11, 13, and 15) who were single finger operators were provided with an assisting input pen when activating the touchscreen alternative inputs in this study. Figure 5-8 shows most of the Group 2 participants achieved acceptable outcomes, except for Subject 01, 13, and 14 who presented the lower accuracy of 27.59 %, 46.55 %, and of 58.62 % respectively when using the 5.7-inch touchscreen device. On the other hand, the average accuracy outcomes ranged between 72.41 % to 100 % for all Group 2 participants when using the 9-inch touchscreen prototype. Accordingly, Subject 01, 13 and 14 did better with the larger 9-inch device (82.76 %, 72.41 % and 82.76 %) than the smaller 5.7-inch device (27.59 %, 46.55 %, and 58.62 %). This showed that first the three subjects had lower control of upper-limb function than other Group 2 members did; second, the key size on the 5.7-inch device seemed to be too small; third the subjects were impeded by their established practice and as the layout of 9-inch touchscreen was precisely similar to their normal input devices. These conclusions were to explain the incompatible outcomes between the two touchscreen devices, and to provide recommendations on longer time device utilisation and practice for the subjects. The subjects in Group 2, equipped with the assisting input pen, presented above-average outcomes in comparison with both Group1 and Group 3.

5.2.3.3 Group 3: Subject operated without any AT

According to the upper-limb function, the Group 3 participants, including Subjects 03 and 12, who can neither spread their hands nor grasp things and who used to an input device either with the single fingertip or with the joint of finger, accomplished tasks on the touchscreen devices without any assistive supports as like their habitual operating modes, as described in Appendix F and Appendix G. Figure 5-9 shows the outcomes gathered from Subjects 03 and 12. Compared with the outcomes of Group 1 and Group 2, the Group 3 subjects who operated the novel devices without assistive support presented inferior accuracy performance on both 5.7-inch and 9-inch touchscreen prototypes. For instance, the lowest results, such as Subject 03's 27.59 % and Subject 12's 25.86%, were shown at the their first use of 5.7-inch touchscreen device, whether the 9-inch device outcomes, improving the input accuracy of 56.90 % (Subject 03) and 67.24 % (Subject 12), still revealed below average performance compared the results of Group 1 and Group 2.

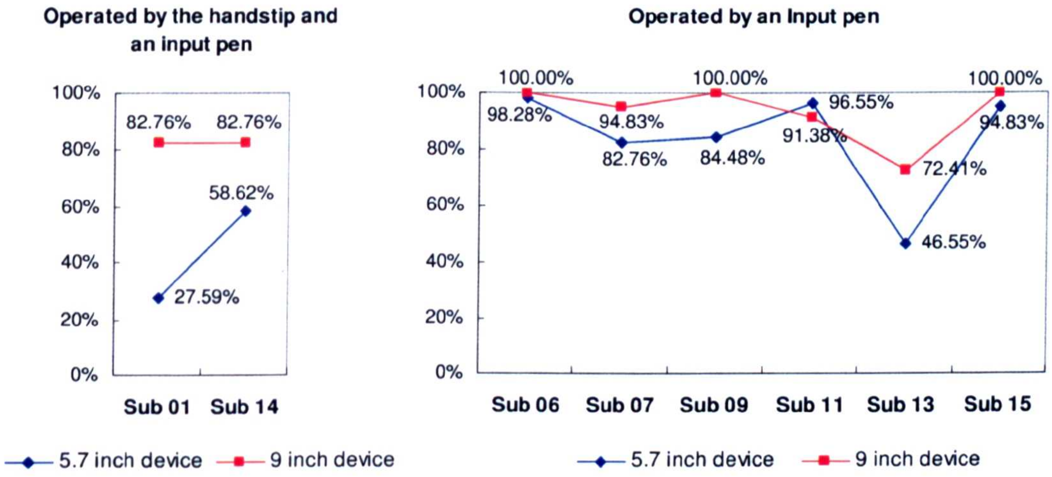


Figure 5-8 The accuracy rates performed by those subjects who operated the touchscreen prototypes with an input pen (Group 2).

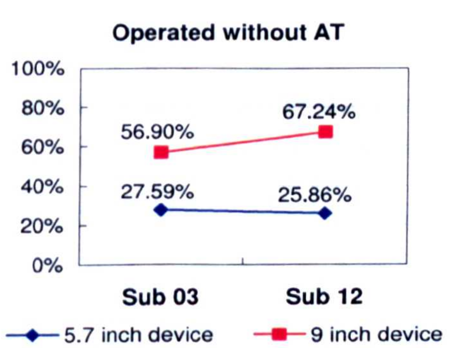


Figure 5-9 The accuracy rates performed by those subjects who operated the touchscreen prototypes without any assistive support (Group 3).

5.2.3.4 User Response

The previous sections conveyed the quantitative experimental outcomes of the introductory phase of the device. This section turns to a different stage of the evaluation process, to the users' perspectives. Appendix H highlights the subjects' perspectives on the use of the device, satisfaction and expectation. The user's satisfaction was expressed in terms of the perceived features and usefulness of the touchscreen input devices and the subjects' willingness to attempt further use and practice. Such benefits gained from the touchscreen device were firstly the user-friendly character, which allowed the users to operate the novel input device straightforwardly on initial use; secondly the brand-new operating mode – lightly sliding across or tapping on the stationary and smooth surface was labour-saving which diminished the repetitive operating strain; thirdly the integration of the keyboard and mouse functions, which brought advantages to those users who encountered difficulties in using either a keyboard or a mouse. The portable design of 5.7-inch input device was an applicable idea for the wheelchair users such as persons with spinal cord injuries. The 9-inch desktop device provided a conventional QWERTY keyboard layout was desired by those experienced computer users. Finally the embedded PDA function enhanced the attraction and value of the touchscreen devices. Ergonomic concerns were also expressed. For instance, the ability of the touchscreen holder, which could be set on the wheelchair and on the desk in order to improve the stability when operating the device. To match the users' viewing angle and to lessen the viewing distance between the device and its operator was considered to be of value by the users. An additional support, such as an input pen, was preferred by most of the participants and recommended when using the touchscreen input devices; in addition, the dimensional consideration was addressed. The key size on the 5.7-inch was seemed to be too small for some subjects due to the very limited hand function and unfamiliarisation with the novel touchscreen device. For a portable device, the thinner and lighter construction was also suggested for the 5.7-inch touchscreen device. In terms of further function improvements, the better mouse function, i.e. increasing of sensibility of dragging, dropping, and pointing tasks, was required by some graphic designers; the wireless installation could be more convenient especially for the portable device for the wheelchair operators; in addition to the PDA function, an electronic book was wanted. In Table 5-4 the users' perspectives of the newly developed touchscreen device are elaborated on the individual state.

Following the users' experiences of device utilisation at the introductory phase described in Appendix H and the criteria of SCI users' needs hierarchy, i.e. single key-in operation, easy to use, reduce input tiredness and accuracy as illustrated in Figure 4-14. Table 5-4 and Table 5-5 ranked the users' perspectives of both 5.7-inch and 9-inch touchscreen input devices among the 14 CSI subjects at their introductory phase of device use. However, the speed factor was not discussed in this section of the introductory phase. According to the information in Table 5-4 and Table 5-5, both the 5.7-inch and the 9-inch touchscreen devices were operated by the mode of single key-in which is the specific character of individuals with cervical spinal cord injuries as mentioned in Chapter 4. These were easier to use and reduced operating tiredness more than their current input devices used by the 14 CSI subjects. In terms of input accuracy, the ranking scale used was from Good, to Average, to Poor. The scale of Good indicated that the accuracy outcomes ranged from 80% to 100%; the average indicated experimental results in the range from 50% to 79%; and Poor signified a result under 50%. The 5.7-inch portable touchscreen device was new to every participant. Because of the varied levels of functional limitations of the participants and their normal practices, some subjects, especially those who had very limited upper limb motion ability, could not perform an acceptable input accuracy at the initial use of the novel 5.7-inch device. Because of this, the keys of the 5.7-inch device were seen to be too small for those users with very severe physical impairments, i.e. Subjects 01, 03, 04, 05, 12 and 13. In addition, for long term adaptation, practice was recommended when using the smaller touchscreen device. Conversely, all subjects showed obvious improvements in input accuracy when operating the 9-inch touchscreen device, which was also novel to all the subjects but provided a larger area for the keys and possessed similar layout as the subjects' normal input device (i.e. conventional keyboards). It meant the 9-inch touchscreen device was more easily accepted than the smaller 5.7-inch device which needed to be operated differently to the subjects' normal practice. Suggestions for device improvements were also highlighted in Table 5-4 and Table 5-5, such as the inclusion of an assisting input pen, additional support for device set-up, etc.

In summary, positive feedback was gathered and a high level of acceptability was expressed from most of the CSI subjects in their initial use of the new touchscreen input devices, but clearly the 9-inch device was preferred.

Table 5-4 User's perspectives of 5.7-inch touchscreen prototype at the introductory phase.

NO.	5.7-INCH TOUCHSCREEN PROTOTYPE												COMMENTS
	Single key-in operation			Easy to use			Reduce input tiredness			Accuracy			
	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	
01	●				●		●					●	The inclusion of PDA function enhances its value.
03	●				●		●					●	Require an additional input support, such as an input pointer.
04	●				●		●					●	The eyestrain caused by viewing the flat panel for a prolonged time.
05	●					●		●				●	The computer keys seemed to be too small and require more concentration when opening it.
06	●			●			●			●			To operate with an input pen is easily accepted.
07	●			●			●			●			The operating method is similar to the conventional PDA and a good proper idea for wheelchair users.
09	●				●		●			●			The keys are too small for the viewing distance, but the idea of PDA enhances attractions.
10	●			●			●			●			Longer-term practices is required for the familiarisation with the prototype.
11	●			●			●			●			To operate with an input pen is more effective; Further ergonomic design requires more attention.
12	●					●		●				●	Because of her very limited finger force, the device cannot function properly and required repetitive attempts.
13	●			●			●					●	It can be suitable for the wheelchair users, but requires some additional improvements.
14	●			●			●				●		The subject believes that he can achieve familiarisation with the device in the near future.
15	●			●			●			●			The integration of keyboard and mouse and PDA function can benefit the single key-in operators.
20	●				●		●				●		The key size seems to be too small for the subject.

★The range of accuracy: **Good** indicates a result ranged from 80% to 100%; **Average** indicates a result ranged from 50% to 79%; **Poor** indicates a result under 50%.

Table 5-5 User's perspectives of 9-inch touchscreen prototype at the introductory phase.

	9-INCH TOUCHSCREEN PROTOTYPE												
	Single key-in operation			Easy to use			Reduce input tiredness			Accuracy			
NO.	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	COMMENTS
01	●			●			●			●			The inclusion of PDA function enhances its value
03	●			●			●				●		The QWERTY keyboard layout is preferred by the subject.
04	●			●			●			●			The combining of keyboard and mouse functions in a device brings advantages.
05	●			●			●			●			The requirement of longer-term trial use is proposed.
06	●			●			●			●			A great potential for replacing the existing conventional inputs.
07	●			●			●			●			A great potential for replacing the existing conventional inputs.
09	●			●			●			●			It is easier to operate than the user's mouse and on-screen keyboard.
10	●			●			●			●			Longer-term practices is required for the familiarisation with the prototype.
11	●			●			●			●			To operate with an input pen is more effective; further ergonomic design requires more attention.
12	●			●			●				●		Unlike other input devices, the touch screen can allow the subject to operate at the first attempt.
13	●			●			●				●		It can be easier to use than the conventional inputs; some design improvements are required.
14	●			●			●			●			Unlike other input devices, the touch screen can allow the subject to use at the first attempt.
15	●			●			●			●			If the touchscreen were provided for those computer beginners, it would reduce time spent on adaptation.
20	●			●			●			●			The touchscreen can more easily work with the subject's assistive device than the conventional inputs.

★The range of accuracy: **Good** indicates a result ranged from 80% to 100%; **Average** indicates a result ranged from 50% to 79%; **Poor** indicates a result under 50%.

5.2.4 Summary of User-Centred Validation at Introductory Phase

The initial validation study focused on the usability of the novel touchscreen alternative devices among those users with cervical spinal cord injuries was revealed in this section via the scientific- and user-based outcome measurements. The novel validation method, which focused on the experimental outcomes and users' perspectives, was used to validate the appropriateness of the newly developed touchscreen prototypes in the introductory phase of device use. Positive feedback was obtained from most of the subjects with cervical spinal cord injuries. In terms of experimental results, most of CSI subjects established their desk work-zone and were accustomed to operating the conventional keyboards. However, all subjects performed better outcomes performance on the 9-inch desktop prototype which performed similar key size and layout as the conventional keyboards than on the 5.7- inch portable device which was far smaller and displayed a ABC layout on the interface. The 9-inch touchscreen device was more acceptable than the smaller 5.7-inch device, based on the users' responses. Even so, there is no doubt that both touchscreen alternative inputs allowed every CSI participant to activate them during their first use, including some subjects, who deemed themselves a slow learner.

As mentioned earlier, the user is the nucleus of the development of an assistive technology. With concerns of users' perspectives, the actual needs of a user need to be investigated. Based on the users' perspectives in this study, for people with severe physical disabilities, being able to use an input device is a top priority when they access computers. There is no 'correct' computer input device that can satisfy each operator and match every individual user's needs. As indicated above, most disabled users build their habitual practice and preference by hundreds of attempts, adjustments, and failures. Following the research outcomes, it is found that the majority of users with spinal cord injuries must adapt themselves to a new input device. That is, the devices come first rather than the disabled users when meeting difficulties in accessing a device. Because of this, an appropriate input device which offers the user improved quality and usefulness is likely to minimize the frustrations and lessen the length of time being taken on adaptation and practice. In this study, the brand-new touchscreen operating mode and the device functions were positively accepted by most of CSI subjects in their first use. Likewise, the touchscreen prototypes were easier to use than the conventional input devices and considered as an ideal and practical solution for those users who have partial or limited upper-limb function performance.

5.3 Study D: User-Centred Validation on Shorter-Term Use and Training Effects

Fuhrer (2003) assumed that the use of an assistive device and measures of the outcomes should be reviewed in sequence. The preceding section, Study C, concentrated on measuring the usability of the novel 5.7-inch and 9-inch touchscreen prototype among those users with cervical spinal cord injuries, at the introductory stage. There were the methodological (the mixing of quantitative and qualitative approaches) and theoretical issues (the user-centred nature and the principal conceptual models) surrounding the complex validation studies. Consideration needed to be given to the practicalities of the device utilisation among real subjects in their real-life situations. Following the initial study of measuring usability outcomes at the introductory phase (Section 5.2), the new research methodology of validating an assistive technology, involving both scientific demonstration and user-based response, was again employed in this study.

As shown in Section 5.2, the novel touchscreen input devices was acknowledged and considered to be an effective solution for those users with severe upper-limb impairments from the experimental evidence (i.e. the accuracy performance) and user perspectives (i.e. the 14 subjects who sustained cervical spinal cord injuries and who had computer work experience of at least one year, post-injury). Although the former study showed that a high level of acceptability was expressed by the experienced computer users with high level of spinal lesions at their initial attempt of the new touchscreen prototypes, some new research issues were pointed out which required further discussion, such as the application to the users who have no or little computer experience and the impact of training effects. Hence, the next step subsequent to the introductory use and outcomes entailed an emphasis on measuring usability of this specific input device during shorter term use and training, among beginners to computer use.

Scherer (2000d) pointed out that a trial period and training with assistive devices in the actual settings are required at the technology selection stage. Research works such as Lau and Oleary (1993) and Fagarasanu et al. (2005), indicated a relative short-period training session enables the users to improve performing effectiveness and increase the acceptance of new alternative input devices. Lau and Oleary (1993) compared the effects of short-term training on the performing effectiveness (input speed, accuracy, and level of perceive exertion) on three alternative input devices (Tongue Touch Keypad, HeadMaster, and the mouthstick) on four participants, which included two with spinal cord injuries and two with muscular dystrophy. Further, Fagarasanu et al. (2005) showed the accomplishment of short-period training on three different keyboards (the conventional keyboard, Maltron E-type and Goldtouch Adjustable Ergonomic Keyboard) on two groups (20 trained and 10 untrained). Eight-hours of training improved the typing performance (typing speed and error rate) and diminished overall applied force on the alternative input devices. Following the results, with the training of device use, the alternative input devices had the potential to replace the widespread conventional keyboard.

As frequently emphasized, a user is the true kernel for assistive device outcome measures. As demonstrated in Section 5.2, the research outcomes associated with the experimental data and user responses were inevitably affected by the device users' normal practices and experiences. The 14 CSI participants in the earlier study had performed computer activities daily for more than one year. It stands to reason that, with their previous training and experience of computer operation, they would perhaps have psychological barriers to the initial use of a new input device. Furthermore, experienced users would be positively influenced to select an assistive device similar to their previous experience. For example, in Section 5.2, the input performance of 9-inch touchscreen device, which had a similar key size and layout to the users' normal practice with the conventional keyboards and which matched the subjects' usual activities (i.e. home-/office-based desktop computer works), revealed a higher performance and acceptability than the smaller and portable 5.7-inch device from these experienced computer users. The results also indicated that all of the 14 CSI subjects used to perform their computer activities with the desktop-based input devices. In addition, some subjects were not able to successfully operate the smaller 5.7-inch touchscreen prototype, at the introductory phase, because of their very limited upper-limb motion. From this point of view, in order to ensure an assistive device is more widely applicable to a user, it should first consider the user characteristics and previous device-use experiences and second match their demands to support their normal activities and workplaces.

This study assesses whether the short-period training has an effect on typing performance (i.e. input accuracy and speed) and device acceptance on the users who have little or no experience in computer access, for the novel touchscreen input device. More importantly, only the 9-inch desktop touchscreen device was provided in accordance with the participant's preferences indicated in Section 5.2. This study aims to investigate the improvements in usability when involving CSI individuals with the touchscreen alternative input prototype during a short-term training programme. The steps of this evaluation assessment are as follows.

- To establish the subject criteria and select subjects who can fit the criteria;
- To document the experimental procedure and conduct the assessments;
- To analyse data and draw up conclusions.

5.3.1 Method

A key issue here concerns an intensive two-week training embedded into the short-term phase of the touchscreen device's use. Accordingly, the device user, assistive device, and the training programme were decisive factors in the measurement of outcomes.

Two subjects with cervical spinal cord injuries volunteered for a two-week training course. Both subjects did not use a computer regularly and performed their desktop computer activities only in the office. The 'user' is always emphasised as the core of this type of evaluation studies. When an assistive device is selected, it often requires other changes and adjustments in the settings in which a technology is actually used in order to match users' needs. Due to the nature of the intensive training programme and the users' work routine and usual activities, the subjects' office was used as the experimental setting. The 9-inch touchscreen prototype was selected in this study. An intensive training programme was the key event in the short term phase of touchscreen device use, which required the researcher's guidance and instruction, involving a 20-minute practice on each training day and repeated assessments.

Data collection methods and research techniques were applied similarly to the earlier study (Section 5.2). These measured device outcomes, with 14 CSI subjects, involved single-case study, field experiments, observation and unstructured interviews. The researcher not only worked within the conventional quantitative method (i.e. the experimentation) which standardises measurements and was designed for gathering objective factual data that are accountable to statistical analysis, but also harmonised with qualitative techniques (i.e. observation and unstructured interview), which were used to obtain the subjective perspectives and experiences of participants in the studies. The subjects' descriptive information, the adopted instruments, the training programme and experimental procedure will be discussed in detail in later sections.

5.3.1.1 Subjects

The Association of Spinal Cord Injury, Taipei, Taiwan (TPESCI) provided assistance in enlisting two subjects for this study. The participants (Subject 21 and Subject 22) met the screening criteria, which were (a) diagnosed with cervical spinal cord injuries; (b) had a stable medical status as indicated by the onset of SCI over a 6 month period; (c) had sufficient physical tolerance for sitting upright in a wheelchair for more than 1 hour; (d) had no significant cognitive, visual, or hearing impairments. In addition, the subjects gave consent for participation prior the study. Their brief biographical details and their range of motion are given in Table 5-6 and Table 5-7.

Subject 21 was a 30-year-old man who is a C4 spinal cord injury sufferer with limited motor abilities on his upper extremities. The subject relied mostly on his wife as his personal assistant. Furthermore, he used a powered wheelchair, which alone gave him control over much of the mobility he had lost in a motorcycling accident. As a high-level tetraplegic, he had less voluntary control over the movements of his shoulders or arms. His shoulders were able to perform certain movements and his elbows were able to flex. In terms of computer use, Subject 21 had no computer use experience prior to his spinal cord injury and attempted to activate a computer at the time of the onset of SCI. In addition, the subject required help from others before accessing a computer, e.g. pressing the power button to start a computer and the change of keyboard position from the desk to his thigh. However, his physical functional limitations resulting from spinal cord injury, led to great disappointment and failures in activating conventional input devices. The unfortunate experiences minimised his desire for computer access and resulted in his lack of familiarity with computer use.

Subject 22 was a 32-year-old man with a C5-6 level spinal cord injury resulting from a sports injury. He used a powered wheelchair both indoors and outdoors. With the use of an assistive device, unlike Subject 21, he could ultimately be less dependent on others for many of his activities. His two shoulders, elbows, and wrists were able to execute most functional movements, but his hands had limited motor abilities. In parallel, he also had difficulties in computer operation. At the beginning, to operate a computer took a considerable time and much practice to press a single key on a keyboard and a button on a mouse. His attendance at vocational training developed the skills and improved his confidence with computer. In addition, the subject performed the usual computer activities, such as internet and game playing, in the office. Once in the office, his desk did not allow his wheelchair to slide under is so that his thigh became his desk where the keyboard and mouse were put and used. Even now he acknowledged that there remains a great deal of physical and emotional challenges in performing computer activities.

Table 5-6 Brief biographical summary of both subjects.

	ACQUIRED SPINAL CORED INJURIES IN ADULTHOOD	
	Subject 21	**Subject 22**
TYPE OF INJURY	C4 level SCI at age 22 from a motorcycle accident	C5-6 level SCI at age 15 from a sport injury
GENDER	Male	Male
AGE IN 2005	30 (7+ yrs post-injury)	32 (16+ yrs post-injury)
DEVICE USED	Powered wheelchair	Powered wheelchair
LIVING STATUS	Apartment with family	Apartment with his mother
WORK STATUS	Counsellor for TPESCI	Former President of TPESCI; Counsellor for TPESCI.

Table 5-7 Range of motion between the subjects.

	RANGE of MOTION																
	LEFT HAND								RIGHT HAND								
NO.	Elbow	Forearm	wrist	Thumb	Index finger	Middle finger	Ring finger	Little finger	Elbow	Forearm	wrist	Thumb	Index finger	Middle finger	Ring finger	Little finger	CATEGORY
21	◐	◐	◐	○	○	○	○	◐	◐	◐	◐	○	○	○	○	○	C4
22	◐	◐	◐	○	◐	○	○	○	◐	◐	◐	○	○	○	○	◐	C5. 6

○ No or minimal contraction or movement
◐ Partial movement
● Normal or near normal movement

5.3.1.2 Technology and Environment

According to the subjects' usual activities and preferences, their offices were selected as the experimental place in which the two-week training programme was conducted. The place was a serious work area and included 8 desktop computers, 2 LaserJet printers and 8 conventional office desks. In order to be accessible to people in wheelchairs, there were flat floors without stairs. However, some users' wheelchairs could not pull up to the office desk, including Subject 21 and Subject 22. Thus the subjects' wheelchairs were their desk chairs and their thighs became the desk where a keyboard and/or a mouse were placed and operated. When the touchscreen input device was added to the workplace, some changes were required but mainly followed the original set-ups and arrangements.

In addition to the 9-inch desktop touchscreen input device, detailed in Section 3.4.2, No. 1 in Figure 5-10, the hardware, including a desktop computer and monitor (No. 2), and an additional input pen (No. 3), were required. In order to assess the typing performance during the short-period training, the software, 'TypingMaster Pro' (2006), was selected. Examples from the software are shown in Figure 5-11. 'TypingMaster Pro' was developed by TypingMaster in Finland, and used by hundreds of schools and companies worldwide. This software is a reliable and effective programme for typing training and testing for both organisational customers and home users. In addition, it is a leading product in its category. TypingMaster Pro typing trainer is available in nine languages, including English, and is associated with versatile features and user-friendly design. It was used in this study for evaluating the subjects' typing performance (i.e. accuracy and speed) during the short-period training.

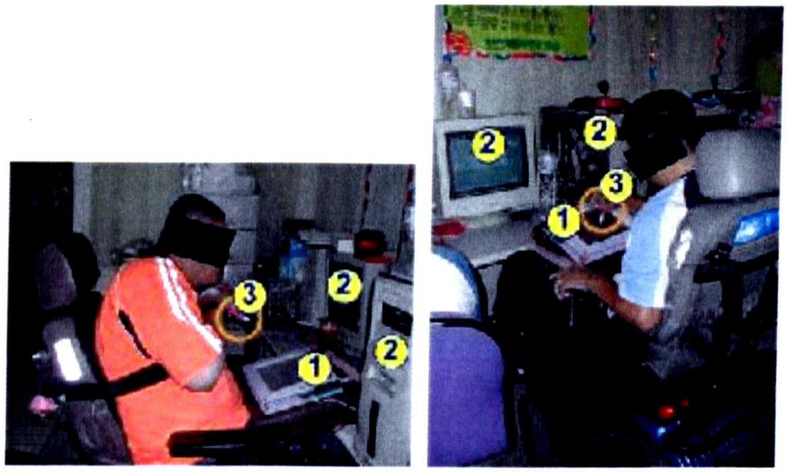


Figure 5-10 The arrangement of instruments and environment for Subject 01 (the left-hand side) and Subject 02 (the right-hand side).

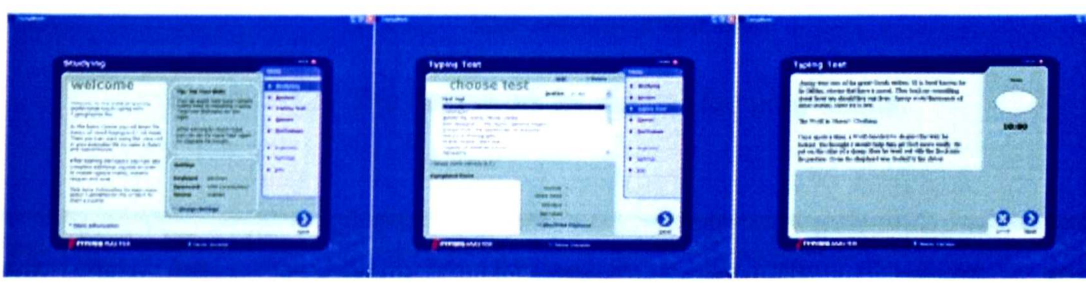


Figure 5-11 Interfaces of "TypingMaster Pro".

5.3.1.3 Short-Period Training Programme

At this stage of usability evaluation, the short-period training was designed to examine the effects of the touch screen input device on typing performance and satisfaction by the two CSI subjects. The 'TypingMaster Pro' programme was employed in order to provide standardise exercises during the subjects' keyboarding training; the duration of each exercise was 20 minutes per training day. In addition, this training programme gathered typing accuracy and speed progress data and further analysed these data. Following the framework shown in Figure 5-12, the first day's results, derived from the subjects, were considered as the initial training outcomes and as the baseline data as the initial test results; the sixth training session's results were considered the interim outcome of the two-week training period; the last test was conducted in the eleventh typing session. In addition to the framework for this training programme drawn up in Figure 5-12, the timetable, shown in Figure 5-13, indicates the fixed schedule of this work.

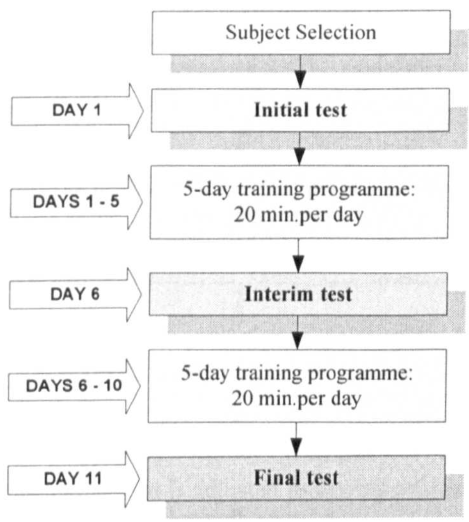


Figure 5-12 The framework for the training programme.

Week 1 & 2	Day 1	Day 2	Day 3	Day 4	Day 5			Day 6	Day 7	Day 8	Day 9	Day 10	Final
	Mon.	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
	2 PM	2 PM	2 PM	2 PM	2 PM			2 PM	2 PM	2 PM	2 PM	2 PM	2 PM
Subject 01	initial test							interim test					final test
	20 min. training	20 min. training	20 min. training	20 min. training	20 min. training			20 min. training	20 min. training	20 min. training	20 min. training	20 min. training	Interview
Week 3 & 4	Day 1	Day 2	Day 3	Day 4	Day 5			Day 6	Day 7	Day 8	Day 9	Day 10	Final
	Mon.	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
	2 PM	2 PM	2 PM	2 PM	2 PM			2 PM	2 PM	2 PM	2 PM	2 PM	2 PM
Subject 02	initial test							interim test					final test
	20 min. training	20 min. training	20 min. training	20 min. training	20 min. training			20 min. training	20 min. training	20 min. training	20 min. training	20 min. training	Interview

Figure 5-13 Timetable for the training programme.

5.3.1.4 Standard Operating Procedure of Experiments

The standard operating procedure, shown in Figure 5-14, was documented by a step-by-step process for the repetitive training activity to follow, in order to ensure that experiments were systematic, accurate and effective.

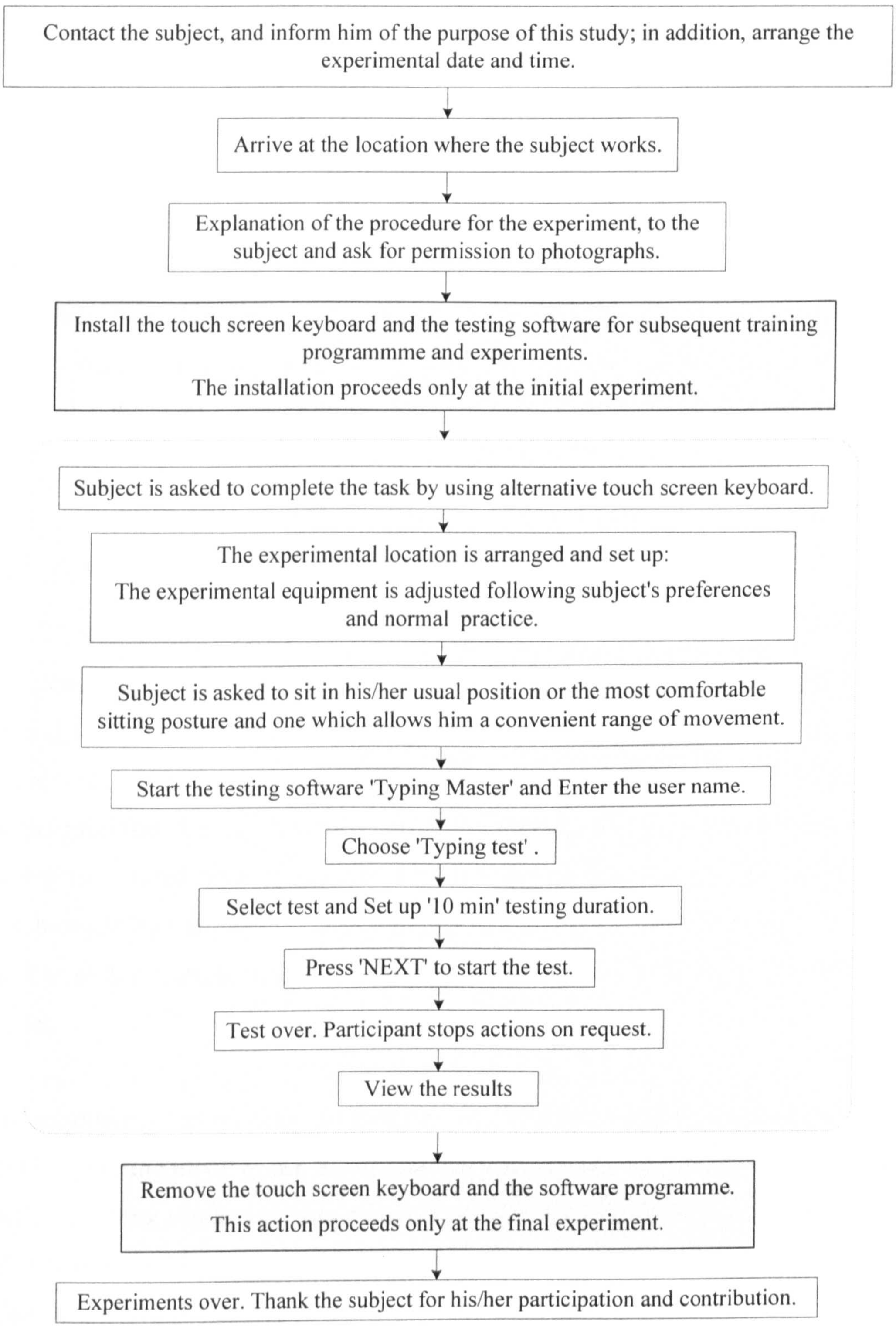


Figure 5-14 Standard operating procedure for the training activity.

5.3.2 Results and Analysis

As previously noted, when equipping a person with a new assistive device inevitably requires changes, modifications or additional assistance, in the places in which the user actually uses the device. The highest priority, prior to the training activity, should be assigned to setting up the touchscreen in the experimental place (i.e. the subject's workplace) in accordance with individual subject's normal practices and preferences. It must conform to the subject's preferred operating mode, satisfaction and comfort. Section 5.3.2.1 details the different operating modes between the two CSI subjects. The subjects' actual workplace and instrument set-ups are described in Section 5.3.2.2. Once the instruments were set up, the short-term training was carried out in order to gather the required data. Section 5.3.2.3 discusses the effects of the two-week training, including typing accuracy and speed with the 9-inch touchscreen device. More significantly, the user viewpoints on the touchscreen device are described in Section 5.3.2.4.

5.3.2.1 Operating Mode

Subject 21 was simply an outsider to the computer world. His first attempt of computer access came about after his spinal cord injury. The level of Subject 21's spinal cord injury and the fact, that he has very limited control over the movements of his shoulders, arms and both hands, meant that he could not operate a conventional input device freely. Respecting the fact that the computer use for the subject signified a continuous struggle to overcome a great deal of failures and disappointment, he gradually gave up the benefit brought by computer technology and turned himself into an outsider who was unfamiliar with a computer. As a result, Subject 21 had no fixed mode for operating a computer.

Before conducting the training programme, the researcher had to assist Subject 21 to adjust his operating mode to use the touchscreen prototype. Three steps for adjusting the subject's operating mode are shown in Figure 5-15. No.1 in Figure 5-15 represents the initial attempt for Subject 21. He operated the touchscreen device only with his left-handed metacarpophalangeal joint without any support. However, the left-handed operation was not acceptable. The touchscreen device could not function properly because of his very limited force from his left hand. The subject's hands cannot spread out; his left hand (i.e. the metacarpophalangeal joint of his left little finger) could not produce adequate force to activate the touchscreen device. In contrast to his left hand, the subject had less voluntary control over the movement of his right hand except for the wrist performance. The second step for adjustment is shown as No. 2 in Figure 5-15, Subject 21 accessed the prototype with his right hand, wearing a handstrip to hold the input pen correctly but problems were encountered. Firstly the head of the input pen did not allow this pointer to slide over the screen easily because of its smooth and slippery surface. Secondly, the unstable input operations performed by his right hand were discovered and required an additional support. For these reasons, the subject's left hand was used to support the right-handed operations. In addition, non-slip material was applied to the head of the input pen, as seen in the No.3 step in Figure 5-15.

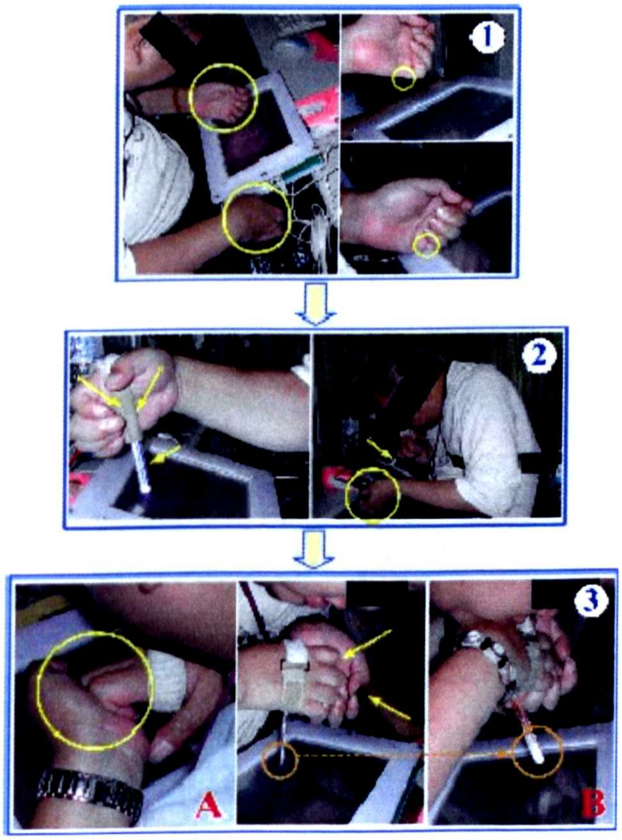


Figure 5-15 The process of adjusting operating mode for Subject 21.

The normal practice of Subject 22 was to activate a conventional keyboard with single index fingertip of his left hand. In addition, he operated the mouse buttons only with the metacarpophalangeal joint of his right-handed little finger. In terms of functional performance, the index finger's force on his left hand allowed the subject to press keys on a keyboard but cannot grasp. In the opposite way, his right hand was incapable of spreading out but was able to hold a pen. His right-handed function equipped Subject 22 to hold an input pen when using the touchscreen prototype. In order to support the operations, the input pen belonging to Subject 22 was applied a skidproof material near its point, as shown in No.1 of Figure 5-16. Unlike Subject 21 who wore a handstrip for holding the pen tightly, Subject 22 was unable to keep his right hand steady for holding the input pen because of the slippery surface of the input pen. Because of this, the input pen was substituted for a pen with a thicker, longer and non-slip surface as shown in No. 2 of Figure 5-16.

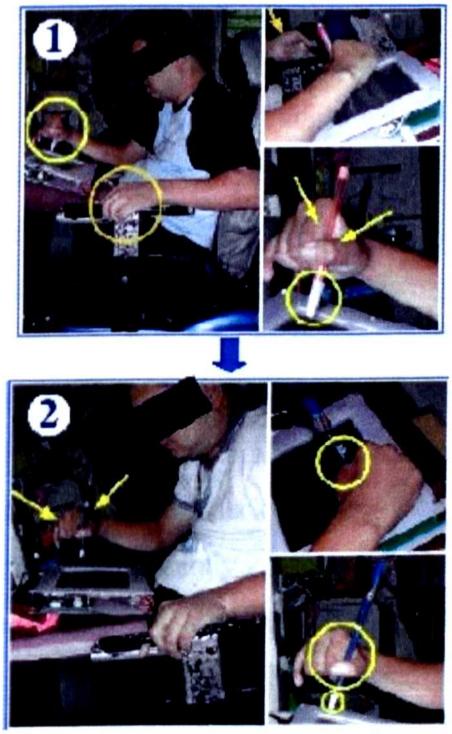


Figure 5-16 The process of adjusting operating mode for Subject 22.

5.3.2.2 Set-up and Working Positions

In field experiments, the research outcomes are gathered from real-life situations rather than in a contrived laboratory environment. The experimental place in this study was the subject's office, in which they performed computer activities. Once the operating mode was adjusted and set, the next step was to arrange the device in the experimental position. As mentioned, some changes were required to add the new assistive device. This section reveals how the touchscreen device was fitted to the subjects' workplace prior to the typing experiments.

In Figure 5-17 is shown the first attempt for the set up of the touchscreen device for Subject 21. The office desk did not allow the subject's wheelchair to slide under it so that his thigh became the desk on which the touchscreen was placed. Light reflection that is a feature concerned with most liquid crystal display (LCD) panels, and was a factor with the novel touchscreen device. For this reason, it was necessary to raise the touchscreen device and adjust its angle in order to match users' eye level. For Subject 21, the initial attempt for the set up of the device was to lean the touchscreen prototype against the office desk and to adjust the panel angle with a 8cm-depth tissue box. As seen in the lower images of Figure 5-17, the red line was Subject 21's normal seating posture. The subject's torso and neck were vertical and at an angle greater than 90 degrees from the thighs. His thighs were inclined with his hips lower than the knee, and the lower legs straight. The entire soles of the feet rested on the footrest; the yellow line on the left-hand side of the figure and the green line on the-right hand side illustrate Subject 21's postures when operating the 9-inch touchscreen device. The yellow line shows how the subject bent his torso and neck to view the monitor. The centre of the computer monitor was located approximately 25 degrees below the horizontal eye level. The green line indicates the curve of his torso when he lowered his head to hit the keys on the touch screen. Figure 5-17 shows the awkward postures when the neck and torso were not straight and how the subject had to incline his torso forward to view the screen. It can be said that the working postures of Subject 21 were not in a neutral position in which the joints could be naturally aligned and necessitated further adjustments.

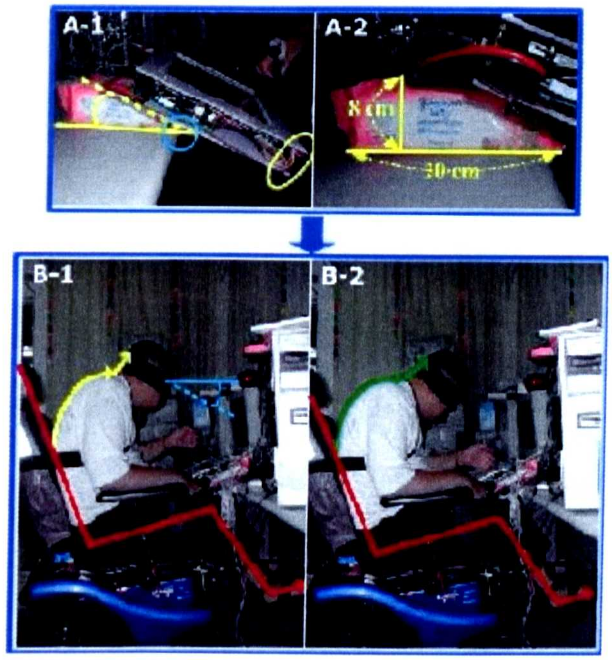


Figure 5-17 The first attempt at device set-up for Subject 21.

Figure 5-18 shows the second adjustment of the device. The touchscreen was again elevated by placing another piece of rigid material, which was 33cm in length and 4.2cm in depth with a skidproof slipcover, under the device, as seen in upper images in Figure 5-18. The images below show firstly that Subject 21's body curve when viewing the monitor as the yellow line on the left-hand side. Further, the centre of the computer monitor was positioned approximately 35 degrees below horizontal eye level, which displays a wider range compared with the first device set-up shown in Figure 5-17. Secondly, the right-hand green line pictured the torso and neck curve while the subject was keying data into the touchscreen input device. In Figure 5-18, the second adjustment of the device set-up showed that the subject's viewing angle was not interfered by the light reflection caused by the flat-panel of the touchscreen. However, compared with the red line (the subject's usual wheelchair seating posture), the subject's neck and torso were not vertical and in-line, therefore, his torso had to be leant down to access the device as similar as the working postures in Figure 5-17. Merging ideas from the first and second attempts at the touchscreen set-up, it was necessary to change Subject 21's operating posture to a more comfortable working position for the purpose of reducing stress and strain on the muscles, tendons, and skeletal system. Indeed, a third adjustment on the device set-up was needed.

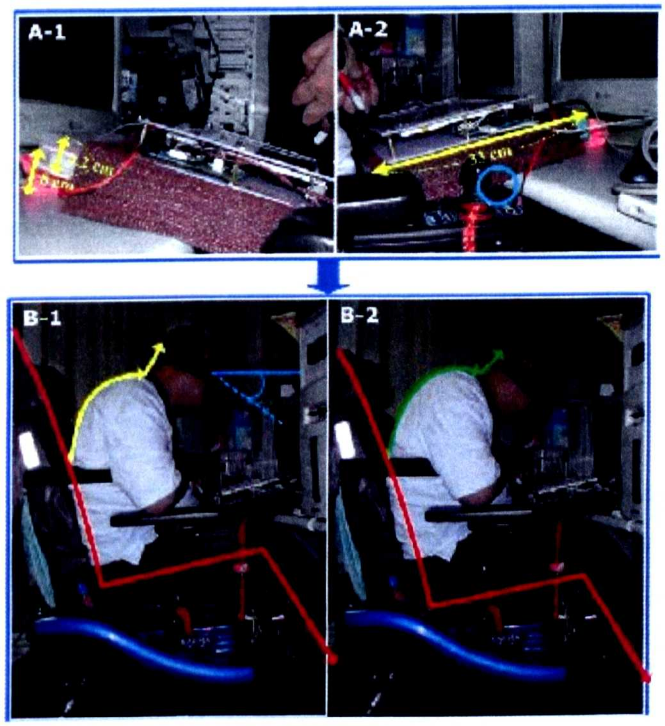


Figure 5-18 The second attempt at device set-up for Subject 21.

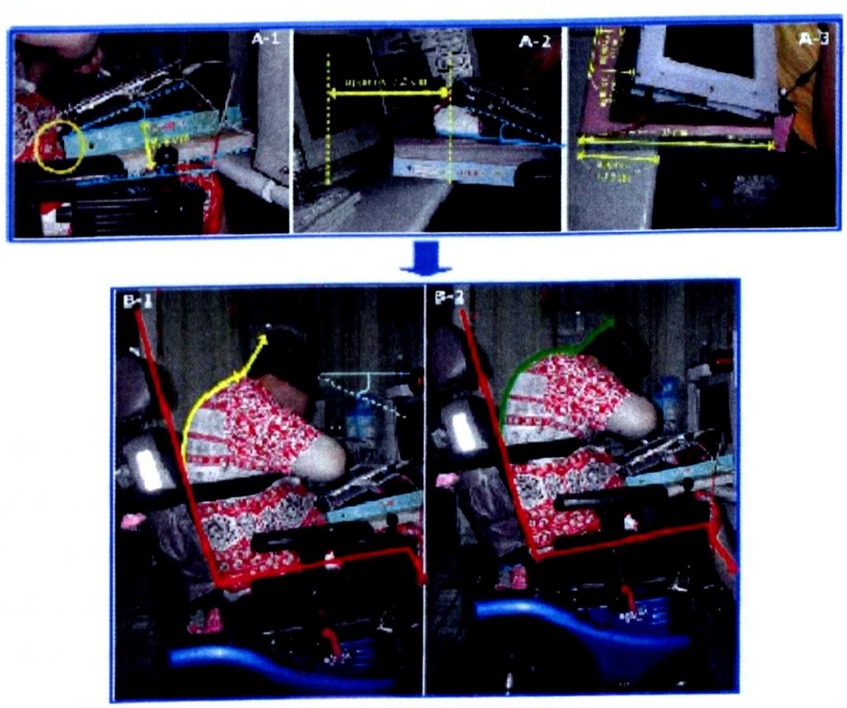


Figure 5-19 The third attempt at device set-up for Subject 21.

The last adjustment at the device set-up in the office is shown in Figure 5-19. In order to shorten the range of bending of the neck and torso for Subject 21, one more solid object (33 cm in length and 4.2 cm in depth) was added to raise the touchscreen device. Similarly, a skidproof slipcover was spread on these objects for supporting steadiness. The orange-coloured circle in the figure shows the touchscreen prototype with its support and how it was placed against the subject's stomach. This resulted in unsteadiness when performing computer operation. Moreover, the improved working postures for the subject are pictured in Figure 5-19.

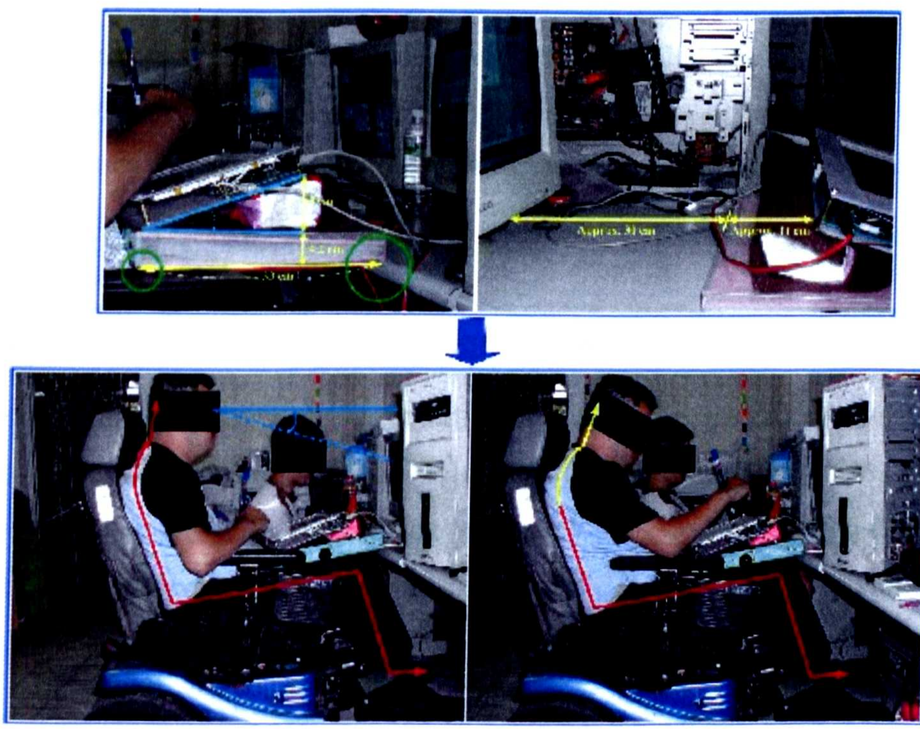


Figure 5-20 The touchscreen device set-up for Subject 22.

Similarly, the touchscreen device was raised by an object (8cm in depth) and one piece of rigid material (33cm in length and 4.2 cm in depth) for displaying the flat-panel to fit Subject 22's viewing angle, as shown in Figure 5-20. This figure shows that skidproof material was again used to cover these rigid materials for stabilising the touchscreen prototype. The viewing distance between the subject and the monitor was between 60 cm and 70 cm. In terms of working posture, the red line in Figure 5-20 represents the body curve of Subject 22 when viewing the monitor; the yellow line on the right-hand side in this figure signified his torso and neck curve while he was inputting data into the touchscreen input device. Furthermore, the centre of monitor was positioned approximately 25 degrees below the subject's horizontal eye level.

The highest priority for the set-up in the subjects' workplace had to conform to ergonomic guidelines and to the user's comfort. Because of this, the set-up of touchscreen device attempted to take ergonomic considerations into account when arranging a computer working area, and consequently to maintain neutral body postures while working with the touchscreen during the short-period of training. However, due to the environmental restriction and equipment shortage, the experimental conditions in the subjects' actual workplace could not be controlled as precisely as in a laboratory-based environment. Even though the instrument set-up in the subject's actual workplace was not ideal, satisfaction and comfort were still obtained from both subjects after the final adjustments.

5.3.2.3 Experimental Results – Accuracy and Speed

After the adjustments were made, the short-term training programme was carried out. After two-week training period, a significant effect on typing performance, including input speed (words per minute) and accuracy and performance by Subject 21 and Subject 22, was achieved. These are shown in Table 5-8 and presented graphically in Figure 5-21.

Table 5-8 Results of typing performance on accuracy and speed.

	Subject 21		Subject 22	
	Duration: 20 min.		Duration: 20 min.	
Day	**Speed (wpm): Gross / Net**	**Accuracy**	**Speed (wpm): Gross / Net**	**Accuracy**
01	1 / 0	39%	3 / 2	68%
02	2 / 0	6%	5 / 5	89%
03	1 / 0	44%	5 / 4	85%
04	3 / 1	53%	6 / 6	87%
05	2 / 1	50%	7 / 6	86%
06	2 / 1	68%	6 / 6	91%
07	2 / 2	74%	7 / 7	96%
08	2 / 2	75%	7 / 7	92%
09	2 / 2	82%	8 / 7	93%
10	3 / 2	80%	8 / 7	92%
11	2 / 2	84%	8 / 8	94%

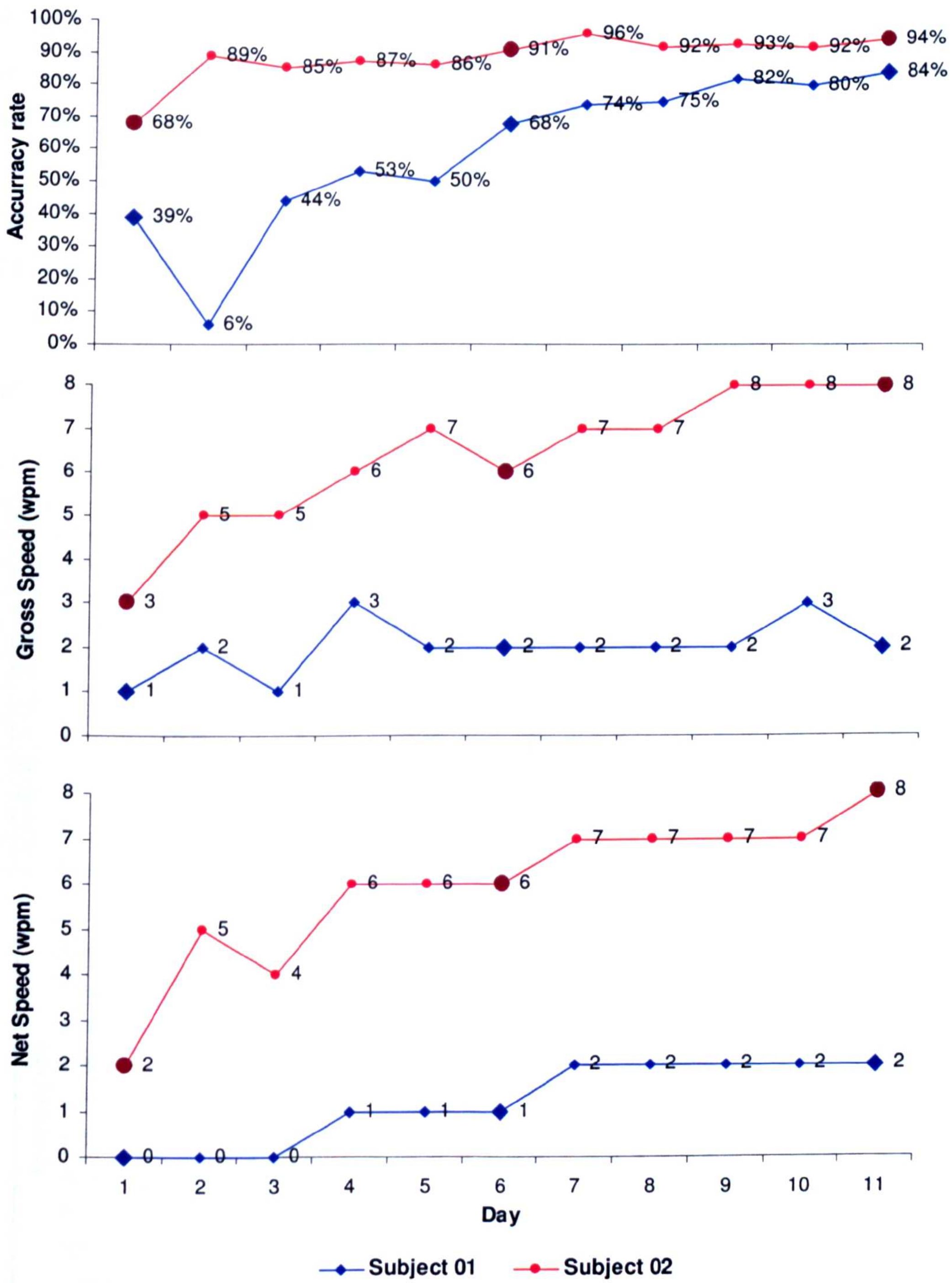


Figure 5-21 The results from the subjects' practice.

The results, shown in Table 5-8 and Figure 5-21, demonstrate the improvement in typing performance during the intensive training programme for the two CSI subjects. The accuracy outcomes performed by Subject 21 show a range of improvement from 6% to 84%; and the accuracy rates of Subject 22 ranged between 68% and 94%. Speed was expressed in words per minute (wpm), the gross speed was expressed as subjects' gross hits per minute, the hit errors was subtracted from the gross hits and the net speed was expressed in words per minute. The range of the input speed was between 0 and 2 wpm for Subject 21 and 2 wpm to 8 wpm for Subject 22 during the two-week training performance.

Table 5-9 Results of accuracy performance.

	Subject 21	Subject 22
	Duration: 20 min.	Duration: 20 min.
Day	Accuracy	Accuracy
01	39%	68%
02	6%	89%
03	44%	85%
04	53%	87%
05	50%	86%
06	68%	91%
07	74%	96%
08	75%	92%
09	82%	93%
10	80%	92%
11	84%	94%

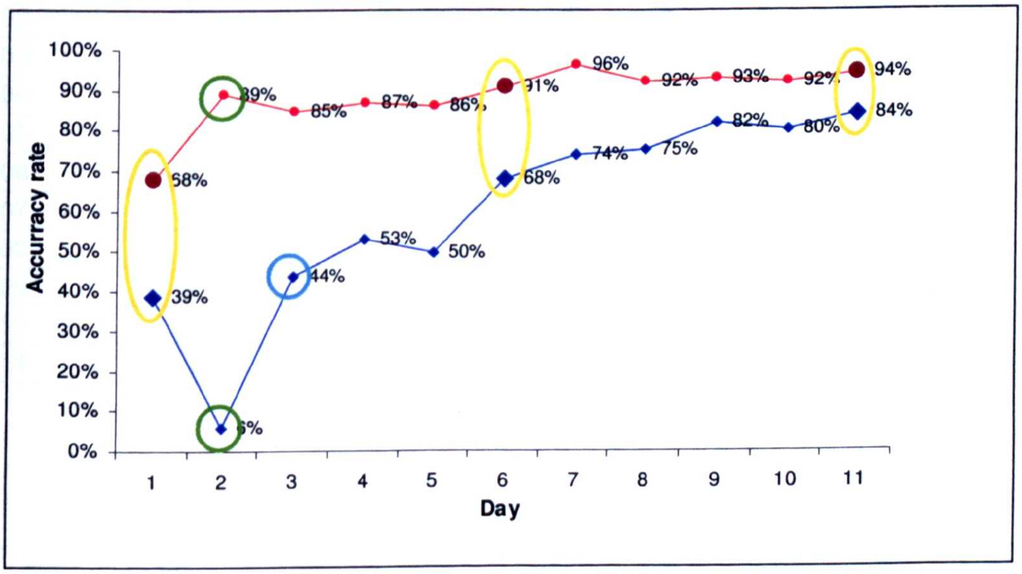


Figure 5-22 Results of accuracy rate.

In Table 5-9 and Figure 5-22, the yellow circles represented the initial, interim, and final testing outcomes between the two subjects. The accuracy results of 39% for Subject 21 and 68% for Subject 22 were achieved in the first typing test. These were listed as the baseline data. In the second test, Subject 21 showed great eagerness for a better level of achievement. Unfortunately, a disappointing 6% (green circle) was presented as the lowest result. On his next-day's performance, Subject 21 regained his accuracy with a rate of 44%, as shown with the blue circle. Unlike Subject 21, Subject 22 represented a great improvement of 89% (green circle) in his second typing performance, which was 21% higher than his initial attempt. Overall, Subject 21 represented a dramatic development in typing accuracy during this intensive training period, which continually grew from 39% to 84% accuracy rates except the unstable second-time performance (6%). Subject 22 achieved an impressive improvement over his first test (68%) to that obtained in his second test (89%). However, the achievements maintained a range between 85% and 94% between the second training day and the last day of training.

Table 5-10 Results of speed performance.

	Subject 21		Subject 22	
	Duration: 20 min.		Duration: 20 min.	
Day	Gross speed (wpm)	Net speed (wpm)	Gross speed (wpm)	Net speed (wpm)
01	1	0	3	2
02	2	0	5	5
03	1	0	5	4
04	3	1	6	6
05	2	1	7	6
06	2	1	6	6
07	2	2	7	7
08	2	2	7	7
09	2	2	8	7
10	3	2	8	7
11	2	2	8	8

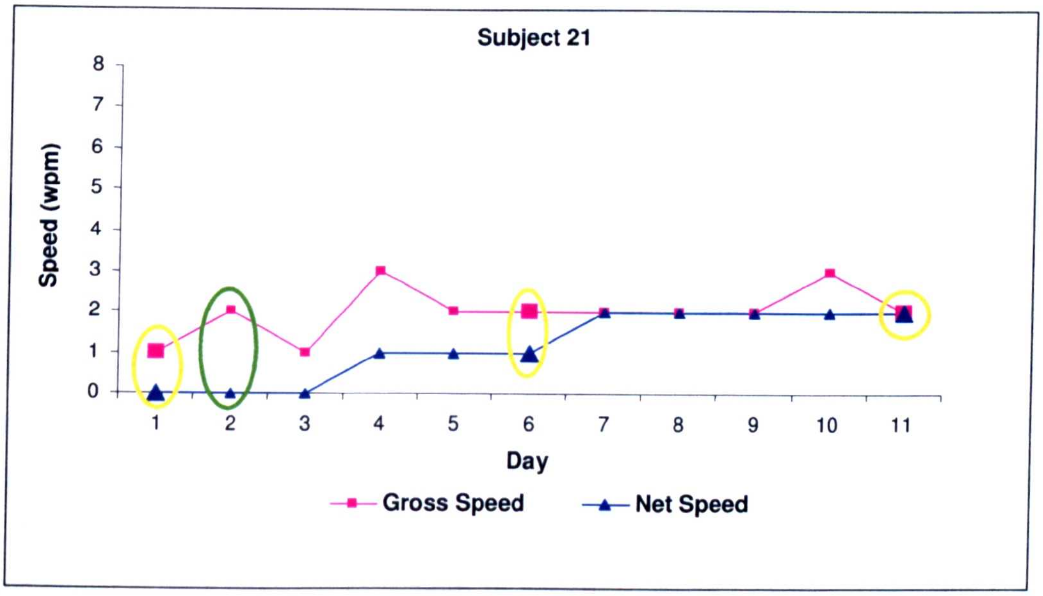


Figure 5-23 Speed results of Subject 21.

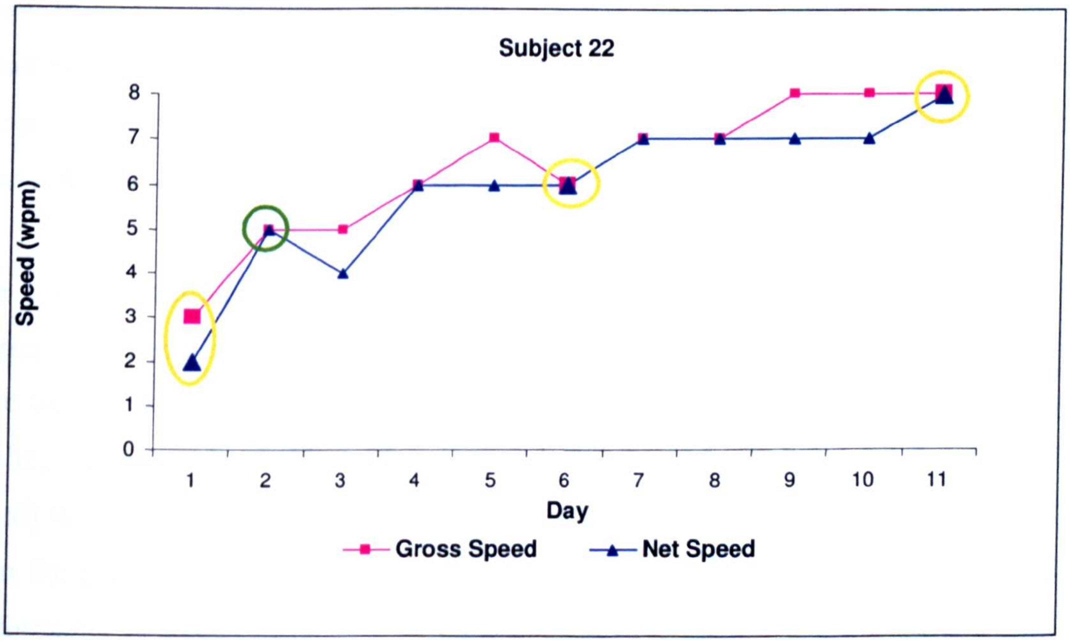


Figure 5-24 Speed results of Subject 22.

Figure 5-23 and Figure 5-24 demonstrate the development of training results concerning speed. The range of the input speed was between 0 and 2 wpm for Subject 21 and 2 wpm to 8 wpm for Subject 22, during the two-week training programme. The yellow circles in both Figure 5-23 and Figure 5-24 display the two subjects' achievements at the initial, interim, and final test stages respectively.

Figure 5-23 displays the speed results from Subject 21. The gradual improvement of typing speed was shown between his first outcome and sixth performance. As seen in the subject's second-day presentation, he was anxious to reach an obvious advancement in typing performance so that he presented higher gross hits (seen in the gross speed line in Figure 5-23) as well as higher error hits; likewise, the high errors resulted in his lowest accuracy (6%) as shown in Figure 5-22 and remained 0 wpm in the net speed like his first-day outcome. On his fourth attempt, the net speed changed from 0 to 1 wpm. From this day, the result of 1 wpm in net speed continued until the sixth day of training. Further, this changed to 2 wpm in net speed during seventh-day. The 2 wpm input speed was almost constant and retained to the last-day of the training programme. The speed results performed by Subject 21 were not very high for typing performance. However, for a person who has very limited upper-limb movement caused by high level of spinal lesions, every little improvement indicates significant progress. In other words, it can be said, that Subject 21 developed from 0 to 2 wpm in net speed (i.e. gross speed – hit errors = net speed) during the two-week training, which demonstrated a great achievement for a person with such severe physical disability.

The speed performance of Subject 22, including gross and net speeds, is shown in Figure 5-24. Because the subject was new to the touchscreen input device, his initial test gave only 2 wpm in net speed. This was his lowest performance during the training period. Subsequently, Subject 22 progressed from 2 wpm (net speed)/ 3 wpm (gross speed) to 5 wpm, from, from 68% to 89% accuracy rates (as shown in Figure 5-22), from the initial typing test to the second performance. As mentioned above, net speed performance is greatly influenced by input accuracy (hit errors). For instance, in Subject 22's third training result, his gross speed was the same as the second-day result (5 wpm). However, the lower accuracy (85%) displayed in his third test (refer to Figure 5-22) resulted in a lower net speed (4 wpm). The speed continually grew from the first to seventh test, ranging between 2 wpm and 7 wpm. In addition, between the seventh and tenth tests, the net speed remained at 7 wpm but the gross speed gradually rose; ultimately, both gross and net speeds reached a speed of 8wpm on the last day of training.

The two subjects, one who sustained a C4-5 level of spinal lesion and the other with a C5-6 spinal cord injury, participated in this study. Experimental results indicated that the both subjects improved typing accuracy and speed with the novel 9-inch desktop touchscreen device after an intensive training programme. The subjects' training involved short-term training period of 20 minutes practice on each training day lasting for two weeks; both Subject 21 and Subject 22 achieved a good level of typing accuracy and speed. Therefore, it is probable that their effectiveness and efficacy on using the novel touchscreen input device would be further enhanced if longer-term practice and use is provided.

5.3.2.4 User Perspectives

User perspective is a primary focus at assistive device selection and use. The perspective of the user is influenced by a number of factors, such as functional needs and preferences, ease and comfortable use, users' performance expectation and even a good match to the working area. Most persons with disabilities have their own views on technology selection and use associated with their physical capabilities, preferences, and experiences. That is to say, a variety of perceptions of the same device were held by different persons with disabilities. Also it is clear that two individuals (like Subject 21 and Subject 22) are likely to have two very dissimilar viewpoints and levels of satisfaction.

Table 5-11 gives the two subjects' brief perspectives along the SCI users' needs hierarchy (Figure 4-14), for use of the novel touchscreen device after the two-week training period. The hierarchy ranked these SCI users' needs in order, beginning with the most basic at the bottom of the hierarchy and working upwards. An input device for persons with spinal cord injuries needs to satisfy the most basic, *single input operation,* then be *easy to use, reduce inputting tiredness,* and finally efficacy and effectiveness, involving *accuracy* and *speed.* Both in the short-term using experience, both subjects ranked the newly developed touchscreen device as GOOD, firstly in being suitable for the users who can access a computer only with single key-in operations. Secondly, the novel device was user-friendly for the novice, like the two participants who were both new to the use of a computer. The novel touch operating mode for the subjects who sustained very limited upper-limb motion was easier to use compared to the conventional input devices. In addition, the use of the touchscreen device required lighter keystrokes. Input tiredness resulting from repetitive and prolonged computer operations, could therefore be greatly reduced by the lighter keystrokes. Finally, with respect to input accuracy and speed, as discussed above, the two subjects greatly improved their typing accuracy and to some extent speed with the touchscreen device after the short-term training (referred to Section 5.3.2.3). It should be noted, although the two subjects only showed limited development in typing speed, their speed performance is likely to become better after a longer period of practice.

Table 5-11 User's perspectives of the touchscreen prototype at the stage of short-term device use.

	9-INCH TOUCHSCREEN PROTOTYPE															
	Single key-in operation			Easy to use			Reduce input tiredness			Accuracy			Speed			
NO.	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	Comments
21	●			●			●			●					●	Both subjects believe that the input speed achieved will be better after a period of practice.
22	●			●			●			●				●		

★ The range of accuracy: Good indicates a result ranged from 80% to 100%; Average indicates a result ranged from 50% to 79%; Poor indicates a result under 50%.
★ The speed is marked based on the subject's perceptions.

In addition to the ranking of the novel touchscreen device against the five criteria of the needs hierarchy, the subjects' psychological barriers caused by their previous unpleasant experiences are described. In this study, Subject 21 is an example of how a wrong input device can become a roadblock to accessing a computer. He had suffered numerous frustrations in attempting to operate a conventional keyboard. These unpleasant experiences had turned the subject away from his ambition to use a computer. Consequently Subject 21 was an outsider to computer use prior to the training programme. With the touchscreen prototype provided and the training in its use, the subject was able to access a computer for the first time since his spinal cord injury. Compared to a conventional keyboard that the subject once used, this novel device was easier-to-use and produced less tiredness. After completing a short-period of training on the touchscreen device, satisfaction was expressed from the subject because of the gradual but obvious improvement in typing performance. According to the subject, it was through the touchscreen device that he had found an effective way of operating a computer, thus giving himself to access to anyone, anywhere in the world. The experience of using this touchscreen reopened a door for Subject 21 to access the world of computer technology, which was abandoned by him over the years.

Unlike Subject 21, his colleague, Subject 22, had fewer difficulties in computer use. Similar to most persons with severe physical limitations, the subject's adjustment to his computer operation was a long and painful process. However, was he a success when working with his adopted conventional inputs? Before meeting Subject 22, his usual computer activities, such as internet exploring and game playing, were performed with a conventional mouse. The subject rarely keyed in data through a keyboard as he tried to avoid such situations while using a computer. As he had to 'accept' his spinal cord injury, he had to 'accept' the fact he cannot operate a keyboard easily and tolerate it. According to Subject 22, a person with spinal cord injury like himself, was trapped in a no-win situation – you learned to live with your condition. Hence, Subject 22, firstly, was pleased with the user-friendly feature and integrated functions on the initial use of the touchscreen prototype. Secondly he was pleased with the great improvements in typing accuracy and speed by such a short period (20-minute on each training day, lasting for two weeks), which he could not achieve with a conventional keyboard. He perceived there was a reduction in operating fatigue caused by repetitive input activities.

5.3.3 Summary of User-Centred Validation during Short-Term Use and Training Effects

The alternative touchscreen input prototypes were designed to match the special needs of users who have severe physical disabilities and who cannot use conventional input devices easily. This research, involved exploring appropriate assistive technology to match the special needs of the SCI computer users listed in Figure 4-14. An input device especially for this specific group of users needs to offer easier and more comfortable operating methods to match the users' physical limitations, reduce tiredness in order to prevent potential computer work-related musculoskeletal disorders, and require less time being taken on learning and adaptation to the device. The novel touchscreen device, which integrated keyboard and mouse functions, characterised by its portable and desktop use, and which required only lighter keystroke in use, was provided in this study. More importantly, the methodological strategy, concerning both user- and scientific-based evidence, integrated qualitative and quantitative approaches, which was used in the previous studies, was employed again in this evaluation study for measuring usability in the use of the novel touchscreen device through a short-period training programme.

The outcomes, including device and workplace set-up, training effects (i.e. typing performance), user perspective and acceptability, were displayed in this study. As indicated above, the experimental place was set up in the subjects' natural environment. Prior to the short-term training, adding the device into the subjects' actual workplace inevitably brought about other changes and adjustment and took account of not only the environmental condition, but also users' operating modes and postures and even their preference and experience. The device set-up in the subject's natural setting was not ideal as it would be in a laboratory environment. Problems were also found as both subjects were accustomed to working using awkward postures when accessing a computer. Subject 21's working posture compared poorly with Subject 22's. In addition to the prolonged and repetitive computer operations, the over-stretching of the upper body resulted from inappropriate arrangements of computer workstation in the work milieu which would result in every likelihood in musculoskeletal disorders, especially with those users who had suffered upper-limb impairments. In terms of training effects, short-term training clearly showed a statistically significant improvement in typing performance (accuracy and speed) with the novel touchscreen input device for the two CSI subjects. With Subject 21, a significant improvement of 45% was attained in terms of accuracy. On the other hand, the net typing speed developed by 2 wpm, increasing from 0 wpm to 2 wpm during the two-week training period. Compared with Subject 21, the accuracy performance for Subject 22 improved from 68% on the first time attempt to the final 94% after training. The training also had a great effect on typing speed. His net typing speed increased from 2 wpm to 8 wpm.

For the two CSI subjects in this study, the short-term training programme with the touchscreen prototype had a positive influence on them. Following the subjects' perspectives, satisfaction was expressed in terms of the perceived user-friendly interface, labour-saving operating method, quality and useful functions, and their willingness to have further work with this touchscreen alternative input. More importantly, the testing outcomes have encouraged both subjects in computer use. The frustrations, caused by their previous unpleasant experiences with conventional input devices resulted in their hesitation in accessing a computer, were reduced after the two-week training period.

In summary, the short-term training achieved a decisive development of the touchscreen device's use with the two CSI subjects. The training outcomes demonstrated the touchscreen prototype not only brought to the subjects a brand-new operating experience, but also compared with the subject's previous experience in operating conventional keyboard and/or mouse, this novel input device lessened their learning and adaptation time for the device use. The methodological limitations, subject and time, were also revealed in this study. As mentioned earlier, the research strategy, single case study design, which involves one subject at a time, is time-consuming, laborious, and a costly undertaking. As the author, herself, was the only researcher conducting this series of assistive technology outcome measures, it stand to reason that there were only two subjects involved in this short-period training programme.

A significant accomplishment in the short-term use and training effects has shown. The challenge should proceed to the next stage, the longer-term use outcome, is discussed in the following section.

5.4 Study E: User-Centred Validation on the Longer-Term Use Outcome and Comparison with Habitual Practice

5.4.1 Introduction

Fuhrer et al.'s ATD specific outcome framework (2003) highlighted that longer-term device outcomes are the key to influencing people on their device selections. That is to say, the outcomes of long term use of an assistive technology can sway the users' decision to either continue or discontinue use of a device. Previous usability evaluations at the introductory phase (Section 5.2) and shorter-term use (Section 5.3) of the novel touchscreen devices showed significant higher usability outcomes and resulted in positive attitudes from the participants (14 CSI subjects at the introductory assessments; 2 CSI subjects at the short-period training); in addition, the users' experience of the newly developed touchscreen prototypes resulted in a willingness for further utilisation from many of the CSI participants in former validation studies in Sections 5.2 and 5.3. Many problems were revealed before conducting this long-term validation study from the earlier research. As showed by the methodological limitations pointed out in Section 3.7, the difficulties are of the subjects' recruitment and time constraint in studies related to the outcome measures of assistive technology devices on people with disabilities. Luckily, in the studies associated with the contextual observational survey (Study A), the usability assessments at the introductory phase of the use of the novel touchscreen devices (Study C) and the short term use and training effects (Study D), a number of the subjects with spinal cord injuries volunteered to participate in the above research activities, i.e. the 34 SCI subjects in Study A, the 14 CSI subjects took part in Study C, and the 2 CSI participants joined the training programme in Study D. In terms of time consideration, time being taken on each of the 34 subjects with spinal cord injuries in the contextual observational survey ranged from one to two days. In the validation study at the introductory phase of device use, the researcher spent one working day (from 9 am to 5 pm) with every CSI subjects for completing experimental tasks and gathering the required qualitative information. Further, a two-week period was spent with the 2 participants, with high level of spinal lesion and who had less experience in computer use, in the study concerned the usability evaluation after the short term device use.

However, at the start of this final study, that aimed to measure the long-term appropriateness and usability outcomes, there were difficulties finding participants who were willing to cope with the long-term use of the device and experimental tasks associated with it.

As repeatedly indicated, the single-case study approach needs to be employed in the field of assistive technology outcome measures, to obtain a better understanding of the physical or psychological needs of users with special disabilities. Scherer (2000e) emphasised that a person with a disability (PWD) has his/her unique life experiences involved personally and socially constructed perspectives. Accordingly, every SCI subject ought to be considered as a unique case and deserved be treated individually.

In addition to the experimental results and users' affirmative feedback in the usage of the touchscreen alternative inputs in Sections 5.2 and 5.3, the users' normal practices and their previous experience in computer operation could have repercussions in the selection of a technology. Section 5.2 showed better accuracy performance with the 9-inch touchscreen device which provided similar key size and layout when compared to the subjects' normal keyboards, than did the portable 5.7-inch prototype. In Section 5.3, the subjects' previous failures and frustrations in accessing a computer through their normal input devices resulted in their lack of motivation either to use a computer or to do the keyboarding tasks. The above two instances have indicated that technology users' experiences and preferences would be the hows and whys that an assistive device is being accepted or rejected by its users. As shown in the preceding study (Section 5.3), obvious improvements in typing performance and acceptability of the touchscreen input device were revealed by the two subjects who had less experience in accessing a computer. Consequently, it is likely that ongoing meaningful longer-term training for the subjects would lead to continuously increase in functional abilities, freedom and independence, and spur on their confidence in accessing computer technology. However, would the brand-new touchscreen input devices have the potential to overcome the normal practice of those experienced users with spinal cord injuries and be a substitute to their normal input devices that the subjects adopted over years? For that reason, particular attention is paid in this study not only to examining the usability performance and observe the relative frequency of the device use and the duration of that usage during long-term use of the novel touchscreen prototype, but also to conduct a comparison with the subject's normal input device.

In addition, previous research, such as that by Wu et al. (2004a), a single-subject multiple probe design to compare the input accuracy and speed performance among three spinal-cord-injured persons who were equipped with appropriate input devices during baseline, intervention and follow up phases. Similarly, the single-subject experimental design was used to investigate the effects of the specific touchscreen input device on typing performance, quantity of frequency and duration of device usage, and user perspectives from the experienced computer user with cervical spinal cord injuries, during a two-mouth period. Other research approaches, field experiments conducted in accordance with scientific method attempted to balance the requirements and limitation in the natural settings. Qualitative methods consisted of unstructured interviews and direct observation provided detailed description of research activities, participants' behaviour, attitudes and visual data, were involved in this study.

Overall, the aim of this validation stage is to investigate the longer-term use of the touchscreen input prototype. In addition, it compares usability outcomes between the provided touchscreen and the subject's currently adopted input device. The objectives of this work presented in this section are:

- to establish the criteria for subject selection and select a suitable subject;
- to install the experimental equipment in the subject's work area;
- to document the standard operating procedure;
- to gather and analyse data;
- to draw up conclusions.

5.4.2 Method

The single-subject experiment design was employed in this study. The single-subject (or single-case) experimental design is usually indicated to be behavioural, associated with the presence or severity of problematic incidents, as well to enable the researcher to observe changes over time (Cheetham et al. 1992b). The key feature of the experimental design is the introduction and manipulation of an independent variable presented in strictly controlled conditions (Cook and Campbell 1979). Single-subject experimentation is designed to bring out the individual's behaviour rather than a group's behaviour, involving a wide range of specific and varied characteristics from the individual subjects and a measure of an individual's behaviour from representative sampling (Hersen and Barlow 1987). The use of single-subject experimentations requires cautious and explicit investigation on the interaction between the individual subject and the environment. Also, new instruction is allowed to be incorporated into the intervention without compromising the experimental integrity (Johnston and Pennypacker 1993).

In this study, a single-subject experimental design was used to assess the usability of the touchscreen alternative input on a subject with a high-level of spinal lesion, under the three controlled conditions. Three experimental phases were conducted, Stage A (adaptation period), Stage B (intensive intervention) and Stage C (Follow-up). In Stage A, the subject was recommended to spend 30 minutes daily on practicing with the touchscreen device; in Stage B, it was anticipated that the subject would intensively operate the touchscreen prototype one hour a day; in Stage C, In Stage C, there was no time constraint for the touchscreen operations of the subject. It should be noted that there were no restrictions on the subject should he/she wish to make changes in her usual activities during the three conditional stages. Secondly, experimentation in each conditional stage was led through well-defined instructions, in the standard operating procedure, in order to minimise research errors and bias This is detailed in Section 5.4.2.4. Thirdly, similar to previous validation studies at introductory and short-term phases, qualitative strategies, direct observation and unstructured interviews, were again used in this phase of long-term device use. This was to provide information about the impact on the participant. More importantly, the subject criteria set-up and selection, instruments used and arranged, should be considered and planned; prior to the experiments, as described in Sections 5.4.2.1 and 5.4.2.2.

5.4.2.1 Subject Selection

The subject (Subject 01), was introduced by the Taiwan Assistive Technology and Vocational Rehabilitation Association and who had taken part in the former validation study at an introductory phase in 2004, had been selected and again participated in this study. The subject met the following screening criteria (a) diagnosed as CSI, (b) stable medical status as indicated by the onset of spinal cord injury over a 6 month period, (c) no significant cognitive, visual, or hearing impairments, and (d) working with a computer for at least one year. Most importantly, the subject's consent to participate in this study and the permission for photographs to be taken were obtained prior to the experimental assessments.

Subject 01 was a 45-year-old woman who sustained a C5-6 spinal cord injury from a fall when she was 35 years old. The motor abilities of her upper extremities, her two shoulders and elbows enabled her to perform most functional movements, but her wrists and hands had limited motor functions. As with most people with a severe high level of spinal cord injuries, she required a great deal of assistance for most functional activities in her life from assistive devices from others, either family members or a hired carer, and required the use of a wheelchair. She was accustomed to using a manual wheelchair indoors and a powered wheelchair outdoors. Table 5-12 shows a biographical summary of the subject.

The subject was not familiar with computer use before her injuries. All her computer skills were learned and developed from a one-year vocational training programme and subsequent three-year experience working with computers. For the subject's normal computer practice, a hand strip was used on her left hand and fastened to the inputting pen, as shown in Figure 5-25. The subject's normal keyboard and mouse are shown in Figure 5-26. Because of her limited motion ability, the keyboard was specially designed and the width was smaller than to conventional keyboards (approximately two-thirds of conventional keyboards' width). The mouse was operated by the subject's right hand. The left and right buttons of the mouse were separated by foam pads and the non-slip cover was used to stabilize her right hand when operating the mouse. With the consideration of the subject's work routine, the invention and assessments of this study were carried out in addition to her regular timetable of work.

Table 5-12 Brief Biographical Summary of the subject in this study.

	ACQUIRED SPINAL CORD INJURIES IN ADULTHOOD
TYPE OF INJURY	C5-6 complete SCI at age 35 from a fall
GENDER	Female
AGE IN 2005	45 (9 yrs+ post-injury)
DEVICES USED	Manual wheelchair (home), and power wheelchair (outdoors), waist belt, handstrip
LIVING STATUS	Ground floor apartment with family and carer
WORK STATUS	Computer employee (3½ yrs working experience)

Figure 5-25 An assistive device supporting the subject in computer use.

Figure 5-26 Subject's normal keyboard (left) and mouse (right).

5.4.2.2 Technology and the Environment

At the time of experimental assessments, the subject lived with her family in their ground floor apartment. The arrangement of the home was based on the subject's needs. Her house was designed to be a serious work area, especially for computer use. The subject had been working at home with her computer for three and half years since she completed her rehabilitation and vocational training. A computer, keyboard and mouse were on a conventional office desk and her wheelchair became her desk chair, as seen in Figure 5-27. The experimental place was set up in her own work area. In addition, the device set-up and environmental arrangements followed the subject's normal practice. The required experimental devices were as follows:

- Subject's current computer input devices (No. 1 in Figure 5-26 and Figure 5-27). The keyboard was specially designed and manufactured for the subject's needs and the width of keyboard is smaller than the conventional keyboard. Two gel spots stayed firmly in place of left and right mouse bottoms for improving her steadiness of hand when operating a mouse;
- The 9 inch touchscreen prototype, detailed in Section 3.4.2, was provided in this study and shows in Figure 5-28;
- The 'TypingMaster Pro' software (2006) was used for typing training and testing; and its interfaces are illustrated in Figure 5-11. The computer software program was designed to record typing speed and accuracy;
- A desktop computer and monitor are shown as no. 3 in Figure 5-27.

It should be noted that, in this long-term evaluation, the dimensions of the subject's keyboard were 15 cm in length, 10 cm in width, and 1 cm in height, as seen in Figure 5-28. For the touchscreen prototype, the size of the computer keys and the interface were nearly the same as the subject's specially designed keyboard. However, the surface dimension of the touchscreen was 25 cm long, with a width of 15 cm, and a height of 5 cm, after enclosing the interface in a rigid plastic covering, as seen in Figure 5-28.

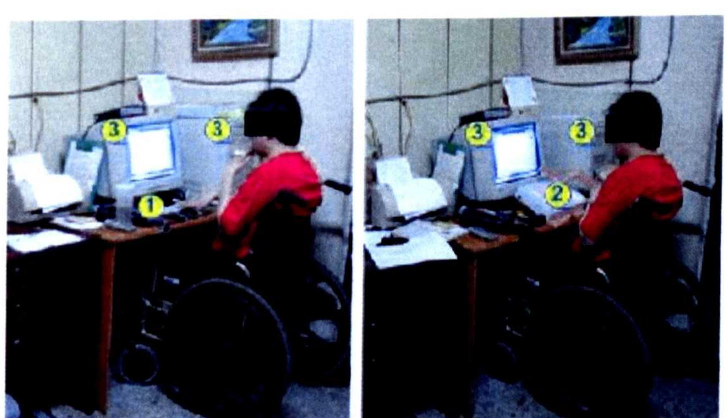


Figure 5-27 The arrangement of subject's experimental workplace.

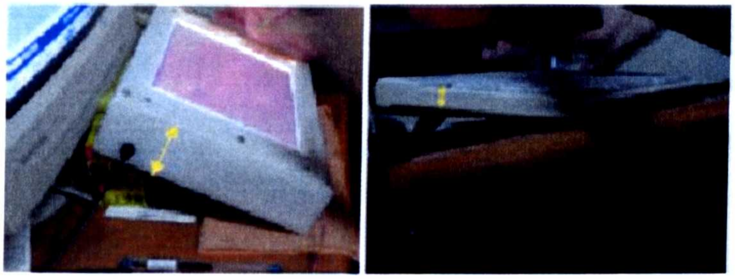


Figure 5-28 The dimensions of the touchscreen and the subject's keyboard.

5.4.2.3 Experimental Design

Prior to the long-term experimental period, the subject received an explanation of the purpose and procedure for the assessments. The single-subject experimental design was applied in this evaluation study. The study was conducted in three training periods; these were Stage A (Adaptation period), Stage B (Intensive intervention), and Stage C (Follow-up).

Stage A (Adaptation period). This was a familiarisation period when the subject accustomed herself to the new device. Practising the touchscreen device for at least 30 minutes a day was recommended to the subject. Additionally she was requested to record the approximate time of daily practice and report this to the researcher. The TypingMaster software program was used for typing training and testing input results and improvement. Each period of 5 working days was divided into sessions and continuous experiments were required in this training programme. Typing tests proceeded with the computer software on the touchscreen device and her normal keyboard on the final days of all sessions. The results from the typing tests for operating the subject's normal keyboard were recorded. Stage A ended when the subject's performance on the touchscreen device reached a stable status. Stage B (Intensive intervention) followed the familiarisation period. There was an interval of 5 days between Stage A and Stage B. Stage B was an intervention period in which the subject was expected to intensively use the touchscreen input device for at least one hour per day, and also requested to report approximate daily use time. Stage C (Follow-up) assessed the effects of the subject's free choice of use of the time. It involved targeting the same behaviour, as in Stages A and B, except that there was no compulsory training time for the subject and the follow-up was based on spontaneous practice.

However, the subject was unable to cooperate in an intensive training programme that consists of inflexible training times because of her fixed timetable for her routine work. Because of this, the subject could adjust her training times under the research restrictions and make them suited to her routine life.

5.4.2.4 Standard Operating Procedure for the Experiment

To ensure the reliability and validity for the experimentations, the standard operating procedure was implemented in the experiments to minimise the errors and bias during the assessments, as shown in Figure 5-29.

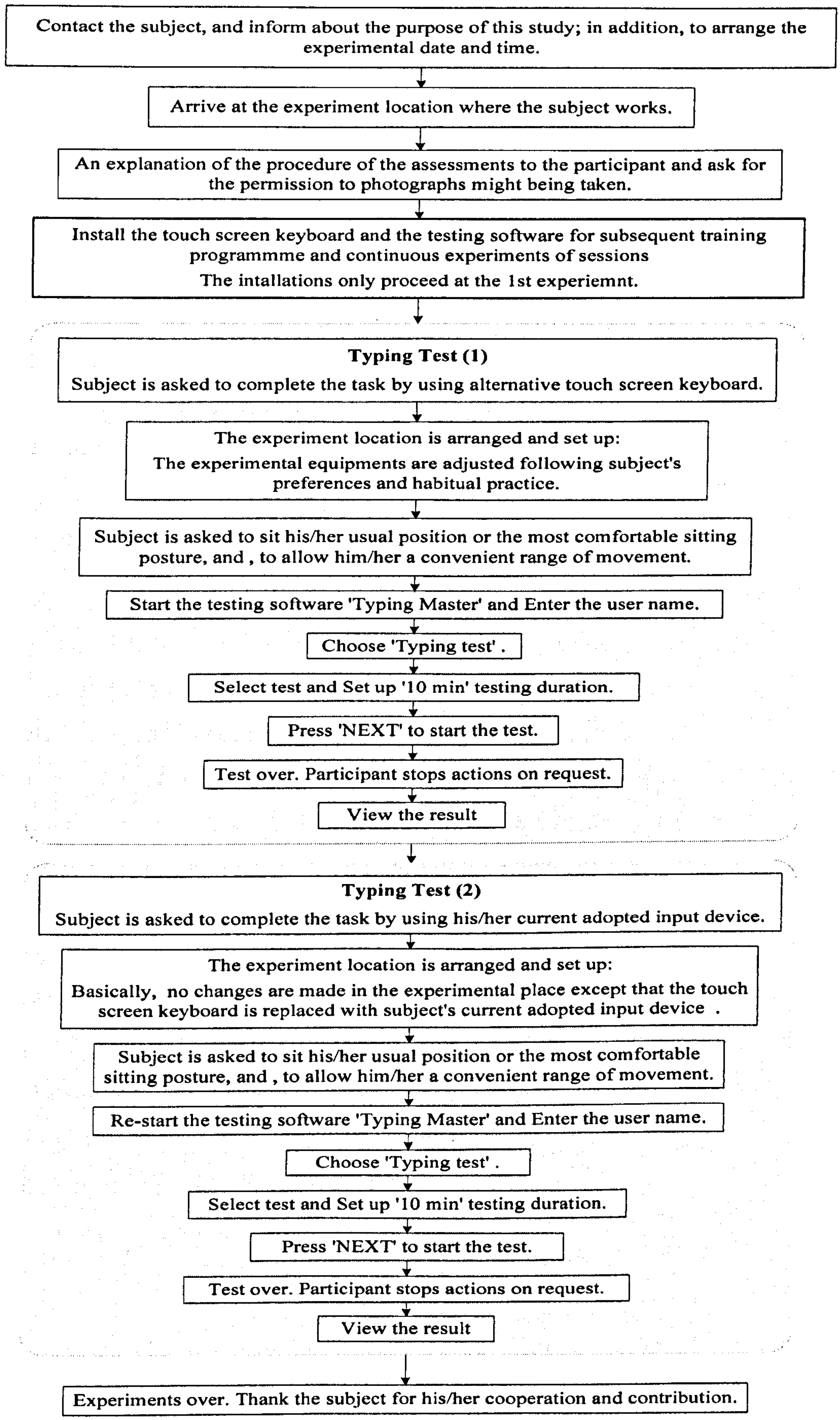


Figure 5-29 SOP of each experiment.

5.4.3 Results and Analysis

Following the previous validation assessments, consideration needed to be given to the participant's normal practice and preference, and also her comfort when adding a device in the subject's actual working area. The experimental results are shown in Section 5.4.3.2 and illustrate the outcomes for two-month period of device use. These include comparisons of typing performance between the touchscreen prototype and the subject's habitual input device. More attention went on the time spent on the touchscreen input during the two-month experimental period. The outcomes are described in Section 5.4.3.3. The users' response and attitude for the long-term period of touchscreen device use are described in Section 5.4.3.4.

5.4.3.1 Set-up for the Touchscreen Prototype

As described in Section 5.4.2.1, the normal practice of Subject 01 was to use a handstrip worn on her left hand in order to fasten an input pen to access an input device. In addition, her right thumb sometimes offered assistance in pressing some keys on the interface of the touchscreen prototype, as shown in Figure 5-30. Subject 01 needed to devote herself to the routine work every day and practice the touchscreen device in the spare time available. The subject was required to alternate between her normal keyboard and the touchscreen device during a normal working day.

In terms of the instrument set-up, the 9-inch touchscreen prototype needed to be raised with the use of some rigid material, so as to match the subject's viewing angle. This can be seen in Figure 5-31. However, the touchscreen device would occasionally slide down in use. Consequently, the hired carer needed to readjust the device. That is, the subject's hired carer provided necessary assistance when Subject 01 operated the touchscreen prototype during the three experimental phases.

Figure 5-30 Subject 01 operated with her left hand with handstrip and the thumb of the right hand.

Figure 5-31 Lift the touchscreen with some rigid material to adjust the touchscreen to fit the subject's viewing angle.

Table 5-13 The overall results when Subject 01 operated both on touchscreen and keyboard under the three conditional stages.

		Touchscreeen		Keyboard	
		Duration: 10 min.		Duration: 10 min.	
		Accuracy (%)	Gross/ Net Speed (wpm)	Accuracy (%)	Gross/ Net Speed (wpm)
Phase A	Session 1	80%	5 / 4	80%	7 / 6
	Session 2	95%	8 / 8	92%	8 / 7
	Session 3	98%	9 / 9	99%	9 / 9
Phase B	Session 4	100%	8 / 8	97%	10 / 10
	Session 5	100%	9 / 9	96%	10 / 9
	Session 6	96%	10 / 10	97%	10 / 10
	Session 7	99%	10 / 10	99%	11 / 11
	Session 8	99%	9 / 9	99%	10 / 10
	Session 9	98%	10 / 10	100%	10 / 10
Phase C	Session 10	99%	9 / 9	98%	10 / 10
	Session 11	100%	10 / 10	92%	7 / 7
	Session 12	98%	9 / 8	99%	10 / 10
	Session 13	94%	9 / 9	93%	10 / 9
AVERAGE		97%	9 / 9	95%	9 / 9

Gross speed = total hits / minutes
Net speed = (gross hits – error hits) / minutes
wpm = words in per minute

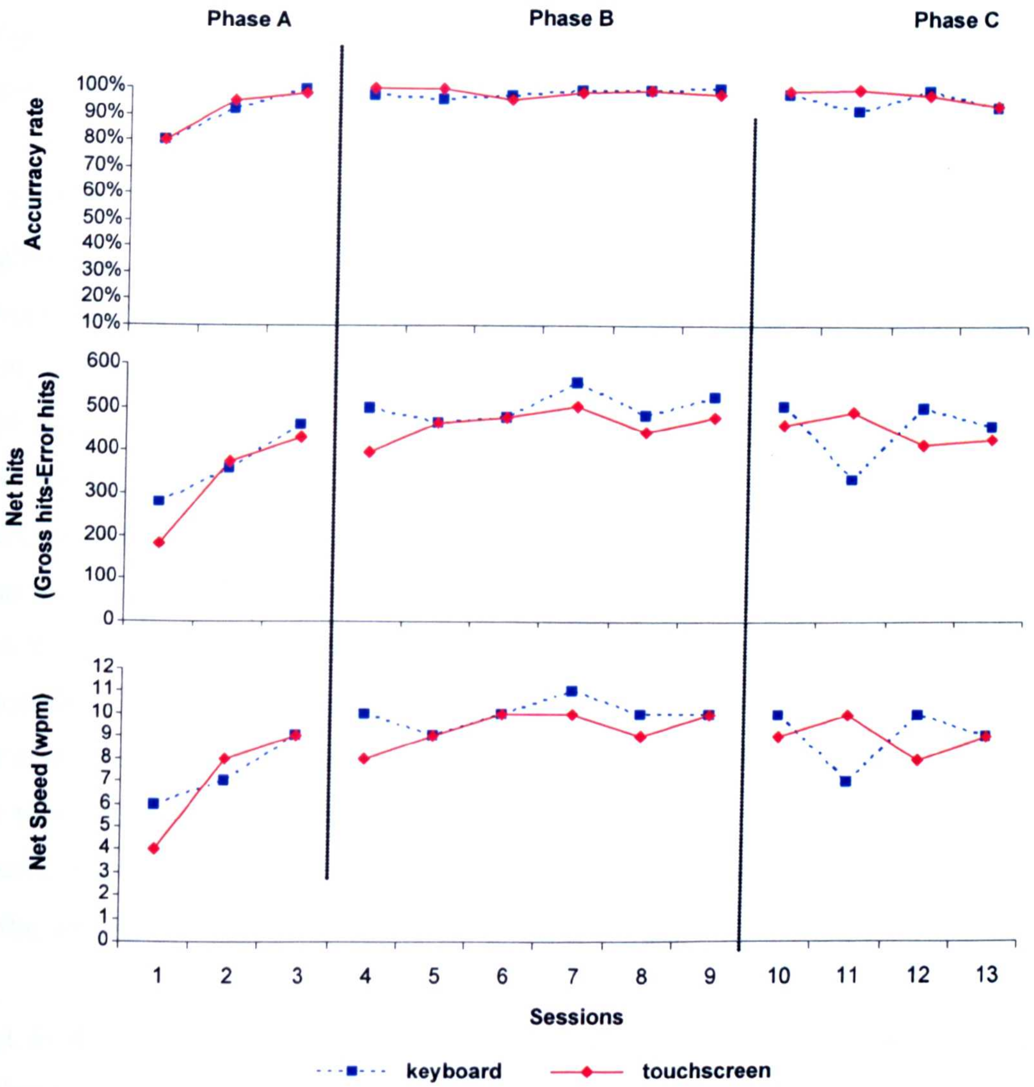


Figure 5-32 The input accuracy and net speed when subject operated both input devices under the three phases.

5.4.3.2 Experimental Outcomes

The experimental results demonstrated the development of typing performance of Subject 01 for the 9-inch touchscreen prototype during long-term use. Table 5-13 and Figure 5-32 show the subject's input accuracy and speed during three training stages. These involved a 10-minute typing test in each session and each session consisted of five working days. A total of 13 sessions made up the three stages in this study. In the ten-minute experimental periods results were gathered via the 'TypingMaster Pro' programme. Like the touchscreen input device with which Subject 01 was unfamiliar, the use of 'TypingMaster Pro' as a testing tool was also a fresh experience for her.

In Table 5-13, Subject 01's average accuracy, when using the touchscreen (97%) was slightly higher than that of her keyboard accuracy (95%). The data indicate obvious development of typing accuracy on both input devices, ranging from 80% to 97% when using the touchscreen device and between 80% and 95% when she used her own keyboard. It can be said that Subject 01 was able to operate the touchscreen device, that was new to her, as accurately as her normal keyboard, which she had used for three years. As indicated above, Subject 01 had offered herself to the former validation study at an introductory phase in 2004 and again joined in this long-term measure in 2005. As seen from her initial performance when using the 9-inch touchscreen prototype at the introductory phase, shown in Section 5.2, she had performed a similar 82.76% accuracy rate compared to the 80% accuracy outcome performed at her first session in this study but this after one and half years. From the above, it can be shown that, as an experienced computer user, the subject could easily operate a 9-inch touchscreen device for the first time

Next to the 80% accuracy achieved by both input devices in the first experimental section (Section 1), results in Figure 5-33 display an improvement in input accuracy with both the touchscreen device or the subject's own keyboard. For instance, Session 2 represents a significant improvement by 15%, ranging from 80% to 95% on the touchscreen prototype, and 12%, from 80% to 92% with the subject's keyboard, in the adaptation period. Significantly, in Sessions 4, 5, and 11, the subject achieved 100% accuracy by completing tasks with the touchscreen device. The accuracy in the adaptation period (Stage A) showed a range from 80% (lowest rate) to 98% (highest rate), which indicated that the performance of Subject 01 was not completely stable. Her operating performance improved greatly in the intensive intervention period (Stage B), followed by the follow-up period (Stage C) which maintained a high accuracy between 94% and 100% on the touchscreen prototype. However, in Section 11 of Stage C, as seen in Figure 5-33, an apparent low rate of accuracy was incurred by an unexpected interference (bowel movement) which resulted in the subject's distractions when testing with the habitual keyboard. In general, it can be seen that the accuracy rate was kept approximately constant within Stages B and C.

Speed was expressed in words per minute (wpm). The experimental outcomes demonstrated the development of typing performance for Subject 01 with the 9-inch touchscreen prototype during long-term use. Table 5-13 shows that Subject 01 had the same average net speed (9 wpm) when she operated either the touchscreen device or her own keyboard, after the 13 session typing tests. Figure 5-34 shows an overview of speed performance during the adaptation, intervention, and follow-up periods. Similar with accuracy performance, the net speed outcomes in Stage A, which was the period that Subject 01 adapted herself to the novel touchscreen prototype and the new testing software (i.e. TypingMaster Pro), revealed an unstable but a range of improvements between 4 wpm and 7 wpm. The subject achieved only 4 wpm on the touchscreen input device and 6 wpm on her normal keyboard in the first session. However, the typing speed for her own keyboard in Session 1 was found to be unexpected when compared with the results from the touchscreen device, which was new to the subject. One plausible explanation was that, the time and testing text were fixed when the typing speed was assessed by TypingMaster Pro, and she experienced pressure and could not perform to her ordinary typing standard (see Figure 5-34). In Stage A, the performance on both the touchscreen prototype and her normal keyboard was influenced by the lack of practice with the typing software. It gave disappointing results on input speed. In Stage B, the suggested time spent for practising with the touchscreen prototype had risen from 30-minutes in Stage A to at least one-hour per day. Accordingly, the enhancement of practice time reflected a gradual increase, ranging between 8 wpm and 10 wpm in this intervention period. It was noticed that a decrease in touchscreen performance occurred in Session 4 after several days without practice (an interval of 5 days between Stages A and B). Subject 01 achieved progress from 9 wpm to 10 wpm in speed but there was a small decrease in accuracy from 99% to 97% when using her own keyboard (Figure 5-33). Her speed performance with the touchscreen device, showed a reduction of 1 wpm, from 9 wpm to 8 wpm but with a rise of 2% in typing accuracy, improving from 98% to 100% (Figure 5-33) during Session 3 (Stage A) and Session 4 (Stage B). In the follow-up (Stage C), the use of the touchscreen device maintained a fairly constant level of speed performance. A significantly unusually low net speed performance was shown in Session 11 when Subject 01 undertook a typing test. As described earlier, an unanticipated incident (bowel movement) in the 11th experimental test (Stage C) resulted in a lower input accuracy (92%) and a disappointing input speed (7 wpm) with her normal input device.

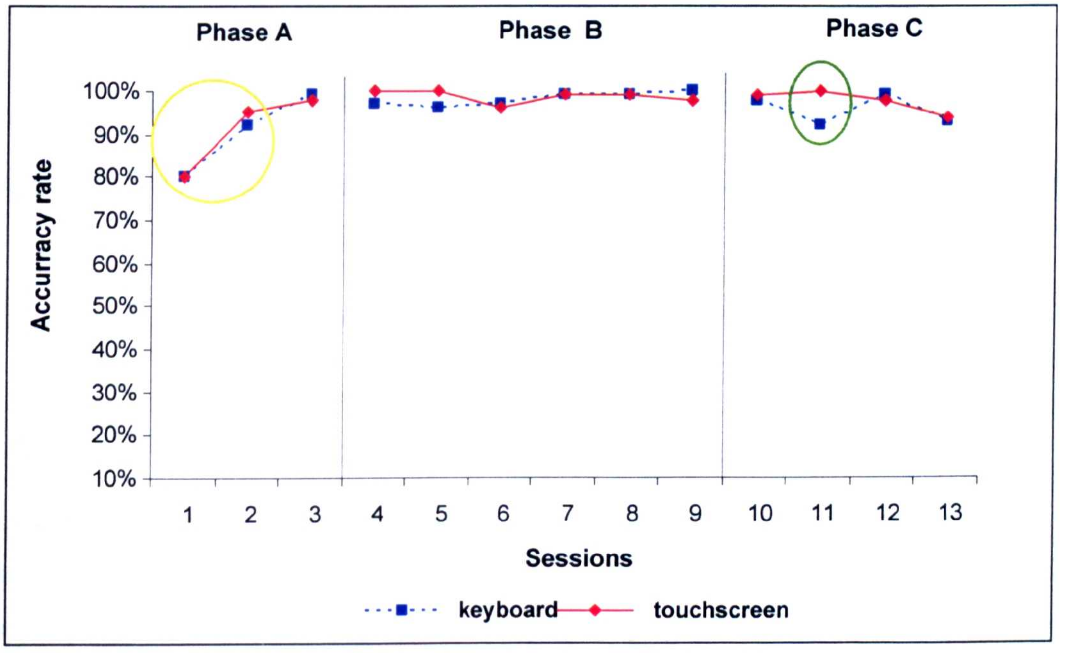


Figure 5-33 The overall results of accuracy of keyboard and touchscreen device.

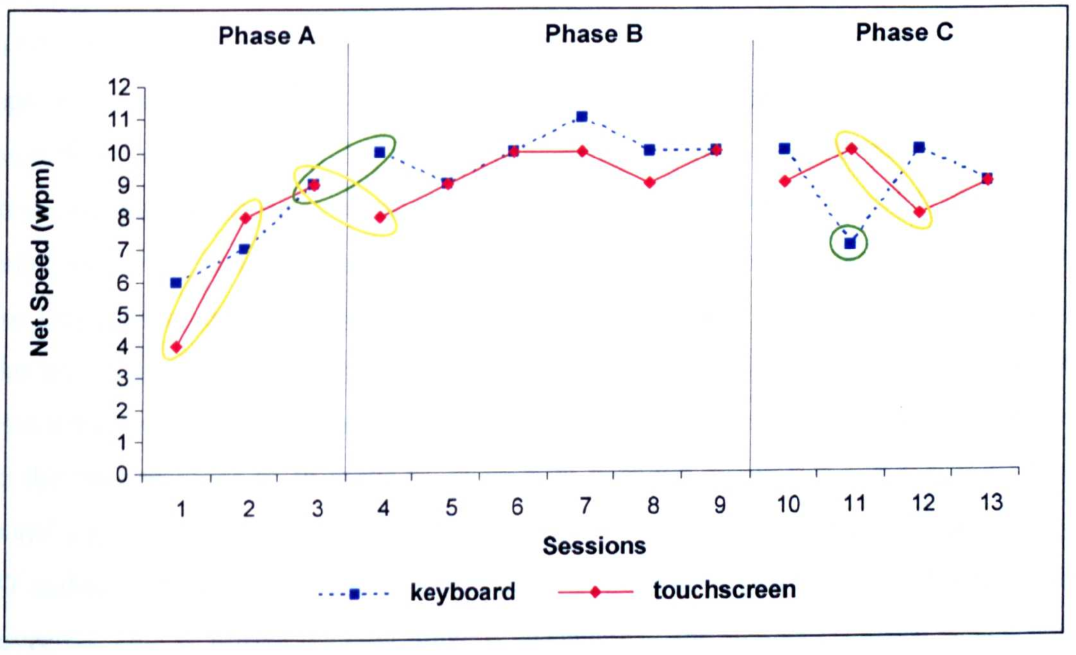


Figure 5-34 Speeds reached during the training period.

Figure 5-35 Over-stretch computer working posture between the touchscreen and the adopted keyboard.

5.4.3.3 Self-Practice Records

As stated during the long-term experimental period, Subject 01 had been expected to dedicate most of time to the routine computer work with her own keyboard and practise the novel touchscreen device in her spare time afterwards. The subject had to alternately operate between her normal keyboard and the 9-inch touchscreen prototype during a working day. Subject 01 had been advised to use the touchscreen input device for 30 minutes a day in the adaptation period (Stage A) and for one hour a day in the intensive intervention (Stage B). On the other hand, there was no restriction time for touchscreen operations in the follow-up period (Stage C). Table 5-14 and Figure 5-36 show the records of operating time of both touchscreen prototype and the subject's normal keyboard during the three experimental stages. In Stage A (Days 1 – 17), Subject 01 practised on the touchscreen prototype for over half an hour on a working day except for Day 5 (the subject had no use of a computer) and Day 12. Time spent in operating the touchscreen device in Stage B (Days 18 - 46) was increased more than Stage A. However, there was less practise time taken in the use of the touchscreen device shown in the later of Stage B. In Stage C, Subject 01 used the touchscreen prototype without constraints, and a significant reduction of practicing time was revealed between Days 47 and 64 in Figure 5-36. The decrease in her spontaneous practice under Stage C was revealed. That is, during the later Stage B and Stage C, the subject occupied herself with various work, such as an e-newspaper editor, an e-tutor, a trainee in an e-learning programme. She was required to attend daily online meetings with other colleagues. Due to the concerns of work effectiveness, she preferred to use her normal keyboard with which she was well-acquainted and which has been use over three years to accomplish most of her tasks rather than the unfamiliar new device. Also, as mentioned earlier, the touchscreen device occasionally slid down when in use; therefore, Subject 01's carer was in demand for readjusting the device during the operation. This became the second reason the subject did not use the new touchscreen device to complete her required work. In addition, the required support from other people (i.e. her personal carer) when using a technology troubled her and could be a potential reason that Subject 01 gradually reduced her practice during the later practice period.

Table 5-14 Records of operating time of the touchscreen prototype and the keyboard.

	OPERATING TIME			
DAY	TOUCHSCREEN	KEYBOARD	TOTAL	CATEGORY
1	0.7	5.3	6	Stage A
2	1.2	5.3	6.5	
3	0.9	4.1	5	
4	1.5	3.5	5	
5	0.0	0.0	0	
6	2.5	3.0	5.5	
7	1.2	3.8	5	
8	1.3	4.7	6	
9	0.8	3.3	4	
10	1.2	2.3	3.5	
11	1.2	2.8	4	
12	0.3	0.3	0.5	
13	1.3	4.7	6	
14	1.5	6.5	8	
15	1.0	5.5	6.5	
16	0.5	4.5	5	
17	1.2	4.8	6	
18	0.3	0.3	0.5	Stage B
19	2.2	3.3	5.5	
20	2.5	3.5	6	
21	1.2	2.8	4	
22	0.8	2.2	3	
23	1.3	2.7	4	
24	1.3	3.7	5	
25	1.8	3.2	5	
26	0.8	2.2	3	
27	1.3	2.7	4	
28	2.0	3.0	5	
29	2.3	4.2	6.5	
30	2.5	2.5	5	
31	2.3	3.7	6	

32	2.5	4.5	7	
33	2.3	3.7	6	
34	3.3	2.7	6	
35	3.7	3.3	7	
36	2.2	4.8	7	
37	1.0	7.0	8	
38	2.0	3.0	5	
39	0.8	7.2	8	
40	1.0	6.0	7	
41	0.8	6.2	7	
42	1.5	6.5	8	
43	1.0	7.0	8	
44	1.5	8.0	9.5	
45	0.8	7.2	8	
46	1.7	5.3	7	
47	0.0	0.0	0	Stage C
48	0.5	7.5	8	
49	1.0	7.0	8	
50	0.5	9.5	10	
51	0.8	7.2	8	
52	0.5	8.5	9	
53	0.5	7.5	8	
54	1.0	8.0	9	
55	1.0	9.0	10	
56	0.5	7.5	8	
57	0.3	9.7	10	
58	1.0	8.0	9	
59	0.7	7.3	8	
60	1.0	7.0	8	
61	0.0	0.0	0	
62	0.3	9.7	10	
63	0.7	8.3	9	
64	0.7	9.3	10	

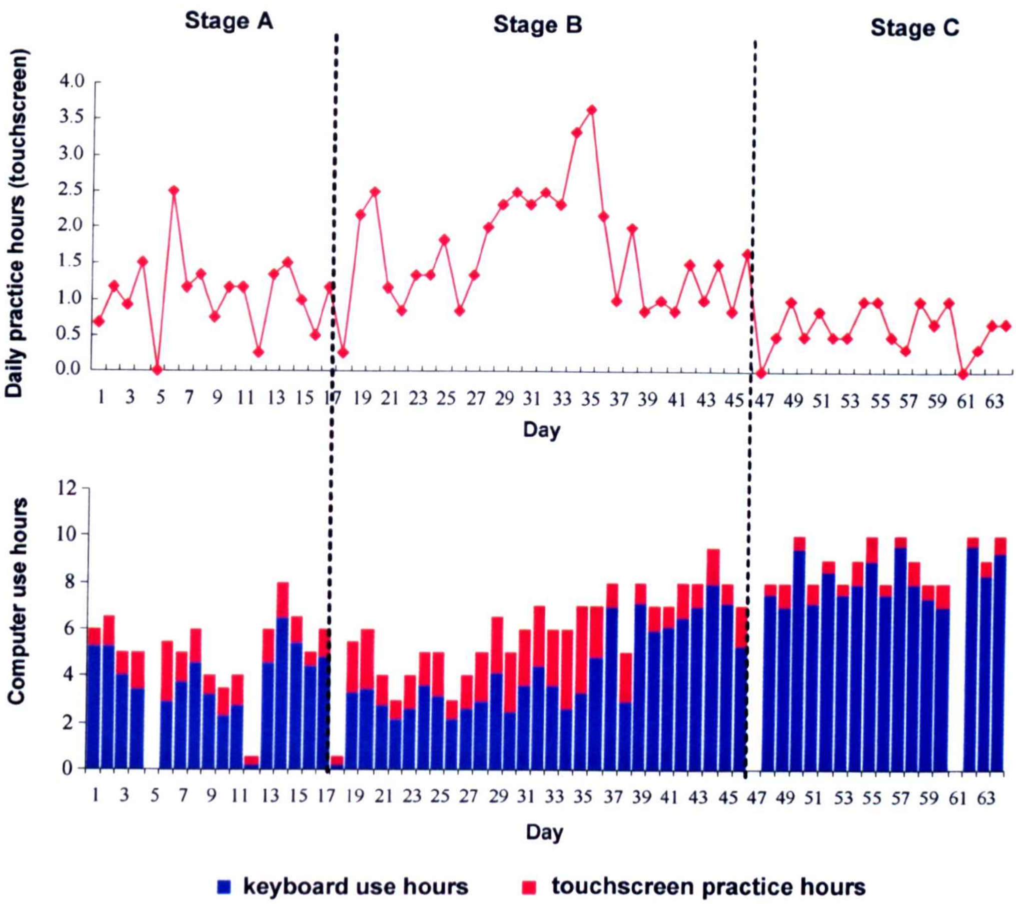


Figure 5-36 Subject's independent daily practice records during the training periods.

5.4.3.4 User Perspectives

Direct observation and unstructured interviews were used in order to obtain viewpoints of the long-term device user (Subject 01) and a better understanding of the user's special needs when operating the touchscreen prototype in the actual workplace, during the three stages. The subject's comments were derived from the continuous observation and the unstructured interviews during the two-month usability assessments. Like Section 5.2.3.4 (Study C) and Section 5.3.2.4 (Study D), the criteria of the SCI users' needs hierarchy (Figure 4-14) was applied again to evaluate the appropriateness of both devices. The rankings of the five required criteria were based on the experimental results and feedbacks from direction observation and unstructured interviews during the long-term usability assessments, as seen in Table 5-15.

Table 5-15 The user's perspectives of the use of the novel touchscreen prototype and her normal keyboard.

	DEVICE FEATURES														
	Single key-in operation			Easy to use			Reduce input tiredness			Accuracy			Speed		
INPUT DEVICE	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor
Touchscreen prototype	●			●			●			●			●		
Subject's keyboard			●			●		●		●			●		

★The range of accuracy: **Good** indicates a result ranged from 80% to 100%; **Average** indicates a result ranged from 50% to 79%; **Poor** indicates a result under 50%.
★The speed is marked based on the subject's standpoints.

Table 5-15 shows the rankings of the novel touchscreen prototype which had been practiced upon by the subject for two months (only in her spare time), and her normal keyboard, that had been frequently used for over three years in terms of the subject's own work experiences and attitude. The first is single input operation. The normal operating mode of Subject 01, i.e. the single input with an input pen worn by the handstrip, was from a small keyboard (as seen in Figure 5-25 and Figure 5-26) and had been used for three years. To be precise, the subject could not originally press a key and met great difficulties in operating the selected keyboard on her first trial. This lasted a year, including daily training and practice at least from 9 am to 5 pm, and was needed by the subject to achieve being able to work with the small keyboard after hundreds of attempts, adjustments and practices. It can be said that the small keyboard, which was selected and used by Subject 01, was not specifically designed for those users who have very limited upper-limb motion and who have to activate an input device by single inputs. Conversely, the novel touchscreen prototypes allowed the subject to use the device immediately (also referred to Study C) and matched her specific single key-in operating mode. The three years of computer working experience might have helped her to access to the new input device. The technology, which was specially designed for the users who can only work with an input device by single input operations (i.e. the touchscreen input devices), was deemed to be suitable for them and reduce certain levels of frustrations, especially for the computer beginners. Because of this, the subject marked the touchscreen device as Good and her normal keyboard as Poor in terms of single key-in operating mode.

The second criterion is ease of use. As mentioned earlier, Subject 01 participated in usability assessments at the introductory use (Study C, Section 5.2). The results showed that the 14 CSI subjects (including Subject 01) who were new to the novel touchscreeen prototypes, produced convincing and satisfying experimental results after approximately a one-hour instruction period in the initial use of the touchscreen device. In this study of long-term device use and measures (Study E), Subject 01 could easily operate the touchscreen input device after an interval of one year between the former Study C and the later Study E. Unlike the use of the new touchscreen devices, as mentioned earlier, considerable time had been taken by the subject to adjust herself to her normal keyboard. Therefore as it was easier to learn, Subject 01 gave the mark of Good to the novel touchscreen device and the Poor to her normal keyboard in terms of the criterion of easy to use.

There was a distinction between the two input devices. The use of the touchscreen device requires pressing keys with only light finger force but the keyboard users required comparatively heavier keystrokes. After two-month practice, the subject found that the lighter inputs with the new touchscreen device were more labour-saving than her normal keyboard for prolonged and intensive computer use. However, for a person with severe upper-limb impairments, such as Subject 01, it is difficult to change over to a different mode of operation in a short time. Subject 01 still could not control her keystroke force as well with the touchscreen device under the condition of alternating between two different operating modes during the long-term practice. Accordingly, because of loss of sensitivity in subject's fingers, the touchscreen reacted with a slow response to her over-gentle keystrokes, and reacted with an overly quick response to her forceful keystrokes.

Moreover, in this validation study of long-term device outcome measures, the touchscreen device, which was new to the subject, accomplished a similar level of typing performance to her normal keyboard during the long-term assessment period. It should be remembered, because of the subject's usual activities and routine work, that the new touchscreen device was only used in her spare time.

In summary, Table 5-15 provides an overview of the subject's perspectives after the longer-term use of the novel touchscreen prototype. In addition to the five criteria evaluated in Table 5-15, other findings were investigated during the two-month continuous observations. First, the dimensions of the device is a key issue for those users with severe physical impairments. In this long-term evaluation, the dimensions of Subject 01's normal keyboard were 15 cm in length, 10 cm in width, and 1 cm in height. In contrast, for the touchscreen prototype, the size of the computer keys and the interface were nearly the same compared with her own keyboard. However, the length of the touchscreen was increased to 25 cm, the width to 15 cm, and a height of 5 cm, after enclosing the interface in a rigid plastic covering (Figure 5-28). Consequently, the depth appeared to be overly thick for the subject and the touchscreen keyboard seems to be oversized when placed in subject's working area. In other words, a re-design and re-arrangement of the working area was required when adding the touchscreen device in the place. Second, light reflection caused by the flat-panel was a feature of the touchscreen input devices. As a user with cervical spinal cord injury, it is difficult for the subject to incline her upper body forward to view the screen, therefore, it was necessary to raise the touchscreen device with some rigid material and adjust its angle for fitting the users' line-of-sight (see Figure 5-31). Furthermore, the touchscreen device could slip in use over time, so her carer would have to repeatedly readjust the device during the practice time. Compared with the novel touchscreen prototype, there was no problems in set-up and viewing angle when using her habitual keyboard. Thirdly, the touchscreen prototype displayed a set of keys on a stationary and smooth surface. Unlike conventional keyboards, the users cannot sense the rebound effect when hitting keys on the flat-panel of the touchscreen device. It was not easy for a novice device user to press keys correctly without viewing the positions on the flat-panel of the touchscreen device. For Subject 01, who had used the 9-inch touchscreen device for two months, she still had to view both monitor and the flat-panel in use and that would slow her typing speed when operating the touchscreen device. On the contrary, the subject had no need to fix her eyes on the interface of her own keyboard all the time when inputting data because after over three years' experience of using her own keyboard. Consequently, longer-term practice of the touchscreen input device is recommended to accustom users to the interface and the new mode of operation. Fourthly, the awkward operating postures were an issue. Subject 01 had an awkward working postures possibly caused by the set-up of the input devices both for the 9-inch touchscreen prototype and her normal keyboard, that the subject had been using for 3 years, as seen in Figure 5-35. These inappropriate operating postures would overstretch the users' upper body, incur early operating fatigue and musculoskeletal disorders, and also could influence users' inclination of device selection and use. Then, the arrangement and set-up of an input device in the actual working milieu requires more consideration. Finally and more importantly, a fear of changes in operating mode for an experienced user as Subject 01 was found. Following the feedback showed in Section 5.4.3.4, the subject believed that the novel touchscreen device had better application to those users with single input operations, was easier to use, more labour saving and offered greater assistance in typing performance (i.e. accuracy and speed) compared to her normal keyboard. However, her normal keyboard took Subject 01 over three years of painstaking learning, adjustments and adaptation to build up to her present operating mode. Because of this, the subject was prejudiced against any other input devices and convinced that her own keyboard was the most applicable for herself after these years with computer work. For most computer users with severe physical disabilities, their preconceived notions about changing their current practice to a new input device would still cause them to suffer as many frustrations as in their previous experience. It stands to reason that the experienced users with cervical spinal cord injuries, such as Subject 01, would have fear of a different input device and consequently this would result in lack of motivation to use a new technology, which might be more suitable to the users with special needs, such as the newly developed touchscreen device. It was also found that the first experience of an input device plays a decisive role for those users with severe physical impairment. Providing an appropriate device for the first use of a computer would reduce the frustrations of adapting, increase learning efficiency, build up confidence in computer work, and encourage users to attempt other new technologies. The above points of view not only reveal the issues associated with the subject's actual computer operations but also provide the recommendations for design improvements for the novel touchscreen devices, such as the developed prototypes.

5.4.4 Summary of User-Centred Validation of Longer-Term Use

The novel touchscreen alternative device was provided in this study for the purpose of validating usability outcomes and comparing device performances with the subject's normal keyboard during longer-term outcome measures. As frequently indicated, a user is the core of studies related to assistive technology outcome measures. A user with a physical disability, such as spinal cord injury, has his/her personal and unique physical and psychological needs and deserves to be treated as an individual case. This is why the single-case experiment design, which emphasises reliable behavioural observations, continual experimentations, and individually analyses of each subject, was employed in a series of user-centred validation studies, including Studies C, D and E (also referred to Section 5.4.2). However, the single-case study method, which aims to explore one subject at a time, is a laborious, time-consuming and costly undertaking. In this longer-term validation study, the two-month research activities, including repeated experimental stages, observations and interviews, highlighted the methodological limitation in subject participation. Hence, there was only a single subject, i.e. Subject 01, who participated in this study as a case study for longer-term assistive technology usability measurements.

Longer-term outcome measures consisted of three evaluation stages, i.e. Stage A (adaptation period), Stage B (intensive intervention) and Stage C (follow-up). In addition, usability outcomes, including experimental results with the novel touchscreen prototype and the subject's normal keyboard, self-practice records and user perspectives, were demonstrated in this study. In terms of experimental result, Subject 01's average accuracy (97%) when using the touchscreen device was slightly higher than that of her own keyboard accuracy (95%); in addition, both input devices had an average net speed of 9 wpm. In other words, the data for typing accuracy indicated an improvement from 80% to 100% on both input devices. In speed performance, the net speed of the touchscreen device improved from 4 wpm to 10 wpm which represented a significant improvement of 6 wpm; in comparison to the net speed increase of 5 wpm for her normal keyboard, which increased from 6 wpm to 11 wpm. Briefly, the accuracy and speed performance on either the touchscreen prototype or the subject's own keyboard was swayed by the unfamiliar typing software (i.e. TypingMaster Pro) and gave inconsistent results but with a wide range of improvement in Stage A. In contrast, the use of both the touchscreen device and the keyboard maintained a fairly constant level of accuracy and speed performance in Stages B and C. In general, the experimental results indicated that the typing accuracy and speed on the novel touchscreen device which was new to Subject 01 can achieve a similar level of performance as her own keyboard, on which she had three and half years' experience in using after the two-month practice. As shown in the daily practice records, the time consumed in practising the touchscreen prototype had been gradually reduced between the later Stage B and Stage C. The principal reason was that the touchscreen prototype demanded support from other people, such as her hired carer. Because of this, Subject 01 would rather expend more time and strength on her own keyboard, which she can operate on her own than on the touchscreen prototype, which requires more support from others.

In user perspectives, compared with her normal keyboard which had been used for over three years, the touchscreen input device was recognised by the subject to be more suitable for single input operations, easier to use, reduced tiredness, and performed as effectively as the subject's normal keyboard. That is, the novel touchscreen device conformed to the criteria based on the needs hierarchy of SCI users for an input device selection and use (referred to Section 4.2), therefore, it can be validated as a suitable device. To be precise, the touchscreen operating mode can provide benefits to those users who suffer cervical spinal cord injuries and who operate a computer only by a single finger, an input pointer or other part of body. On the other hand, this specific operating mode requires only light tapping or sliding on the flat-panel. As is known to all, keyboarding is the customary way for inputting information into a computer. The users can sense the rebound effect from every keystroke when operating a conventional keyboard. However, for a person who sustained severe upper-limb impairments, such as Subject 01, each keystroke signifies frustration for her. In a sense, lighter keystrokes signify that input tiredness, caused by prolonged and repetitive computer operations, can be reduced; and further, the prevalent computer work-related musculoskeletal disorders may possibly be prevented. Another merit, such as easier use, was revealed. Unlike conventional input devices, the novel touchscreen input device, which has merged both keyboard and mouse functions, was agreed by Subject 01 to be easy to use. The acceptable typing performance summarised above was acknowledged by the subject.

Some suggestions for improvement of the touchscreen device were made. The novel touchscreen prototype was still under development. Some ergonomic considerations found during the evaluation period cannot be met 100% and require more attention, such as dimensional consideration for the touchscreen prototype, set-up of the touchscreen prototype, looking at both the monitor and the touchscreen interface at the same time, and control of keystroke force. Moreover, fear of changes in operating mode was revealed as a psychological barrier. Certain levels of frustration and numbers of adjustments over the length of time spent were encountered when Subject 01 adopted her normal keyboard. Her previous painstaking efforts and the fear of returning to a stage of adapting herself to a new device prejudiced the subject against any other new technology. Such psychological issues would influence a new technology selection and use and may become decisive in adoption and abandonment of an assistive device. Addressing the above issues, gathered from user perspectives, are pointed out as further recommendations for improving this novel assistive technology. In conclusion, the new validation strategy, focusing on both scientific and people-related issues, brought out not only the qualitative and quantitative evidence, but also suggestions for design improvement for the devices.

As indicated earlier, time is the key factor in the methodological limitations of subject participation, and also the critical concern in this study. This evaluation study, which required longer time to achieve research tasks, is a laborious and costly undertaking. As the author, who was the only researcher who conducted the series of evaluation studies, she was unable to continue the longer-term outcome measures or carry out the study with more subjects with spinal cord injures. Because of this, this study, which involved only a single subject, was used as a case study for longer-term outcome measures of an assistive technology.

5.5 Validation of Hypotheses

Three hypotheses, which presumed that the novel touchscreen input devices were a possible solution to those persons who have sustained a high level of spinal lesions and who cannot operate conventional input devices easily, were proposed in Section 5.1.3. To validate the hypotheses, advanced demonstration of the assistive device use and outcomes via a systemised sequence of usability assessments was needed. This chapter has highlighted three user-centred evaluation studies, including the outcome of device measures at the introductory phase (Section 5.2), short-term use and training effects phase (Section 5.3), and the long-term use and comparison phase (Section 5.4). In the usability assessments at the introductory phase (i.e. the foremost step of a series of validation studies), fourteen CSI subjects were divided into three groups, based on their varied level of motor limitations and their normal operating modes for measuring usability both on 5.7-inch and 9-inch touchscreen prototypes. In the user-centred validation, in the short-term training programme, two CSI subjects who had less experience of computer access participated in the two-week training programme of the 9-inch touchscreen prototype. The training effects on accuracy and speed performance were assessed and users' perspectives were gathered during the short-term device use. The last validation study focused on the long-term device use and outcome, there was only one CSI subject who had three and half years experience in computer access offered herself to join a two-month testing programme for the 9-inch touchscreen prototype. Single-subject experimental design was employed with three conditional phases. In this stage, not only experimental outcomes between the touchscreen prototype and the subject's normal keyboard, but also users' viewpoints and comments, were collected during three conditional phases. As a result, three hypotheses of this chapter were validated as follows:

- Hypothesis 1: the novel touchscreen alternative input was easy to use and applicable to persons with cervical spinal cord injuries

At the introductory phase, shown in Section 5.2; the 14 CSI participants, who had experience of using a computer for at least one year and who were new to the touchscreen input devices, were requested to input requested text as correctly as possible, but to ignore time and any input errors. The 14 CSI subjects in total achieved adequate input accuracy on the desktop 9-inch touchscreen prototype, ranging from 56.90% (Subject 03) to 100% (Subjects 06, 09, 10, and 15). In contrast, 8 subjects showed acceptable outcomes in their first use of the portable 5.7-inch prototype device and 6 subjects did not. The later had an accuracy of less than 50%. The 14 CSI experienced users were accustomed to operating conventional keyboards. The 9-inch device had similar key size and QWERTY layout as conventional keyboards. The portable 5.7-inch device was far smaller and displayed the ABC layout on the interface. In this initial validation stage, there is no doubt that both touchscreen alternative inputs allow the 14 experienced participants to activate them at their first use, including some subjects who deemed themselves slow learners, especially for the 9-inch touchscreen prototype. In addition to these 14 experienced persons with cervical spinal cord injuries, two SCI subjects, including Subject 21, who was as a stranger to the world of computers and Subject 22 who had less experience in computer use, teamed up in the short-term use and training programme in Section 5.3. Both subjects showed typing accuracy rates of 39% (Subject 21) and 68% (Subject 22) when they operated the 9-inch touchscreen prototype at their first-time attempts (Session 1). In Section 5.4, the longer-term outcome measures, the typing performance of Subject 01 on the novel touchscreen (80%) device was achieved as accurately as on the subject's three-and-half year habitual keyboard (80%) at the initial test. According to all the above experimental outcomes, the results indicated the touchscreen alternative inputs enabled those CSI subjects who had very limited upper-limb motion to operate them and achieve significant typing performance at their first attempt of device use.

Furthermore, in users' perspectives in Sections 5.2.3.4, 5.3.2.4 and 5.4.3.4, satisfaction and acceptability were expressed in terms of the perceived user-friendly interface, labour-saving operating method, quality and useful functions from either the CSI computer experienced users or beginners.

It can be said that both scientific-based and people-issue data validated that the portable 5.7-inch and desktop and 9-inch touchscreen alternative inputs are easy to use and labour-saving, and, therefore, allow those users with cervical spinal injuries to activate them at their first use, and to accomplish a convincing and satisfying performance.

- Hypothesis 2: the touchscreen input device was identified as being able to improve users' effectiveness and efficiency

This hypothesis can be validated by a sequence of experimental outcomes of user-centred validation studies. As indicated earlier, 'effectiveness' involves accuracy and completeness of the specific goals accomplished by device users; 'efficiency' can be related to resources regarding the accuracy and completeness with which users achieve special tasks. Measures of input devices, typing performance, comprised of accuracy and speed were required. The initial validation study displayed an acceptable level of accuracy and positive feedback derived from most of the CSI subjects at their first attempt of the touchscreen device utilisation. This was followed by the short-term use and training. The two-week training period clearly led to a statistically significant improvement in typing accuracy and speed on the novel touchscreen prototype between two CSI subjects who had no or less experience of computer operation. The accuracy performance of Subject 21 achieved a rise from 39% to 84%. His typing net speed developed by 2 wpm, from 0 wpm to 2 wpm during the two-week training. In contrast, an improvement of typing accuracy of Subject 22 developed from 68% to 94%. His typing net speed increased from 2 wpm to 8 wpm, which represented a significant improvement of 6 wpm. In the last stage of the validation studies, the experimental outcomes demonstrated the development of typing performance during the longer-term use of the touchscreen prototype, also, in the comparison of input efficiency and effectiveness with the subject's normal input device. The typing accuracy displayed a significant development from 80% to 100% on both the touchscreen prototype and the subject's own keyboard. In addition, the typing speed improved from 4 wpm to 10 wpm when using the touchscreen device and a development from 6wpm to 11 wpm from her normal keyboard. It can be noted that the experimental results indicated that the typing accuracy and speed on the novel touchscreen device, which was new to the subject achieved a similar level of typing performance as her own keyboard which she had used for three and half years during the two-month practice.

By merging the above experimental demonstrations, it can be seen that the touchscreen input device improved users' effectives and efficiency at the introductory phase, short-term and long-term utilisation. On the other hand, the use of the novel touchscreen input device could be as effective as users' habitual input device after a short-period of meaningful training and practice.

- Hypothesis 3: the novel touchscreen prototype would reduce time spent on adjustment and adaptation compared with subjects' current adopted input device

Individuals with spinal cord injuries have a unique and varied level of loss of motor function and sensation. Hence, a variety of ways and varying lengths of time were taken by each different SCI person to adjust and adapt him/herself to an input device. According to the feedback from interviewing 14 participants (Section 5.2), it was found that they spent at least one year to build up their operating methods. In Section 5.3, an example of how an unsuitable input device can become an impediment to the world of computers was shown. As demonstrated in the introductory phase, each experiment proceeded after approximately 45 minutes of instruction, including the researcher's demonstration and the subject's spontaneous practice. Following the users' response and device use outcomes, it can be said that those users with severe upper-limb impairments were able to operate the touchscreen input device and presented a satisfying performance at their first use. In the short-term use of the touchscreen prototype, changes in users' functional abilities and conspicuous improvements of typing performance were revealed by the two subjects who were unfamiliar with computer operation prior to the two-week training of the touchscreen device use. Compared with the subjects' previous experience in the use of conventional input devices, quicker adaptation was made with the touchscreen input device. Besides, in the long-term device use, Phase A gave unstable results but with a wide range of developments of typing performance on either the touchscreen input device or the subject's habitual keyboard. Next to the unstable Phase A, outcomes in Phase B and Phase C indicated that the novel touchscreen device which was new to the participant, can achieve a similar level of performance as her own keyboard which she had used for more than three years.

Most persons with cervical spinal cord injuries were forced to adapt themselves into an input device by sacrificing a great deal of time and making many attempts. The novel touchscreen input devices can be recognised to be user-friendly, effective, also easily accepted by most of the CSI subjects. Following the users' perspective in a series of validation studies, the touchscreen prototype could shorten the time spent on adaptation, decrease attempts and adjustments, spur on their confidence in computer access, and even enhance their input efficiency and effectiveness.

CHAPTER 6 CONCLUSIONS

6.1 Overview

It is believed that assistive technologies benefit people with disabilities improving an individual's quality of life. Assistive technologies enhance the independent functioning of these people, help them become more self-determining, facilitate community participation, and also raise an opportunity for return-to-work. Further, the widespread computer use fuels possibilities of freedom in their lives beyond the mere physical capability and dreams of accessing anyone, anywhere in the world. As persons, who have survived spinal cord injuries and are living with permanent disabilities, i.e. tetraplegia or paraplegia, computer use and skills enable them to gain post-injury employment and earning. The literature review in Chapter 2 revealed that an appropriate alternative input device is designed to offer useful support for these persons with physical disabilities to access the world of computers. It can also be said that a 'correct' assistive device can not only increase users' functional abilities, independence and spur on their confidence, but also decrease computer work-related musculoskeletal disorders post spinal-cord-injury. As such, the appropriateness of an input device is defined by the efficiency, effectiveness and satisfaction of assistive device use of the device users. However, the current state of assistive device outcome measures does not offer sufficient integration levels of psychosocial factors and experimental evaluation. For instance, the studies, which focused on psychosocial/psychometrical aspects, may immediately achieve user perception of device use, including user satisfaction, comfort, motivation, acceptability, etc., but they would be restricted by subjective or biased data and show a poverty of reliability and validity. On the other hand, although the scientific evidence can demonstrate its reliability and validation of device performance, the types of experimental studies have omitted a salient piece of the jigsaw - the user factor. In addition, they demonstrate no significant difference as with many other assessments. For these reasons, a specific research methodology, concerning both people-issue and scientific-evidence, was proposed for the studies related to assistive technology outcome measures and validated by a series of usability assessments of a novel touchscreen input device by subjects with spinal cord injuries. Moreover, as the research work involved subjects with spinal cord injuries the author was chiefly concerned with the ethical issues. Chapter 3 stated that this research study was guided by 'Ethical principles for conducting research with human participants', establishing in Codes of Conduct, Ethical Principles & Guidelines and publishing by British Psychological Society (BPS 2005). The ethical implications and psychological consequences for every SCI participant was individually considered and involved the consideration of the participants' perspectives, psychological welfare and dignity, health condition, and mutual respect and confidence between the researcher and the participant; further, consent from the participant, confidentiality, and the protection and privacy of participants, were a priority in this study.

The achievements of this research work are as follows:

- The integration of user-centred and scientific-based issues was proposed as a research methodology and validated by a series of usability assessments. These validation studies, conducted over three phases of device use, aimed to assess usability and suitability of the novel assistive devices at the SCI users' real-life workplaces;
- A novel needs hierarchy of input device selection and utilisation for persons with spinal cord injuries was theorised; these needs were ranked in order, beginning with the most basic at the bottom of the hierarchy to the highest at the top; furthermore, a review of the novel touchscreen input devices proposed as the possible solution was required in accordance with the established needs hierarchy;
- A approval of the research proposal was granted by the Human Research Ethics Committee (HREC), De Montfort University prior to the research, prior to the research study; in addition, the relevant ethical implications and psychological consequence for each participant were put into practice during the research investigation.
- A comprehensive diagnosis of the relationship between an assistive technology device and a disabled computer user and the influential factors of input device selection and use was established via the classification of varying degrees of

upper-limb function, operating performance and personal or technical assistance required by SCI individuals when accessing a computer;

- An exploration of latest information on alternative input devices for persons with spinal cord injuries was provided for either estimating the merits and demerits of the existing assistive devices or designating a possible solution (i.e. touchscreen alternative input devices) which had the great potential to match these users' special needs.

The major findings of this research work are summarised in the following sections.

6.1.1 Merging the User-Issue and Scientific-Evidence into a Research Methodology

A user is the true kernel of assistive technology outcome measures. Persons with spinal cord injuries, especially those with a high level of spinal lesions (i.e. cervical spinal cord injuries), were selected as the target participants in this study. Most of the studies in the field of assistive technology, too often, emphasise the physical aspects, i.e. users' physical limitations, functional capability, and the outcomes of technology use, but ignore the user's psychosocial needs and requirements of their real-life situations. A spinal cord injury is primarily caused by traumatic injuries. An able-bodied person suddenly cannot perform usual activities with both lower extremities (i.e. paraplegia); or even worse, is paralysed from the shoulder down (i.e. tetraplegia). Then it is easy to imagine that a SCI person not only encounters physical disabilities, but also confronts a great deal of psychological and social barriers. From the above points of view, a user's physical condition, psychosocial factors and psychological barriers are key factors to ultimately determine assistive technology selection and use. This inclination toward people issue necessitates being involved in measuring outcomes of an assistive technology.

By merging these above ideas, a research methodology, concerning both user issues and scientific evidence and mixing qualitative and quantitative approaches, was proposed and validated in this research study. This specific research technique was used to lead a systematic assistive technology evaluation, including an in-depth survey of SCI computer users and their real-life workplaces (Study A, Section 4.2), a pilot study simulated SCI subjects' physical condition of computer and discussed a dimensional issue of a touchscreen device (Study B, Section 4.3), a series of user-centred evaluation studies from the introductory phase (Study C, Section 5.2), short-term training and use (Study D, Section 5.3), to longer-term use and outcomes (Study E, Section 5.4).

6.1.2 SCI Users' Needs Hierarchy for an Input Device Selection and Use

The initial stage of these systematic assistive technology outcome measures is to obtain better understandings of special needs from those users with spinal cord injuries. An in-depth survey (Study A) was held to give an insight into the function abilities and limitations, habitual practice and preference, choices and utilisation of input devices, personal and/or technical assistance, environmental set-up and arrangements, and special requirements among the 34 experienced computer users with spinal cord injuries. The findings indicated that each individual with a spinal cord injury had his/her unique losses of motor function and sensation in different ways. As for persons who sustained cervical spinal lesions, who have limited or no voluntary control of upper-limb movements and muscle strength, commonly confront considerable difficulties in using a conventional keyboard and a mouse. It was observed that the common characteristic of CSI subjects was to operate an input device only by single key-in operation by his/her single finger (e.g. a fingertip or finger joint), wrist, mouth, additional assistive support, such as a handstrip for grasping an input pen, wrist and/or finger orthoses as a substitute finger, or a mouthstick. In addition, the musculoskeletal pains incurred by prolonged and repetitive computer operations was a prevalent problem among those computer workers with spinal cord injuries. Following the survey findings, every SCI participant emphasised that more improvements and alterations to their current input devices for facilitating computer operations and matching their needs were required. To be precise, there was a strong demand, for the selection of an appropriate input device, from those SCI users.

According to the findings of the contextual survey, a five-layer SCI users' needs hierarchy of input device selection and use was proposed. These needs were ranked in order; beginning with the most basic criterion at the bottom of the pyramid; lower-level criteria must be met before one moves on to the higher levels. The need for *single key-in operation* is laid out as the basis of the hierarchy, then *easy-to-use, lessening operating tiredness* presented as the third layer, followed by the expectation of increasing *input accuracy*, and enhancing *input speed* at the top as the highest layer of the pyramid. In other words, SCI sufferers, especially those with very limited upper-limb function, select an input device based, firstly on their operating modes, then according to whether the device was user-friendly and produced less tiredness. After meeting the satisfaction of lower level needs, the person's expectations of enhancing accuracy and speed performance would be motivated. If an input device achieves the criteria set up in the needs hierarchy, then a good match of person and technology will be achieved.

6.1.3 User-Centred Usability Assessments

Following the SCI users' needs hierarchy, the novel touchscreen input devices which matched the criteria set up in the hierarchy, were suggested as a possible solution for individuals with severe upper-limb impairments. However, a dimensional issue of the computer input device was pointed out, and therefore, it required the establishment of dimensional appropriateness of the suggested touchscreen device via the simulation of function movements of those SCI users before providing it to the real subjects. This simulation study, categorised as Study B, was conducted as a pilot study prior to a series of user-centred evaluation studies. Moreover, three hypotheses based on the SCI user's needs hierarchy and the previous survey findings were proposed to determine the suitability and usability of the novel touchscreen devices. They were (a) the novel touchscreen device was easy to use and applicable to persons with cervical spinal cord injuries; (b) the touchscreen device was identified as being able to improve users' effectiveness and efficiency; and (c) the touchscreen device would reduce time spent on adjustment and adaptation compared with subjects' current adopted input devices.

The proposed hypotheses were validated by a codified sequence of user-centred usability assessments, involving the outcome measures at the introductory phase (Study C), at the short-term use and training (Study D) and at the longer-term use and outcome comparisons (Study E), through the application of the integrated research methodology. In the introductory phase of the touchscreen utilisation, the experimental results and positive feedback were obtained from the 14 CSI experienced computer users. In addition to the experimental results, the concern of 'user-issue' provided information about the user's experiences in computer use, their normal practices, and the actual workplace arrangements and device set-ups. The outcomes shown in this study indicated that firstly all 14 CSI subjects were able to operate the novel touchscreen devices at their initial attempts and agreed that the touchscreen prototypes were easier to use and produced less tiredness than their normal input devices, i.e. conventional keyboards and mice. Secondly, it was found that the users' experiences and normal practices played a decisive role in either accepting or refusing an input device. The outcomes displayed at the stage of a short-term use and training of user-centred validation, included instrument and workplace set-up, training effects (i.e. typing accuracy and speed) and user perspective and acceptability. With the focus on people issues, two CSI subjects had encountered great frustrations in operating conventional input devices. The former unfortunate experiences, became a psychometric roadblock, reduced the subjects' desires to approach the world of computers and resulted in their unfamiliarity with computer operation. For that reason, attention was directed to researching the barriers to accessing a computer, involving an inspection of the subjects' operating modes, working postures, and alterations to their actual setting, in which the devices were used, prior to the successive experimentations, during the short-period training programme. Overcoming the subjects' physical and psychometric barriers were influential elements to bring about scientific improvements in accuracy and speed performance in the short-term device use. Moreover, the subjects' satisfaction and positive feedback from the use of the novel touchscreen prototype represented strong evidence of user-issues. The last step in a series of evaluation studies, the longer-term use outcomes, included experimental results from both the novel touchscreen input device and the subject's normal keyboard, self-practice records, and user perspectives. In terms of scientific-based demonstration, the results indicated that the typing accuracy and speed on the novel touchscreen device, which was new to the subject, achieved a similar level of performance as the keyboard she had used for three and half years, after the two-month practice period. However, there was an observed inconsistency between the scientific evidence and the self-practice records of time being taken in using the novel touchscreen input device. That is, as shown in the self-practice records, the time consumed in practising the touchscreen prototype had been gradually reduced during the long-term device use. The user-issue evidence, i.e. qualitative data, had offered reasonable explanations of the unmatched outcomes. In addition, it provided the information on the merits and demerits of the touchscreen prototype and the reasons which prejudiced users against a new input device, also, the users' expectations and willingness to be challenged.

6.1.4 Research Considerations

This research had some limitations. First, this research, involving human and disability ethics, met more difficulties in subject recruitment in the UK, than other types of studies. This research finally enlisted help in subject participations from three Taiwanese associations. It explains why most of the studies related to the SCI subjects were conducted in Taiwan. The second consideration was time. A total number of 34 SCI subjects participated in the in-depth contextual survey (Study A). The author, who was the only researcher in this research work, necessitated consuming between one and two days for each subject. In the usability assessments, at the introductory phase (Study C), a working day, from 9 am to 5 pm, was spent on each of the 14 CSI subjects. Then, a two-week period was taken by each of the 2 participants in the outcome measures at the short-term phase (Study D). The longer-term usability measures (Study E) required spending two months on a single subject. The author's research timetable, did not allow more subjects to take part in Study D and Study E, which entailed longer-term testing, observations and interviews. Third, funding remained one of the biggest obstacles in this research project. To have subjects participate from the initial attempt, then the intense short-term training, to the longer-term usability measures was the ideal research form. It has to be noted that this research luckily had SCI subjects, who gained no profit from participations, as the volunteers. However, with more financial support, the research project would enable a larger increase in subject numbers especially in the longer-term usability assessments, and also, to recruit one or more research assistants to undertake the laborious and time-consuming work. The above research constraints explained the whys and wherefores of some research shortcomings, and also highlighted the needs for this research project.

6.2 Summary

There is no doubt that a user is the core of assistive technology outcome measures. Each person who has participated has shown his/her unique physical and psychological barriers and life experiences. This research work would be meaninglessness without concern for people-issues. Hence, it is necessary to involve people-issues in the field of assistive technology outcome measures and placed them as a top priority for the research methodology. First, in terms of the user issues, they were concerned with user perspectives for device use, which refers to users' specific characteristics, motivation, personality, function limitations, post-injury experiences in computer use, usual activities, and a perceived discrepancy between desired and current situation. It provided information about the environment and psychosocial setting in which the computer is used, support from other people or assistive devices, and their choices of assistive devices for facilitating computer use. Second, the experimental approach used quantitative methods, which were employed in this study to provide scientific evidence and reliable demonstration in assistive device outcome measures. That is to say, the scientific data obtained from usability assessments from those SCI subjects was used to demonstrate validity and reliability of the effectiveness and efficiency of an assistive device.

In addition, as indicated frequently in the thesis, persons with spinal cord injuries have their specific needs when selecting and using an input device. In order to provide SCI operators with a suitable assistive device, it is necessary for the assistive technology developers and designer to clarity, identify, and predict their requirements in the early stage of designing an alternative input device. Furthermore, these established needs can be used to not only provide useful information to the product developers and designers, but also be used as the key elements and guide the usability measures of such assistive devices on those users with similar difficulties.

In summary, the research work documented in this thesis provides two major contributions to the field of AT outcome measures and assessments:

- A specific research methodology, integrating user-issues and scientific-evidence, was proposed as the key part of this research study and validated through a series of user-centred usability assessments of the novel touchscreen assistive devices among SCI subjects in their real-life workplaces.
- The unique SCI users' needs hierarchy of an input device selection and use was theorised to address the motivational needs of SCI users, especially those with severe upper-limb disorders, when selecting an input device.

CHAPTER 7 RECOMMENDATION FOR FUTURE WORK

7.1 Overview

This research work has contributed much to the field of assistive technology outcome measures. The standpoint of combining both people and scientific issues in a research methodology was strongly emphasised. The specific research methodology was proposed to help fill the gap between such studies merely based on psychosocial measures and the studies only concerned with scientific evidence. This research carried the conviction of the methodological integration that increased reliability and validity of the type of studies associated with assistive technology outcome measures, and therefore, can provide good support to match individuals, assistive device and the real-life setting(s). The research technique was demonstrated through a systemised sequence of usability assessments of novel touchscreen input devices on users with spinal cord injuries.

Many interesting issues arose during the research processes. Following the findings derived from the studies in this thesis, the choice and use of an assistive device is associated with different persons with disabilities. That is to say, the characteristics of the assistive technology have to take into account those users' varying personality traits, different levels of losses or functional limitation, various requirements and expectations, and thus dissimilar environmental conditions which directly affect technology utilisation. In future work, it will be necessary to further explore these issues in order to broaden the frame of assistive technology outcome measures. The recommendations for future work in this area of studies are summarised in the following sections.

7.1.1 Using the Proposed Research Technique as a Design Methodology

A research methodology, integrating user-issue consideration and scientific-based evidence, was proposed and validated by a sequence of case studies related to the novel touchscreen input devices, including pre-visiting and observational survey, and a sequence of usability assessments. With merging the specific research technique and a systematic measuring procedure, a conceptual model of assistive technology outcome measures has been built up and is suggested as a design methodology for this field of study. In addition, the model is designed to facilitate not only the researchers to look at the influence on people's use of assistive technologies from user perspectives and scientific validation, the therapists and counselling professionals to provide an assistive technology to match a user's actual needs, but also to help designers to improve their designs.

However, the improvement of the proposed design methodology hinges on continuing demonstration, involving a wider range of assistive devices and persons with other disabilities. To be precise, in this thesis, the conceptual model was applied and validated by measuring usability of the novel touchscreen input devices among the users with very limited upper-limb functional capability inherited from spinal cord injuries. In order to extend the form of this conceptual model for assistive technology outcome measures, the further application of this conceptual model can be used as a design methodology for different types of devices and users with other disabilities in practice. Moreover, the proposed usability measuring procedures are associated with device outcome measures at the introductory phase, short-term and longer-term use. However, first, for persons with disabilities requiring an assistive device for the first time, a great deal of effort and time is normally required. Second, trial or training periods with devices are sometimes needed, as some novel technologies require specific and new operating modes. Hence, the measuring usability at the initial attempt would probably not fit any user, especially those who have no or little experience in using the type of technology or who have very limited motor ability which would result in slow learning. Because of this, the merging of the outcome measure at the introductory phase and short-term training phase is suggested for future reconsideration.

7.1.2 Deriving a Programmable Formula for Valuing Usability of an Assistive Device

As emphasised frequently in this thesis, there is not only a scientific issue but also a user issue to consider when measuring the usability of an assistive device. In terms of the scientific issue associated to the technology itself, it is concerned with functional status, performance and utility; in terms of the user issue, especially the users with disabilities, such as spinal cord injury, both physiological limitation and psychological barriers need to be carefully considered. In order to correspond with the proposed content and form of AT measures and assessments, the suitability and usability of the newly developed touchscreen input prototypes were evaluated in terms of both scientific and user aspects via a series of user-centred assessments as seen in Studies C, D and E (Sections 5.2, 5.3, and 5.4).

A five-criterion SCI user's needs hierarchy was applied to the sequence of usability assessments. These criteria were ranked in the order in the hierarchy, beginning with the most basic criterion, *single key-in operation,* then *easy-to-use* and *lessening operating tiredness* presented as the primary and compulsory needs for those people with severe upper-limb disorders. After meeting the satisfaction of lower-level needs, the users' expectations of enhancing *accuracy* and *speed* performance would be motivated and are positional as the highest in the hierarchy. In this research project, the usability of the specific touchscreen input devices was investigated using the criteria established for this the hierarchy. On one hand, the criteria, i.e. *single key-in operation*, *easy-to-use* and *lessening operating tiredness,* associated with the user's different level of function and psychosocial barriers, the previous experiences of device use, and further, the natural of environment in which the assistive device is to be used, were attached to the user issue. The three factors in the field of user issue were gauged by the device user and the perspectives of device utilisation, and also, placed in rank order from Good, to Average, and to Poor. On the other hand, the level of effectiveness and efficiency for the touchscreen devices, correlating closely with *accuracy* and *speed,* was assessed by the experimental results as scientific-based evidence. It can be said that the level of usability achieved was confirmed by positive scientific measure outcomes and positive user feedback and the statement of usability could be contextual formulated as

$$\text{Usability confirmation} = \left(\begin{array}{c}\text{Positive}\\ \text{User feedback}\end{array}\right) + \left(\begin{array}{c}\text{Positive}\\ \text{Scientific measures}\end{array}\right)$$

$$\downarrow$$

$$U = a(O + E + F) + b(A + S)$$

A = Accuracy
B = Speed
E = Easy to use
F = Fatigue issue
O = Operating mode
U = Usability confirmation
a = weighting factor for physiological needs
b = weighting factor for the self-actualisation issue

In order to extend the scientific value of usability validation and expand the research work, producing a programmable formula for assessing usability of an assistive device would be a practicable idea for future work. The user-issue and scientific-based factors discussed above would need to be embodied in the usability formula as key elements. In this specific formula, for the purpose of accomplishing the maximum of usability score, it necessitates to obtain the higher subjective user satisfaction at the operating mode for the device use, easy to use, and fatigue issue; and also, the greatest objective accuracy rate and speed for task execution. A future problem might arise when deriving a programmable usability formula, such as gauging and weighing the established criteria and ranking scales and transferring the results of user issues and scientific evidences to a numerical ratio or analysis, and should also be considered.

7.1.3 Design Factors for Improving the Quality of the Specific Touchscreen Devices

The characteristics of assistive technology, such as design factors, were raised. Some ergonomic problems were found during the validation studies. As noted, the touchscreen prototypes were still under development, and some of its functions were not completely effective. First, the depth of the touchscreen prototypes appeared to be overly thick for some SCI subjects and deemed to be oversized when placed in the subjects' working area. Second, light reflections caused by the flat-panel was another negative feature of the touchscreen input devices, so that it was necessary to raise the touchscreen device with some rigid material and adjust its angle for fitting the users' line-of-sight. It is evident from the above that poor ergonomics could trouble the set-up and arrangement of the touchscreen prototype in a user's actual workplace, and, therefore, cause the user to adopt unsuitable working postures. Third, the over-stretching of the upper body would invite early operating fatigue and produce the possibility of computer work-related musculoskeletal disorders as a secondary injury post-SCI. As a result, some suggestions, such as smaller form factor, anti-glare surface, adjustable stand or articulated arm for holding the device and positioning it on the desk or users' wheelchairs, are proposed as design improvements for the touchscreen devices.

Furthermore, attention should be paid to the ergonomic design of either the technology itself or of the environmental arrangements and adjustment in further work. A revised design, taking into account these limiting factors, should be tested using the methodology set out in the thesis on suitable users.

7.2 Summary

The number of assistive technologies designed for enhancing independent functioning of people with disabilities are increasing rapidly. These devices need to be designed appropriately for the individual user. As frequently emphasised, the people issue, which is essential as a primary focus in the field of assistive technology, should lead the process of assistive technology development. Unlike other research approaches which mainly focus on empirical demonstrations of the functioning of this technology, this new research methodology, balancing user-issue and scientific-evidence, is proposed as a design methodology to provide stronger evidence of reliability and validity.

The following recommendations for future work in this area of studies are proposed. First, the conceptual model of assistive technology outcome measures was validated by the novel touchscreen input devices among the real subjects with spinal cord injuries. In any future study, attention needs to be paid to continuous use and refinement of the new methodology on other types of assistive technology and wider ranges of disabled users.

Second, the criteria gathered from the proposed conceptual model of AT outcome measures and the established SCI users' needs hierarchy can be linked up with the formulation of an equation for valuing usability of an assistive technology device. The provision of a programmable usability formula in the future is a likely development for valuing suitability of an assistive device and increasing the reliability and validity of measuring outcomes. Third, through the application of a conceptual framework for validating the touchscreen devices, further ergonomic concerns need to be taken into consideration to improve the quality of the touchscreen devices. Providing a systematic approach to ergonomic design not only enhances quality in use, usability, safety and comfort, but also minimizes risk factors associated with work-related musculoskeletal injury. Third, as described in earlier sections, this research study, associated with disability and human ethics, met great difficulties in participant recruitment in the UK. For the reason of obtaining an insight of users' practice in real-life situations, it is, therefore, hoped that ethical protection in the UK could be reviewed to allow this field of studies to take place more easily.

REFERENCES

AbilityNet. (2005). "Keyboard and Mouse Alternatives." AbilityNet Factsheet, http://www.abilitynet.org.uk/.

ABLEDATA. (1993). "Fact Sheet on Winter Sports and Recreation Equipment." ABLEDATA Database of Assistive Technology.

ABLEDATA. (1994). "Informed Consumer's Guide to Wheelchair Selection." ABLEDATA Database of Assistive Technology.

ABLEDATA. (1995). "Fact Sheet on Computer Access." ABLEDATA Database of Assistive Technology.

ABLEDATA. (1996). "ABLEDATA Informed Consumer's Guide to Assistive Technology for people with Spinal Cord Injuries." ABLEDATA.

ABLEDATA. (2002). "The guide to ABLEDATA indexing terms." Information for Independence, ABLEDATA Database of Assistive Technology.

ADA. (1990). "Americans with Disabilities Act of 1990." U. S. D. o. Justice, ed., U.S. Department of Justice, 101-336.

Akamatsu, M., and MacKenzie, I. S. (2002). "Changes in applied force to a touchpad during pointing tasks." *International Journal of Industrial Ergonomics*, 29(3), 171-182.

Albaugh, P. R., and Fayne, H. (1996). "The ET PA for predicting technology success with learning disabled students: Lessons from a multimedia study." *Technology & Disability*, 5(4), 313-318.

Albaugh, P. R., Piazza, L., and Scholsser, K. (1997). "Using a CD-ROM encyclopaedia: Interaction of teachers, middle school students, library media specialists, and the technology." *Research in Middle Level Education Quarterly*, 20(3), 43-55.

Amell, T., and Kumar, S. (2001). "Work-related musculoskeletal disorders: Design as a prevention strategy. A review." *Journal of Occupational Rehabilitation*, 11(4), 255-265.

Amell, T. K., and Kumar, S. (1999). "Cumulative trauma disorders and keyboarding work." *International Journal of Industrial Ergonomics*, 25, 69-78.

Amell, T. K., and Kumar, S. (2000). "Cumulative trauma disorders and keyboarding work." *International Journal of Industrial Ergonomics*, 25(1), 69-78.

Anderson, C. J., and Vogel, L. C. (2002). "Employment outcomes of adults who sustained spinal cord injuries as children or adolescents." *Archives of Physical Medicine and Rehabilitation*, 83(6), 791-801.

Anderson, J., Bricout, J. C., and West, M. D. (2001). "Telecommuting: Meeting the needs of businesses and employees with disabilities." *Journal of Vocational Rehabilitation* 16(2), 97 - 104

Andrich, R., Ferrario, M., and Moi, M. (1998). "A model of cost-outcome analysis for assistive technology." *Disability and Rehabilitation*, 20(1), 1-24.

Anson, D., George, S., Galup, R., Shea, B., and Vetter, R. (2001). "Efficiency of the Chubon versus the QWERTY keyboard." *Assistive Technology*, 13(1), 40-45.

ASIA/IMSP. (2001). *International standards for neurological and functional classification of spinal cord injury patients*, American Spinal Injury Association/ International Medical Society of Paraplegia, Chicago, IL.

Athanasou, J. A., Brown, D. J., and Murphy, G. C. (1996). "Vocational achievement following spinal cord injury in Australia." *Disability and Rehabilitation*, 18(4), 191-196.

Atkinson, S., Woods, V., Haslam, R. A., and Buckle, P. (2004). "Using non-keyboard input devices: interviews with users in the workplace." *International Journal of Industrial Ergonomics*, 33, 571-579.

Babski-Reeves, K., Stanfield, J., and Hughes, L. (2005). "Assessment of video display workstation set up on risk factors associated with the development of low back and neck discomfort." *International Journal of Industrial Ergonomics*, 35(7), 593-604.

Barlow, D. H., and Hersen, M. (1984). *Single-case experimental designs: strategies for studying behaviour changes*, Pergamon, New York.

Batavia, A. I., and Hammer, G. S. (1990). "Toward the development of consumer-based criteria for the evaluation of assistive devices." *Journal of rehabilitation research and development*, 27(4), 425-436.

BellaireElectronics. (2003). "CyKey Keybaord." Bellaire Electronics, Devon, UK.

Bergqvist, U., Wolgast, E., Nilsson, B., and Voss, M. (1995a). "The influence of VDT work on musculoskeletal disorders." *Ergonomics*, 38(4), 754-762.

Bergqvist, U., Wolgast, E., Nilsson, B., and Voss, M. (1995b). "Musculoskeletal disorders among visual display terminal workers: individual, ergonomic, and work organizational factors." *Ergonomics*, 38(4), 763-776.

Bertuca, D. J. (2001). "Letting go of the mouse: using alternative computer input devices to improve productivity and reduce injury " *OCLC Systems & Services* 17(2), 79 - 83

Blatter, B. M., and Bongers, P. M. (2002). "Duration of computer use and mouse use in relation to musculoskeletal disorders of neck or upper limb " *International Journal of Industrial Ergonomics*, 30, 295-306.

Boulton, W. R. (1995). "Building the electronic industry's roadmaps." Japanese technology Evaluation Center (JTEC), Maryland.

BPS. (2005). "Ethical Principles for conducting Research with Human Participants." Code of Conduct, Ethical Principles & Guidelines, The British Psychological Society (BPS), Leicester, 8-12.

Bricout, J. C. (2004). "Using telework to enhance return to work outcomes for individuals with spinal cord injuries." *Neurorehabilitation*, 19(2), 147-159.

Brooks, N. A. (1991). "User's responses to assistive devices for physical disability." *Social Science & Medicine*, 32(12), 1417-1424.

Brown-Triolo, D. L. (2002). "Understanding the person behind the technology." Assistive Technology: Matching Device and Consumer for Successful Rehabilitation, M. J. Scherer, ed., American Psychological Association, Washington, DC, 32.

Bryman, A. (2004). "Research designs." Social Research Methods Oxford Univeristy Press Inc., New York, 26-58.

Cail, F., and Aptel, M. (2003). "Biomechanical stresses in computer-aided design and in data entry." *International journal of occupational safety and ergonomics* 9(3), 235-255.

Cakir, A. (1995). "Acceptance of Adjustable Keyboard." *Ergonomics*, 38(9), 1728-1744.

Campbell, D. T., and Stanley, J. C. (1963). "Problem and Background." Experimental and quasi-experimental designs for research Houghton Mifflin Company, Boston, 1-5.

Carter, J. B., and Banister, E. W. (1994). "Musculoskeletal problems in VDT work: A review." *Ergonomics*, 37(10), 1623-1648.

Chang, J. H. (2004). "A study of an integrated design of an alternative computer input device and personal digital assistant.," Master, National Taiwan University, Taipei, Taiwan.

Cheetham, J., Fuller, R., McIvor, G., and Petch, A. (1992a). "Methods of data collection." Evaluating social work effectiveness, Open University Press, Buckingham, 37-47.

Cheetham, J., Fuller, R., McIvor, G., and Petch, A. (1992b). "Review of evaluative strategies." Evaluating social work effectiveness, Open University Press, Buckingham, 21-36.

Chen, Y. L., Chen, W. L., Kuo, T. S., and Lai, J. S. (2003). "A head movement image (HMI)-controlled computer mouse for people with disabilities." *Disability and rehabilitation.*, 25(3), 163-167.

CherryCorporation. (2005). "Cherry G84-4100 Keyboard." Cherry Electrical Products Ltd. , Luton, Beds, United Kingdom.

Clarke, A., and Dawson, R. (1999a). "Methods of data collection." Evaluation Research: An Introduction to Principles, Methods and Practice, Sage Publications Ltd, London, 64-92.

Clarke, A., and Dawson, R. (1999b). "Quantity and Quality: Paradigmatic Choices in Evaluation Methodology." Evaluation Research: An Introduction to Principles, Methods and Practice, Sage Publications Ltd, London, 35-63.

Coll, R., Zia, K., and Coll, J. H. (1994). "A comparison of three computer cursor control devices: pen on horizontal tablet, mouse and keyboard." *Information & Management*, 27(6), 329-339.

Colle, H. A., and Hiszem, K. J. (2004). "Standing at a kiosk: Effects of key size and spacing on touch screen numeric keypad performance and user preference." *Ergonomics*, 47(13), 1406-1423.

Compusult. (2006). "Jouse 2 joystick-operated mouse ", Compusult Limited, Mount Pearl, NF.

Cook, A. M., and Hussey, S. M. (1995). "A Framework for Assistive Technologies." Assistive Technologies: Principles and Practice, Mosby, St. Louis, Missouri, 45-75.

Cook, T. D., and Campbell, D. T. (1979). *Quasi-experimentation : design & analysis issues for field settings* Rand McNally, Chicago.

Cooper, A., and Straker, L. (1998). "Mouse versus keyboard use: A comparison of shoulder muscle load." *International Journal of Industrial Ergonomics*, 22(4-5), 351-357.

Cooper, R. A. (1998). *Wheelchair Selection and Configuration* Demos Medical Publishing, Inc, New York.

Coury, H. (2005). "Time trends in ergonomic intervention research for improved musculoskeletal health and comfort in Latin America." *Applied Ergonomics*, 36(2), 249-252.

Covington, G. A., and Hannah, B. (1996). *Access by Design*, John Wiley & Sons.

Curtis, K. A., Drysdale, G. A., Lanza, R. D., Kolber, M., Vitolo, R. S., and West, R. (1999). "Shoulder pain in wheelchair users with tetraplegia and paraplegia." *Archives of physical medicine and rehabilitation*, 80(4), 453-457.

Cushman, L. A., and Scherer, M. J. (1996). "Measuring the relationship of assistive technology use, functional status over time, and consumer-therapist perceptions of ATs." *Assistive Technology*, 8(2), 103-109.

Cushman, W. H., and Rosenberg, D. J. (1991). *Human Factors in Product Design*, Elsevier, Amsterdam.

Dabbs, J. M. (1982). "Making things visible." Varieties of qualitative research J. v. Maanen, J. M. Dabbs, and R. R. Faulkner, eds., Sage Publications, Inc, Beverly Hills, CA, 31-63.

Day, H., and Jutai, J. (1996). "Measuring the psychosocial impact of assistive device: The PIADS." *Canadian Journal of Rehabilitation*, 9, 159-168.

Day, H., Jutai, J., and Campbell, K. A. (2002). "Development of a scale to measure the psychosocial impact of assistive devices: lessons learned and the road ahead." *Disability and Rehabilitation*, 24(1-3), 31-37.

Day, H., Jutai, J., Woolrich, W., and Strong, G. (2001). "The stability of impact of assistive devices." *Disability and rehabilitation*, 23(9), 400-404.

De Treville, S., Antonakis, J., and Edelson, N. M. (2005). "Can standard operating procedures be motivating? Reconciling process variability issues and behavioural outcomes." *Total Quality Management & Business Excellence*, 16(2), 231-241.

Dejong, G., Branch, L. G., and Corcoran, P. J. (1984). "Independent Living Outcomes in Spinal-Cord Injury - Multivariate Analyses." *Archives of Physical Medicine and Rehabilitation*, 65(2), 66-73.

Delisle, A., Imbeau, D., Santos, B., Plamondon, A., and Montpetit, Y. (2004). "Left-handed versus right-handed computer mouse use: effect on upper-extremity posture " *Applied ergonomics*, 35, 21-28.

Demers, L., Weiss-Lambrou, R., and Ska, B. (1996). "Development of the Quebec User Evaluation of Satisfaction with assistive Technology (QUEST)." *Assistive Technology*, 8(1), 3-13.

Demers, L., Weiss-Lambrou, R., and Ska, B. (2000). "Item analysis of the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST)." *Assistive Technology*, 12(2), 96-105.

Demers, L., Wessels, R., Weiss-Lambrou, R., Ska, B., and De Witte, L. P. (1999). "An international content validation of the Quebec user evaluation of satisfaction with assistive technology (QUEST)." *Occupational Therapy International*, 6(3), 159-175.

Denzin, N. K. (1970a). "The experiment and its variations." The research act in sociology: the theoretical introduction to sociological methods Butterworths, London, 147-163.

Denzin, N. K. (1970b). "Strategies of multiple triangulation." The research act in sociology: the theoretical introduction to sociological methods Butterworths, London, 297-313.

DeRuyter, F. (1995). "Evaluating outcomes in assistive technology: do we understand the commitment?" *Assistive technology* 7(1), 3-16.

DeRuyter, F. (1997). "The importance of outcome measures for assistive technology service delivery systems." *Technology and Disability*, 6, 89-104.

Devereux, J. J., Vlachonikolis, I. G., and Buckle, P. W. (2002). "Epidemiological study to investigate potential interaction between physical and psychosocial factors at work that may increase the risk of symptoms of musculoskeletal disorder of the neck and upper limb." *Occupational and Environmental Medicine*, 59(4), 269-277.

DfEE. (1995). "Disability Discrimination Act 1995 (DDA1995)." D. f. E. a. E. (DfEE), ed., UK Statutes Crown.

DHHS(NIOSH). (1995). "Ergonomics and Prevention of Musculoskeletal Injuries." Cumulative trauma disorders in the workplace: bibliography, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human services (DHHS), Washington, DC, 133-142.

DonJohnston. (2006). "Jelly Bean Switch ", Don Johnston Incorporated, Volo, IL

Drainoni, M.-L., Houlihan, B., Williams, S., Vedrani, M., Esch, D., Lee-Hood, E., and Weiner, C. (2004). "Patterns of internet use by persons with spinal cord injuries and relationship to health-related quality of life." *Archives of Physical Medicine and Rehabilitation*, 85(11), 1872-1879.

Dvorak, A. (1943). "There is a better typewriter keyboard." *Natl Business Educ Quart*, 12(2), 51-58.

DWP. (2006). "Updated estimate of the numbers of disabled people including people with limiting longstanding illnesses, and their associated spending power." D. f. W. a. Pensions, ed., Department for Work and Pensions.

Edyburn, D. (2003). "Measuring Assistive Technology Outcomes: Key Concepts." *Journal of Special Education Technology*, 18(1), 53-55.

Eggers, J., Feillet, D., Kehl, S., Oliver Wagner, M., and Yannou, B. (2003). "Optimization of the keyboard arrangement problem using an Ant Colony algorithm." *European Journal of Operational Research*, 148(3), 672-686.

EPA. (2001). "Introduction." Guidance for Preparing Standard Operating Procedures (SOPs), The U.S. Environmental Protection (EPA) Agency, Washington, DC, 1-2.

Evans, D. G., Drew, R., and Blenkhorn, P. (2000). "Controlling mouse pointer position using an infrared head-operated joystick." *IEEE transactions on rehabilitation engineering* 8(1), 107-17.

Fagarasanu, M., and Kumar, S. (2003). "Carpal tunnel syndrome due to keyboarding and mouse tasks: a review." *International Journal of Industrial Ergonomics*, 31(2), 119-136.

Fagarasanu, M., Kumar, S., and Narayan, Y. (2005). "The training effect on typing on two alternative keyboards." *International Journal of Industrial Ergonomics*, 35(6), 509-516.

Fallentin, N., Viikari-Juntura, E., Waersted, M., and Kilbom, A. (2001). "Evaluation of physical workload standards and guidelines from a Nordic perspective." *Scandinavian Journal of Work Environment & Health*, 27, 1-52.

Faucett, J., and Rempel, D. (1994). "Vdt-Related Musculoskeletal Symptoms - Interactions between Work Posture and Psychosocial Work Factors." *American Journal of Industrial Medicine*, 26(5), 597-612.

Feuerstein, M., Armstrong, T., Hickey, P., and Lincoln, A. (1997). "Computer keyboard force and upper extremity symptoms." *Journal of Occupational and Environmental Medicine*, 39(12), 1144-1153.

Finsen, L., Sogaard, K., and Christensen, H. (2001). "Influence of memory demand and contra lateral activity on muscle activity." *Journal of electromyography and kinesiology* 11(5), 373-380.

Fuhrer, M. J. (1999). "Assistive Technology Outcomes Research: Impressions of an Interested Newcomer." International Conference on Outcome Assessment in AssistiveTechnology Oslo, Norway

Fuhrer, M. J. (2001). "Assistive technology outcomes research: challenges met and yet unmet." *American Journal Of Physical Medicine & Rehabilitation / Association Of Academic Physiatrists*, 80(7), 528-535.

Fuhrer, M. J., Jutai, J. W., Scherer, M. J., and DeRuyter, F. (2003). "A framework for the conceptual modelling of assistive technology device outcomes." *Disability And Rehabilitation*, 25(22), 1243-1251.

Galliers, R. D. (1992). "Choosing Information Systems Research Approaches." Information Systems Research: Issues, Methods and Practical Guidelines, R. D. Galliers, ed., Henley-on-Thames, Alfred Waller, 144-162.

Galvin, J. C., and Scherer, M. J. (1996). *Evaluating, Selecting, and Using Appropriate Assistive Technology*, Aspen Publications, Gaithersburg, MD.

Gatti, N., Matteucci, M., and Sbattella, L. "An Adaptive and Predictive Environment to Support Augmentative and Alternative Communication." *Computers Helping People with Special Needs, 9th International Conference, ICCHP 2004*, Paris, France, 983-990.

Gerard, M. J., Jones, S. K., Smith, L. A., Thomas, R. E., and Wang, T. (1994). "An Ergonomic Evaluation of the Kinesis Ergonomic Computer Keyboard." *Ergonomics*, 37(10), 1661-1668.

Gerhart, K. A. (1991). "Spinal cord injury outcomes in a population-based sample." *The Journal of trauma*, 31(11), 1529-1535.

Gips, A., DiMattia, P. A., and Gips, J. "The effect of assistive technology on educational costs: two case studies." *Computers Helping People with Special Needs, 9th International Conference, ICCHP 2004*, Paris, France, 206-213.

Gironda, R. J., Clark, M. E., Neugaard, B., and Nelson, A. (2004). "Upper limb pain in a national sample of veterans with paraplegia." *The journal of spinal cord medicine*, 27(2), 120-127.

Gitlin, L. N. (2002). "Assistive technology in the home and community for older people: psychological and social considerations." Assistive technology matching device and consumer for successful rehabilitation, M. J. Scherer, ed., American Psychological Association, Washington, DC, 109-122.

Gold, R. L. (1969). "Roles in sociological field observations." Issues in participant observation: a text and reader, G. J. McCall and J. L. Simmons, eds., Addison-Wesley, London, 30-38.

Hales, T. R., Sauter, S. L., Peterson, M. R., Fine, L. J., Putzanderson, V., Schleifer, L. R., Ochs, T. T., and Bernard, B. P. (1994). "Musculoskeletal Disorders among Visual-Display Terminal Users in a Telecommunications Company." *Ergonomics*, 37(10), 1603-1621.

Hammersley, M. (1992). "Deconstructing the qualitative-quantitative divide." What's wrong with Ethnography?, Routledge, London, 159-173.

Harr'e, R. (1985). *The philosophies of science: an introductory survey*, Oxford University Press, Oxford.

Harris, F., and Sprigle, S. (2003). "Cost analyses in assistive technology research." *Assistive Technology*, 15(1), 16-27.

Harrison, G. W., and List, J. A. (2004). "Field Experiments." *Journal of Economic Literature*, XLII, 1009-1055.

Hart, C. (1998). "The literature review in research." Doing a Literature Review : Releasing the Social Science Research Imagination, Sage Publications Ltd., London, 1-25.

Haufler, A. J., Feuerstein, M., and Huang, G. D. (2000). "Job stress, upper extremity pain and functional limitations in symptomatic computer users." *American Journal of Industrial Medicine*, 38(5), 507-515.

Hawking, S., and ATAccess. (2000a). "Product Descriptions: Alternate Input." Computer and Web Resources for People with Disabilities: A guild to Exploring Today's Assistive Technology, Hunter House Inc., Alameda CA, 173-209.

Hawking, S., and ATAccess. (2000b). "A Review of the Technology Tools." Computer and Web Resources for People with Disabilities: A guild to Exploring Today's Assistive Technology, Hunter House Inc., Alameda CA, 43-62.

Healy, A. F., Kole, J. A., Buck-Gengler, C. J., and Bourne, J. L. E. (2004). "Effects of Prolonged Work on Data Entry Speed and Accuracy." *Journal of Experimental Psychology: Applied*, 10(3), 188-199.

Hedge, A., and Powers, J. R. (1995). "Wrist postures while keyboarding: Effects of a negative slope keyboard system and full motion forearm supports." *Ergonomics*, 38(3), 508-517.

Hersen, M., and Barlow, D. (1987). *Single-case experimental design: strategies for studying behaviour changes* Pergamon Press, New York.

Hess, D. W., Ripley, D. L., McKinley, W. O., and Tewksbury, M. (2000). "Predictors for return to work after spinal cord injury: A 3-year multicenter analysis." *Archives of Physical Medicine and Rehabilitation*, 81(3), 359-363.

Hesse, B. W. "Curb cuts in the virtual community: telework and persons with disabilities " *28th Hawaii International Conference on System Sciences (HICSS '95)*, 418-425.

Hobday, S. W. "A keyboard to increase productivity and reduce postural stress." *The Annual International Industrial Ergonomics and Safety Conference*, New 0rleans, 321 - 330

Holstein, J. A., and Gubrium, J. F. (1997). "Active interview." Qualitative Research: Theory, Method and Practice, D. Silverman, ed., Sage publications, London, 113-129.

Holzinger, A. "Finger instead of mouse: touch screens as a means of enhancing universal access." *Universal Access: Theoretical Perspectives, Practice, and Experience*, Paris, France, 387-397.

Hurst, W. (2000). "User interfaces for telepresentations -- Input devices, interaction concepts and design issues." *Journal of Network and Computer Applications*, 23(1), 1-15.

Hwang, F., Keates, S., Langdon, P., Clarkson, P. J., and Robinson, P. "Perception and haptics: towards more accessible computers for motion-impaired users." *The 2001 workshop on Perceptive user interfaces* Orlando, Florida, 1 - 9

ICCP. (2005). "International Campaign for Cures of spinal cord injury Paralysis (ICCP) Information Package
", International Campaign for Cures of spinal cord injury Paralysis.

Infogrip. (2003a). "BIGtrack Mouse." Infogrip, Inc., Ventura, CA

Infogrip. (2003b). "Easy Cat touchpad ", Infogrip, Inc., Ventura, CA

Infogrip. (2003c). "HelpiJoy Mouse." Infogrip, Inc., Ventura, CA

Infogrip. (2003d). "VerticalMouse." Infogrip, Inc., Ventura, CA

IOSH. (2003). "Introduction into Spinal Cord Injury." Institute of Occupational Safety & Health (IOSH). Taipei, Taiwan.

Isaman, V., and Thelin, R. (1995). "Standard operating procedure (SOPs): reason for, types of, adequacy, approval, and deviations from and revisions to." *Quality Assurance*, 4(3), 167-171.

ISO9241-11. (1998). "Ergonomic requirement for office work with visual display terminal (VDTs)-Part 11: Guidance on usability (ISO 9241-11: 1998)." CEN, European Committee for Standardization, 1-19.

Jacobs, R., Hendrickx, E., Van Mele, I., Edwards, K., Verheust, M., Spaepen, A., and Van Steenberghe, D. (1997). "Control of a trackball by the chin for communication applications, with and without neck movements." *Archives of Oral Biology*, 42(3), 213-218.

Jang, Y., Wang, Y.-H., and Wang, J.-D. (2005). "Return to work after spinal cord injury in Taiwan: The contribution of functional independence." *Archives of Physical Medicine and Rehabilitation*, 86(4), 681-686.

Johnston, J. M., and Pennypacker, H. S. (1993). *Strategies and tactics of behavioural research*, Lawrence Erlbaum Associates, Hillsdale, NJ.

Jutai, J. (1999). "Quality of life impact of assistive technology." *Rehabilitation Engineering*, 14(1), 2-7.

Jutai, J., Ladak, N., Schuller, R., Naumann, S., and Wright, V. (1996). "Outcomes Measurement of Assistive Technologies: An Institutional Case Study." *Assistive Technology*, 8, 110-120.

Jutai, J., Rigby, P., Ryan, S., and Stickel, S. (2000). "Psychosocial impact of electronic aids to daily living." *Assistive Technology*, 12(2), 123-131.

Kannisto, M., Merikanto, J., Alaranta, H., Hokkanen, H., and Sintonen, H. (1998). "Comparison of health-related quality of life in three subgroups of spinal cord injury patients." *Spinal Cord*, 36(3), 193-199.

Karl, L. R., Pettey, M., and Shneiderman, B. (1993). "Speech versus mouse commands for word processing: an empirical evaluation." *International Journal of Man-Machine Studies*, 39(4), 667-687.

Karlqvist, L., Bernmark, E., Ekenvall, L., Hagberg, M., Isaksson, A., and Rosto, T. (1999). "Computer mouse and track-ball operation: Similarities and differences in posture, muscular load and perceived exertion." *International Journal of Industrial Ergonomics*, 23(3), 157-169.

Karlqvist, L., Hagberg, M., and Selin, K. (1994). "Variation in upper limb posture and movement during word processing with and without mouse use." *Ergonomics*, 37(7), 1261-1267.

Keir, P. J., Bach, J. M., and Rempel, D. (1999). "Effects of computer mouse design and task on carpal tunnel pressure." *Ergonomics*, 42(10), 1350-1360.

Kilbom, A. (1999). "Possibilities for regulatory actions in the prevention of musculoskeletal disorders." *Scandinavian Journal of Work Environment & Health*, 25, 5-12.

Kirk, J., and Miller, M. L. (1985). "Reliability and Validity." Reliability and validity in qualitative research Sage Publications, Inc., Beverly Hills, 13-20.

Kitchin, R., Shirlow, P., and Shuttleworth, I. (1998). "On the margins: disabled people's experience of employment in Donegal, West Ireland." *Disability & Society*, 13(5), 785-806.

Kohn, J. G., Mortola, P., and LeBlanc, M. (1991). "Clinical trials and quality control: checkpoints in the provision of assistive technology." *Assistive Technology*, 3, 67-74.

Kondraske, G. V. (1990). "Quantitative measurement and assessment of performance." Rehabiliation engineering, R. V. Smith and J. H. Leslie, eds., CRC Press, Boca Raton, Florida, 104.

Krause, J. S. (2003). "Years to employment after spinal cord injury." *Archives of Physical Medicine and Rehabilitation*, 84(9), 1282-1289.

Krause, J. S., and Crewe, N. M. (1987). "Prediction of long-term survival among persons with spinal cord injury: An 11-year prospective study." *Rehabilitation Psychology*, 32, 205-213.

Krause, J. S., Kewman, D., DeVivo, M. J., Maynard, F., Coker, J., Roach, M. J., and Ducharme, S. (1999). "Employment after spinal cord injury: An analysis of cases from the model spinal cord injury systems." *Archives of Physical Medicine and Rehabilitation*, 80(11), 1492-1500.

Kroemer, K. H. E. (1992). "Performance on a prototype keyboard with ternary chorded keys." *Applied Ergonomics*, 23(2), 83-90.

Kruse, D., Krueger, A., and Drastal, S. (1996). "Computer use, computer training and employment. Outcome among people with spinal cord injuries." *Spine*, 21(7), 891-896.

Lau, C., and O'Leary, S. (1993). "Comparison of computer interface devices for persons with severe physical disabilities." *The American journal of occupational therapy*.

Lau, C., and Oleary, S. (1993). "Comparison of Computer-Interface Devices for Persons with Severe Physical-Disabilities." *American Journal of Occupational Therapy*, 47(11), 1022-1030.

Lee, K., Swanson, N., Sauter, S., Wickstrom, R., Waikar, A., and Mangum, M. (1992). "A Review of Physical Exercises Recommended for Vdt Operators." *Applied Ergonomics*, 23(6), 387-408.

Lenker, J. A., and Paquet, T. L. (2003). "A review of conceptual models for assistive technology outcomes research and practice." *Assistive Technology*, 15(1), 1-15.

Lenker, J. A., Scherer, M. J., Fuhrer, M. J., Jutai, J. W., and DeRuyter, I. (2005). "Psychometric and administrative properties of measures used in Assistive technology device outcomes research." *Assistive Technology*, 17(1), 7-22.

Liao, M. H., and Drury, C. G. (2000). "Posture, discomfort and performance in a VDT task." *Ergonomics*, 43(3), 345-359.

Lin, R. T., and Kreifeldt, J. G. (1993). "A New Approach to Input Device Key Design Using Fingerprints." *Applied Ergonomics*, 24(6), 413-420.

Lincoln, A. E., Vernick, J. S., Ogaitis, S., Smith, G. S., Mitchell, C. S., and Agnew, J. (2000). "Interventions for the primary prevention of work-related carpal tunnel syndrome." *American journal of preventive medicine*, 18(4S), 37-50.

Lofland, J., and Lofland, L. H. (1995). "Starting where you are." Analyzing social settings : a guide to qualitative observation and analysis, Wadsworth Publishing Company, Belmont,CA, 11-15.

Louise-Bender Pape, T., Kim, J., and Weiner, B. (2002). "The shaping of individual meanings assigned to assistive technology: a review of personal factors." *Disability and Rehabilitation*, 24, 5-20.

Loy, B. (2005). "Alternative computer input devices: Options to consider." O. o. D. E. P. Job Accommodation Network (JAN), U.S. Department of Labour, ed., Job Accommodation Network.

Lun, K. C. (1995). "New user interfaces." *International Journal of Bio-Medical Computing*, 39(1), 147-150.

MacKenzie, I. S. (1995). "Input devices and interaction techniques for advanced computing." Virtual environments and advanced interface design, W. Barfield and F. T.A., eds., Oxford University Press, Oxford, UK, 437-470.

Mackenzie, I. S., Nonnecke, B., Riddersma, S., McQueen, C., and Meltz, M. (1994). "Alphanumeric Entry on Pen-Based Computers." *International Journal of Human-Computer Studies*, 41(5), 775-792.

Malchaire, J., Cock, N., and Vergracht, S. (2001). "Review of the factors associated with musculoskeletal problems in epidemiological studies." *International Archives of Occupational and Environmental Health*, 74(2), 79-90.

Maltron. (2006a). "Expanded Keyboard ", Maltron Ltd, East Molesey, Surrey.

Maltron. (2006b). "L Type Two-handed Keyboard ", Maltron Ltd, East Molesey, Surrey.

Maltron. (2006c). "Mouth / Head Stick Keyboard ", Maltron Ltd, East Molesey, Surrey.

Maltron. (2006d). "Single handed keyboards ", Maltron Ltd, East Molesey, Surrey.

Marklin, R. W., and Simoneau, G. G. (2001). "Effect of setup configurations of split computer keyboards on wrist angle." *Physical Therapy*, 81(4), 1038-1048.

Marklin, R. W., Simoneau, G. G., and Monroe, J. F. (1999). "Wrist and forearm posture from typing on split and vertically inclined computer keyboards." *Human Factors*, 41(4), 559-569.

Maslow, A. H. (1987). "A theory of human motivation." Motivation and personality Addison-Wesley Educational Publishers Inc., New York, 15-31.

May, T. (1997). "Interviewing: methods and process." Social research : issues, methods and process, Open University Press, Buckingham, 109-131.

McKinley, W., Tewksbury, M. A., Sitter, P., Reed, J., and Floyd, S. (2004). "Assistive technology and computer adaptations for individuals with spinal cord injury." *NeuroRehabilitation*, 19(2), 141-146.

McMulkin, M. L., and Kroemer, K. H. E. (1994). "Usability of a one-hand ternary chord keyboard." *Applied Ergonomics*, 25(3), 177-181.

Medicine, C. f. S. C. (1999). *Outcomes following traumatic spinal cord injury: A clinical practice guideline for health care professionals*, Paralyzed Veterans of America (PVA), Washington, DC.

Miles, M. B., and Huberman, A. M. (1994a). "Focusing and bounding the collection of data: further design issues." An Expanded Sourcebook: Qualitative Data Analysis, Sage Publications, Inc, Thousand Oaks, CA, 40-49.

Miles, M. B., and Huberman, A. M. (1994b). "Introduction." An Expanded Sourcebook: Qualitative Data Analysis, Sage Publications, Inc, Thousand Oaks, CA, 1-15.

Mills, J. E., Wong-Ellison, C., Werner, W., and Clay, J. M. (2001). "Employer liability for telecommuting employees." *The Cornell Hotel and Restaurant Administration Quarterly*, 42(5), 48-59.

MOI. (2005). "Total Taiwan Population in 2005." Ministry of the Interior, Taiwan R.O.C (MOI).

Muhlehner, M., and Miesenberger, K. "HeadControl+: A multi-modal input device." *Computers Helping People with Special Needs, 9th International Conference, ICCHP 2004*, Paris, France, 774-781.

Muhlehner, M., and Miesenberger., K. "HeadControl+: A multi-model input device." *9th International Conference, ICCHP 2004*, Paris, France, 774-781.

Mulroy, S. J., Newsam, C. J., Gutierrez, D. D., Requejo, P., Gronley, J. K., Haubert, L. L., and Perry, J. (2005). "Effect of fore-aft seat position on shoulder demands during wheelchair propulsion: part 1. A kinetic analysis." *The journal of spinal cord medicine*, 28(3), 214-221.

Murray, B., and Kenny, S. (1990). "Telework as an employment option for people with disabilities." *International journal of rehabilitation research*, 13(3), 205-214.

Nichols, K., Brown, A., and Sett, P. (2005). "Spinal cord injury: the condition and its acute management." *Hospital Pharmacist*, 12, 91-94.

O'Hare, E. A., and McTear, M. F. (1999). "Speech recognition in the secondary school classroom: an exploratory study." *Computers & Education*, 33(1), 27-45.

Ortiz-Hernandez, L., Tamez-Gonzalez, S., Martinez-Alcantara, S., and Mendez-Ramirez, I. (2003). "Computer use increases the risk of musculoskeletal disorders among newspaper office workers." *Archives of Medical Research*, 34(4), 331-342.

OSH. (1996). "Approved code of practice for the use of visual display units in the place of work." D. o. L. Occupational Safety and Health Service (OSH), ed., Occupational Safety and Health Service (OSH), Department of Labour, Wellington, New Zealand.

Oyama, S., Yairi, I. E., Igi, S., and Nishimura, T. "Walking support using compact terminals with infrared audio communication." *Computers Helping People with Special Needs, 9th International Conference, ICCHP 2004*, Paris, France, 468-475.

Park, K. S., and Lee, K. T. (1996). "Eye-controlled human/computer interface using the line-of-sight and the intentional blink." *Computers & Industrial Engineering*, 30(3), 463-473.

Park, K. S., and Lim, C. J. (2001). "A simple vision-based head tracking method for eye-controlled human/computer interface." *International Journal of Human-Computer Studies*, 54(3), 319-332.

Pascarelli, E. F., and Kella, J. J. (1993). "Soft-tissue injuries related to use of the computer keyboard: A clinical study of 53 severely injured persons." *Journal of Occupational Medicine*, 35(5), 522-532.

Patton, M. Q. (1987). "Depth interviewing." How to use qualitative methods in evaluation, Sage Publications, Newsbury Park, CA, 108-143.

Pell, S. D., Gillies, R. M., and Carss, M. (1997). "Relationship between use of technology and employment rates for people with physical disabilities in Australia: implications for education and training programmes." *Disability and Rehabilitation*, 19(8), 332-338.

Pell, S. D., Gillies, R. M., and Carss, M. (1999). "Use of technology by people with physical disabilities in Australia." *Disability and Rehabilitation*, 21(2), 56-60.

Phillips, B., and Zhao, H. (1993). "Predictors of assistive technology abandonment." *Assistive Technology*, 5(1), 36-45.

PrentkeRomich. (2006). "HeadMaster Plus." Prentke Romich Company, Wooster, OH.

Pulaski, K. H. (1998). "Adult neurological dysfunction." Willard and Spackman's occupational therapy, M. E. Neistadt and E. B. Crepeau, eds., Lippincott, Philadelphia, 660-80.

Radwin, R. G., Vanderheiden, G. C., and Lin, M. L. (1990). "A method for evaluating head-controlled computer input devices using Fits' Law." *Human Factors*, 32(4), 423-438.

Rogers, J. C., and Holm, M. B. (1992). "Assistive technology device use in patients with rheumatic disease: a literature review." *The American journal of occupational therapy*, 46(2), 120-127.

Rutter, B. G., and Dainoff, M. J. (1996). *The Ergonomics Office: Standard, Specifications, Design Guidelines*, Metaphase Design Group, Inc., Saint Louis.

Ryff, C. D. (1995). "Psychological Well-Being in Adult Life." *Current Directions in Psychological Science*, 4(4), 99-104.

Sauter, S. L., Chapman, L. J., Knutson, S. J., and Anderson, H. A. (1987). "Case example of wrist trauma in keyboard use." *Applied Ergonomics*, 18(3), 183-186.

Sauter, S. L., Schleifer, L. M., and Knutson, S. J. (1991). "Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task." *Human Factors*, 33(2), 151-167.

Scherer, M. J. (1988). "Assistive device utilization and quality-of-life in adults with spinal cord injuries or cerebral palsy." *Journal of Applied Rehabilitation Counseling*, 19, 21-30.

Scherer, M. J. (1990). "Assistive device utilization and quality of life in adults with spinal cord injuries or cerebral palsy two years later." *Journal of Applied Rehabilitation Counselling*, 21, 36-44.

Scherer, M. J. (1991). *The Scherer MPT Model: Matching People with Technologies.*, Scherer and Associates, Webster, NY.

Scherer, M. J. (1996). "Outcomes of assistive technology use on quality of life." *Disability and rehabilitation*, 18(9), 439-448.

Scherer, M. J. (1998). *Matching Person and Technology*, The Institute for Matching Person & Technology, Webster, NY.

Scherer, M. J. (2000a). "Assistive technologies as "world-openers"." Living in the State of Stuck: How Assistive Technology Impacts the Lives of People with Disabilities, Brookline Books, Inc., Cambridge, MA, 37.

Scherer, M. J. (2000b). "Author's Introduction." Living in the State of Stuck: How Assistive Technology Impacts the Lives of People with Disabilities, Brookline Books, Inc., Cambridge, MA, xiv.

Scherer, M. J. (2000c). "Dilemmas, Challengers, and Opportunities." Living in the State of Stuck: How Assistive Technology Impacts the Lives of People with Disabilities, Brookline Books, Inc., Cambridge, MA, 119-138.

Scherer, M. J. (2000d). "Living in the state of shock." Living in the State of Stuck: How Assistive Technology Impacts the Lives of People with Disabilities, Brookline Books, Inc., Cambridge, MA, 158-184.

Scherer, M. J. (2000e). "Rehabilitation success: the relativity of theory." Living in the State of Stuck: How Assistive Technology Impacts the Lives of People with Disabilities, Brookline Books, Inc., Cambridge, MA, 55-73.

Scherer, M. J. (2002). "Matching Consumers with appropriate assistive technologies." Clinician's guide to assistive technology, D. A. Olson and F. DeRuyter, eds., Mosby, St. Louis, Missouri, 3-12.

Scherer, M. J., and Cushman, L. A. (2000). "Predicting Satisfaction with Assistive Technology for a Sample of Adults with New Spinal Cord Injuries." *Psychological Reports*, 87, 981-987.

Scherer, M. J., and Cushman, L. A. (2001). "Measuring subjective quality of life following spinal cord injury: a validation study of the assistive technology device predisposition assessment." *Disability and Rehabilitation*, 23(9), 387-393.

Scherer, M. J., and Cushman, L. A. (2002). "Determining the content for an interactive training programme and interpretive guideline for the Assistive Technology Device Predisposition Assessment." *Disability and rehabilitation*, 24(1/2/3), 126-130.

Scherer, M. J., and Frisina, D. R. (1998). "Characteristics associated with marginal hearing loss and subjective well-being among a sample of older adults." *Journal of Rehabilitation Research and Development*, 35(4), 420-426.

Scherer, M. J., and Glueckauf, R. (2005). "Assessing the benefits of assistive technologies for activities and participation." *Rehabilitation Psychology*, 50(2), 132-141.

Scherer, M. J., and McKee, B. G. "The Development of Two Instruments Assessing the Predispositions People Have Toward Technology Use: The Value of Integrating Quantitative and Qualitative Methods." *Annual Meeting of the American Educational Research Association*, Chicago, IL, 27.

Scherer, M. J., Sax, C., Vanbiervliet, A., Cushman, L. A., and Scherer, J. V. (2005). "Predictors of assistive technology use: The importance of personal and psychosocial factors." *Disability and Rehabilitation*, 27(21), 1321-1331.

SCSRC. (2006a). "Spinal Cord Injury and Employment." Taoyuan County Spinal Cord Injury Rehabilitation Centre (SCSRC), Taiwan.

SCSRC. (2006b). "Vocational training programmes, support and useful links." Taoyuan County Spinal Cord Injury Rehabilitation Centre (SCSRC).

Sears, A. (1991). "Improving touchscreen keyboards: design issues and a comparison with other devices." *Interacting with Computers*, 3(3), 253-269.

Sears, A., and Zha, Y. (2003). "Data entry for mobile devices using soft keyboards: Understanding the effects of keyboard size and user tasks." *International Journal of Human-Computer Interaction*, 16(2), 163-184.

Shaw, I. (1999). *Qualitative evaluation*, Sage Publications, Thousand Oaks, CA.

SIA. (2004). "2003-2004 SIA Annual Report." Spinal Injuries Association (SIA).

SIA. (2005). "2004-2005 SIA Annual Report." Spinal Injuries Association (SIA).

Sillanpaa, J., Huikko, S., Nyberg, M., Kivi, P., Laippala, P., and Uitti, J. (2003). "Effect of work with visual display units on musculo-skeletal disorders in the office environment." *Occupational Medicine-Oxford*, 53(7), 443-451.

Silverman, D. (2005). *Doing qualitative research : a practical handbook*, Sage, London.

Simon, S. E., and Patrick, A. (1997). "Understanding and assessing consumer satisfaction in rehabilitation." *Journal of Rehabilitation Outcomes Measurement*, 1(5), 1-14.

Slater, D., and Meade, M. A. (2004). "Participation in recreation and sports for persons with spinal cord injury: Review and recommendations." *Neurorehabilitation* 19(2), 121-129.

Sleator, A., Gore, D., and Vidler, G. (1998). "Variety and nature of work related upper limb disorders." Work Related Upper Limb Disorders, House of Commons Library, UK Parliament UK, 7-19.

Smith, M. J., Karsh, B. T., Conway, F. T., Cohen, W. J., James, C. A., Morgan, J. J., Sanders, K., and Zehel, D. J. (1998). "Effects of a split keyboard design and wrist rest on performance, posture, and comfort." *Human Factors*, 40(2), 324-336.

Smith, M. L. (1986). "The whole is greater: combing qualitative and quantitative approaches in evaluation studies." Naturalistic evaluation: New directions in program evaluation, D. D. Williams, ed., Jossey-Bass, San Francisco, CA, 37-54.

Smith, R. O. (1996). "Measuring the outcomes of assistive technology: challenge and innovation." *Assistive Technology*, 8(2), 71-81.

SpineLine. (2005). "Spine Anatomy." Medtronic Sofamor Danek.

Stake, R. E. (2000). "Cases studies." Handbook of qualitative research, N. K. Denzin and Y. S. Lincoln, eds., Sage Publications, Thousand Oaks, CA, 435-454.

Stauffer, P. (1999). "Making lab tests more accurate: Ghanaian effort offers model process." *Impact on HIV.*, 1(2), 23-24.

Stickel, M. S., Ryan, S., Rigby, P. J., and Jutai, J. W. (2002). "Toward a comprehensive evaluation of the impact of electronic aids to daily living: evaluation of consumer satisfaction." *Disability and Rehabilitation*, 24, 115-125.

Swanson, N. G., Galinsky, T. L., Cole, L. L., Pan, C. S., and Sauter, S. L. (1997). "The impact of keyboard design on comfort and productivity in a text-entry task." *Applied ergonomics*, 28(1), 9-16.

Szabo, R. M. (1998). "Carpal tunnel syndrome as a repetitive motion disorder." *Clinical Orthopaedics and Related Research*, -(351), 78-89.

Szeto, G. P., and Lee, R. (2002). "An ergonomic evaluation comparing desktop, notebook, and subnotebook computers." *Archives of Physical Medicine and Rehabilitation*, 83(4), 527-532.

Szeto, G. P. Y., and Ng, J. K. F. (2000). "A comparison of wrist posture and forearm muscle activities while using an alternative keyboard and a standard keyboard." *Journal of Occupational Rehabilitation*, 10(3), 189-197.

Szeto, G. P. Y., Straker, L. M., and O'Sullivan, P. B. (2005a). "A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work - 1: Neck and shoulder muscle recruitment patterns." *Manual Therapy*, 10(4), 270-280.

Szeto, G. P. Y., Straker, L. M., and O'Sullivan, P. B. (2005b). "A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work - 2: Neck and shoulder kinematics." *Manual Therapy*, 10(4), 281-291.

Tanimoto, Y., Rokumyo, Y., Furusawa, K., Tokuhiro, A., Suzuki, Y., Takami, K., and Yamamoto, H. (2005). "Development of a computer input device for patients with tetraplegia." *Computer Standards & Interfaces*, 28(2), 166-175.

Tanimoto, Y., Rokumyo, Y., Furusawa, K., Tokuhiro, A., and Yamamoto, H. "Development of a computer input device for patients with tetraplegia." *The Second IEEE International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS'2003)* 140- 143.

Teng, Z. C., and Chen, R. C. "Designing a barrier free solution for students with Muscular Dystrophy." *The 10th Annual meeting Ergonomics Society of Taiwan*, Taichung, Taiwan.

Tinker, A., and Lansley, P. (2005). "Introducing assistive technology into the existing homes of older people: feasibility, acceptability, costs and outcomes." *Journal of Telemedicine and Telecare*, 11, 1-3.

Tittiranonda, P., Burastero, S., and Rempel, D. (1999). "Risk factors for musculoskeletal disorders among computer users." *Occupational Medicine-State of the Art Reviews*, 14(1), 17-38.

Tomassen, P. C. D., Post, M. W. M., and van Asbeck, F. W. A. (2000). "Return to work after spinal cord injury." *Spinal Cord*, 38(1), 51-55.

Trachtman, L. (1994). "Outcome measures. Are we ready to answer the tough questions? (Editorial)." *Assistive Technology*, 6, 91-92.

Trieschmann, R. B. (1988). *Spinal cord injuries: psychological, social, and vocational rehabilitation*, Demos Publications, New York.

Tseng, C. C. (2003). "A study of an integrated alternative keyboard for persons with disabilities.," Master, National Taiwan Normal University, Taipei, Taiwan.

Tyfa, D. A., and Howes, M. (2000). "Speech recognition for command entry in multimodal interaction." *International Journal of Human-Computer Studies*, 52(4), 637-667.

TypingMaster. (2006). "TypingMaster Pro." TypingMaster, Inc. , Helsinki, Finland.

UAB. (1991). *Learning About Spinal Cord Injury*, Department of Physical Medicine and Rehabilitation, Spain Rehabilitation Center, University of Alabama at Birmingham, Birmingham, Alabama.

UN. (2004). "United Nations Population Division: World Population Prospects: The 2004 Revision Population Database
", United Nations (UN).

Wacom. (2006). "Graphire Tablet 4x5 ", Wacom Technology Corp., Vancouver, WA.

Wagner, M. O., Yannou, B., Kehl, S., Feillet, D., and Eggers, J. (2003). "Ergonomic modelling and optimization of the keyboard arrangement with an ant colony algorithm." *Journal of Engineering Design*, 14(2), 187-208.

Wallace, J. F., Flippo, K. F., Barcus, J. M., and Behrmann, M. M. (1995). "Legislative foundation of assistive technology policy in the United States." Assistive Technology: A Resource for School, Work and Community, K. F. Flippo, K. J. Inge, and J. M. Barcus, eds., Brookes, Baltimor, 3-22.

Warren, C. G. (1993). "Cost effectiveness and efficiency in assistive technology service delivery." *Assistive Technology*, 5(2), 61-65.

Wei, Z., Duffy, V. G., Linn, R., and Luximon, A. (1999). "Voice recognition based human-computer interface design." *Computers & Industrial Engineering*, 37(1-2), 305-308.

Weiss-Lambrou, R. (2002). "Satisfaction and Comfort." Assistive Technology: Matching Device and Consumer for Successful Rehabilitation, M. J. Scherer, ed., American Psychological Association, Washington, DC, 77-94.

Weiss-Lambrou, R., Tremblay, C., LeBlanc, R., Lacoste, M., and Dansereau, J. (1999). "Wheelchair seating aids: How satisfied are consumers?" *Assistive Technology*, 11(1), 43-53.

Welch, R. D., Lobley, S. J., O'Sullivan, S. B., and Freed, M. M. (1986). "Functional independence in quadriplegia: Critical levels." *Archives of physical medicine and rehabilitation*, 67, 235-240.

West, M. D., and Anderson, J. (2005). "Telework and employees with disabilities: Accommodation and funding options." *Journal of Vocational Rehabilitation* 23(2), 115 - 122

Westgaard, R. H., and Winkel, J. (1997). "Ergonomic intervention research for improved musculoskeletal health: A critical review." *International Journal of Industrial Ergonomics*, 20(6), 463-500.

Woods, M., and Babski-Reeves, K. (2005). "Effects of negatively sloped keyboard wedges on risk factors for upper extremity work-related musculoskeletal disorders and user performance." *Ergonomics*, 48(15), 1793-1808.

Wu, J. (2003). "An investigation into the development of PDA for wheelchair users with Spinal Cord Injury and Muscular Dystrophy," De Montfort University, Leicester, U. K.

Wu, T.-F., Wang, H.-P., Chen, M.-C., and Wu, W.-T. "Computer access for persons with spinal cord injury." *Computers helping people with special needs, 9th International Conference, ICCHP 2004*, Paris, France, 865-872.

Wu, T. F., Wang, H. P., Chen, M. C., and Wu, W. T. "Computer access for persons with spinal cord injury." *Computers Helping People with Special Needs, 9th International Conference, ICCHP 2004*, Paris, France, 865-872.

Wynne, R., and McAnaney, D. (2004). "Employment and disability: Back to work strategies." T. E. F. f. t. I. o. L. a. W. Conditions, ed., The European Foundation for the Improvement of Living and Working Conditions.

Yang, C.-H., Luo, C.-H., Jeang, Y.-L., and Jon, G.-J. (2000). "A novel approach to adaptive Morse code recognition for disabled persons." *Mathematics and Computers in Simulation*, 54(1-3), 23-32.

Yarkony, G. M., and Chen, D. (1996). "Rehabilitation of patients with spinal cord injuries." Physical medicine and rehabilitation, R. L. Braddon, ed., W.B. Saunders Co., Philadelphia, 1149-1179.

Yasuda, S., Wehman, P., Targett, P., Cifu, D. X., and West, M. (2002). "Return to work after spinal cord injury: A review of recent research." *Neurorehabilitation*, 17(3), 177-186.

Yeh, Y. T. (2001). "A study of the computer input assistive technology design for the single upper limb amputee.," Master, National Yunlin University of Science & Technology, Yunlin, Taiwan.

Yin, R. K. (2003a). *Case study research: Design and Methods*, Sage Publications, Inc., London.

Yin, R. K. (2003b). "Conducting case studies: collecting the evidence." Case study research: Design and Methods, Sage Publications, Inc., London, 83-108.

Yin, R. K. (2003c). "Designing case studies." Case study research: Design and Methods, Sage Publications, Inc., London, 19-56.

Yin, R. K. (2003d). "Introduction." Case study research: Design and Methods, Sage Publications, Inc., London, 1-18.

Yin, R. K. (2003e). "The role of theory in doing case studies." Applications of case study research, Sage Publications, Thousand Oaks, CA, 1-27.

Young, P. M. C., Leung, R. M. W., Ho, L. M., and McGhee, S. M. (2001). "An evaluation of the use of hand-held computers for bedside nursing care." *International Journal of Medical Informatics*, 62(2-3), 189-193.

Yu, F. J., Hwang, S. L., and Huang, Y. H. (1999). "Task analysis for industrial work process from aspects of human reliability and system safety." *Risk analysis*, 19(3), 401-415.

Zecevic, A., Miller, D. I., and Harburn, K. (2000). "An evaluation of the ergonomics of three computer keyboards." *Ergonomics*, 43(1), 55-72.

Zennaro, D., Laubli, T., and Krueger, H. (2003). "Motor unit identification in two neighbouring recording positions of the human trapezius muscle during prolonged computer work." *European Journal of Applied Physiology*, 89(6), 526-535.

APPENDIX A: THE WORKPLACE SET-UP AND ARRANGEMENT OF 20 CSI SUBJECTS (STUDY A)

	COMPUTER EXPERIENCE	WORK-PLACE	COMPUTER SEATING	COMPUTER DESK	VISUAL DATA
01	2 yrs	Home	Manual wheelchair with a belt support	Conventional office desk	
02	2 yrs	Home	Powered wheelchair with a belt support	General computer desk (by 60cm in width, 48cm in depth and 78cm in height) with special adjustments. The workstation is adjustable by an extended table which can be set up on the wheelchair and improve the situation when the wheelchair cannot pull up to the desk	
03	14 -15 yrs	Home	Walking aid + computer chair. Due to the space limitation of the house, subject is unable to use a wheelchair at home and at work. He uses the walking aid indoors and a computer chair when accessing a computer	General computer desk	
04	2 yrs	Home	Manual wheelchair Due to the space limitation of the house, subject uses a manual wheelchair at home and at work.	Specially designed workstation which is specially manufactured for subject's special needs, such as height, width and depth. A special desk allows his wheelchair to slide under it.	

05	2 yrs	Home	Manual wheelchair with a neck and back cushion support	General computer desk with special design manufacture and adjustment. The monitor, the keyboard, and the assisted input mouthstick are supported by a specially made frame; also, the desk is extended to enlarge the work area.	
06	7 - 8 yrs	Office	Powered wheelchair	Conventional office desk. Subject is used to putting the keyboard on his thigh.	
07	3 - 4 yrs	Office	Powered wheelchair	Conventional office desk. Subject is used to putting the keyboard on his thigh.	
08	5 - 6 yrs	Home	Manual wheelchair with a belt support	Conventional office desk. Subject's desk is crammed with many document files and paper strewn along the top.	
09	8 - 9 yrs	Home	Lying on bed; Subject does all indoor work on a bed; the powered wheelchair is used only outdoors.	General computer desk	
10	1 ½ yrs	Office	Powered wheelchair	Conventional office desk	

11	9 - 10 yrs	Home	Manual wheelchair with a belt support	General computer desk	
12	5 - 6 yrs	Home	Powered wheelchair with a belt support	Conventional office desk	
13	7 - 8 yrs	Office	Powered wheelchair with a belt support	Conventional office desk; Subject is used to putting the keyboard on his thigh	
14	2 yrs	Office	Powered wheelchair with a belt support	Conventional office desk; Subject is used to putting the keyboard on his thigh	
15	7 yrs	Home	Manual wheelchair	General computer desk. The desk allows the wheelchair to slide under it.	

16	1 yr	Lab	Manual wheelchair	Conventional office desk	
17	3 - 4 yrs	Lab	Manual wheelchair with a belt support	Conventional office desk with adjustment; The height of the desk was raised by one brick's height.	
18	1 yr	Lab	Manual wheelchair	Conventional office desk	
19	1 yr	Lab	Manual wheelchair with a belt support	Conventional office desk with adjustment; The height of the desk was raised by one brick's height.	
20	1 yr	Lab	Manual wheelchair with a neck and back cushion support	Wheelchair table; Specially designed and manufactured table which can be installed on the wheelchair as a desk.	

Office: located in TPESCI
Lab: the computer lab is in the SCSRC vocational training centre (SCSRC)

APPENDIX B: THE WORKPLACE SET-UP AND ARRANGEMENT OF 14 TSI/LSI SUBJECTS (STUDY A)

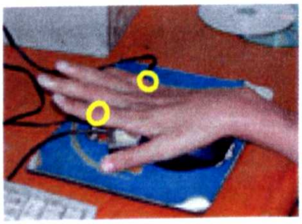
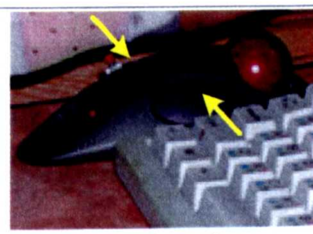
	COMPUTER EXPERIENCE	WORK-PLACE	COMPUTER SEATING	COMPUTER DESK	VISUAL DATA
23	4 - 5 yrs	Home	Manual wheelchair	General computer desk	
24	7 - 8 yrs	Home	Manual wheelchair	General computer desk. The desk is set up at the higher level of the floor, and the subject is in the lower position when using a computer.	
25		Home	Manual wheelchair	Conventional office desk. The subject's wheelchair seat is higher than the computer desk.	
26	7 - 8 yrs	Home	Manual wheelchair	Conventional office desk. The desk allows his wheelchair to slide under it.	

27	5 - 6 yrs	Home	Manual wheelchair.	General computer desk. The desk allows his wheelchair to slide under it.	
28	7- 8 yrs	Lab	Manual wheelchair.	Conventional office desk.	
29	1½ yrs	Lab	Manual wheelchair.	Conventional office desk.	
30	1 yr	Lab	Manual wheelchair.	Conventional office desk.	
31	1 yr	Lab	Manual wheelchair.	Conventional office desk.	

32	1 yr	Lab	Manual wheelchair.	Conventional office desk.	
33	1 yr	Lab	Manual wheelchair with a cushion supports the subject's back.	Conventional office desk.	
34	1 yr	Lab	Manual wheelchair.	Conventional office desk.	
35	4 - 5 yrs	Lab	Manual wheelchair.	Conventional office desk.	
36	1 yr	Lab	Manual wheelchair.	Conventional office desk.	

Office: located in TPESCI
Lab: the computer lab is in the SCSRC vocational training centre

APPENDIX C: THE CSI SUBJECTS' ADOPTED INPUT DEVICE, HABITUAL PRACTICE AND PREFERENCE (STUDY A)

	OPERATING MODE	KEYBOARD	MOUSE
01	  **The input pen with handstrip on the left hand + the right hand.** Using the handstrip on the left hand for supporting the inputting pen is the main computer operating mode; her right thumb (IP joint) is used for supporting some computer keys, such as ENTER, BACKSPACE, and SPACE. The mouse is worked with the 2nd PIP and 5th MCP joints of her right hand.	 **Specially designed keyboard.** Keyboard's width is smaller than a conventional keyboard. The subject's keyboard is approximately 32 cm in width and 12 cm in height.	 **Conventional mouse.** The mouse is placed at the right-hand side of the keyboard and the foam tapes are stuck on the surface in order to assist operations and to separate the right key from the left key of the mouse.
02		**Conventional keyboard.**	 **Special designed trackball mouse.** The mouse is placed on the left hand-side of the keyboard. The right and left keys are separated by two buttons on the surface of

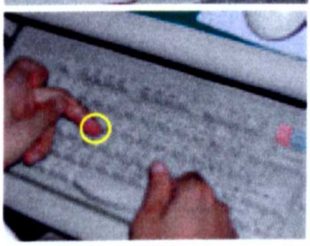
the mouse.

Left-hand wrist and finger orthosis.

Operating a computer by using only the left-hand finger and wrist orthosis as a substitute finger.

The mouse is also worked with the subject's wrist of the left hand.

03



Both hands.

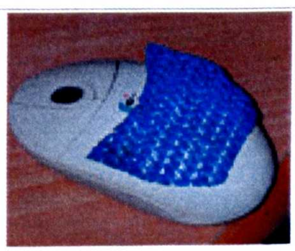
Using only his middle fingertip (left hand) and his index fingertip (right hand) when operating a keyboard; The index fingertip of the right hand is also used to operate a mouse.

Conventional keyboard.

Conventional mouse.

The mouse is set up on the computer desk at the right-hand side of the subject.

04



Conventional mouse.

The mouse which is put at the left-hand side of the keyboard and on which he has stuck a non-slip cover

Left-hand finger orthosis + right-hand wrist and finger orthosis.

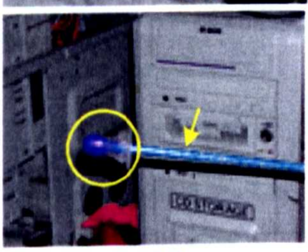
Subject is capable of operating a computer by using the left hand with finger orthosis and the right hand with wrist and finger orthosis. The function ability of the left hand is better than that of the right hand. The left hand occupies the main key-ins, and the right hand gives assistance for some keys such as SPACE, ENTER,BACKSPACE…etc.

Conventional keyboard.

The ergonomic arm support device is used and placed at the right-hand side of the subject.

in order to assist the operation to stabilize it

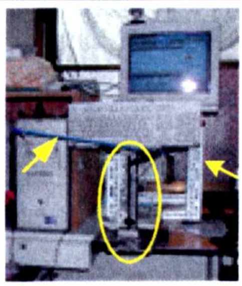
05



The mouthstick.

Paralysis in both arms and legs has resulted in quadriplegia.

The mouthstick is used as an inputting device. It is made from an arrow shaft in which are bored many holes in order to reduce its weight. In addition, the placing of a baby's dummy on one end allows the user to grip the mouthstick.



Conventional monitor and keyboard.

The monitor, the keyboard and the mouthstick are supported and held in place by metal frames which are specially manufactured for supporting all devices
The subject operates a computer by using a mouthstick.

No mouse use.

The subject cannot operate a mouse.

06

Both hands.

The index fingertip of subject's left hand is used to operate a keyboard only; the MCP joint of the little finger of his right hand operates the mouse.

Conventional keyboard.

The keyboard is put on the navy colour bag which is used to raise the height of the input devices on his thigh.

Conventional mouse.

The mouse which is set up on the subject's thigh is operated by the MCP joint of his little finger.

07

Both hands.

The main computer operating mode is carried out by subject's middle fingertip of the left hand; the index fingertip of the right hand supports inputting actions of the left hand.

The index fingertip of the subject's right hand is also used to operate a mouse.

Conventional keyboard.

Conventional mouse.

The mouse is placed on the desk and at the right-hand side of the keyboard.

08

On-screen keyboard.

Due to the subject not being able to operate a normal keyboard, he uses an on-screen keyboard in place of a standard keyboard.

Conventional mouse.

The mouse is put in front of the monitor.

Both hands.

Both of the subject's arms have no ability to move or raise and can be put only on the desk.

The mouse is the input device the subject used and is operated with both his hands. The left key of the mouse is operated by his thumb of the left hand; the right key of the mouse is worked with the PIP joint of the index fingertip of his right hand.

09

Left hand.

As there is limited mobility of the subject's right hand, the left hand of the subject is able to grasp and operate the mouse.

The right key of the mouse is worked with the PIP joint of the index finger of his left hand; the left key of the mouse is used by the MCP joint of the little finger of his left hand.

On-screen keyboard.

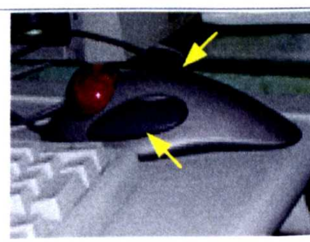
Operating a mouse is easier for the subject than operating a keyboard. He uses an on-screen keyboard as a substitute keyboard for keying in data.

Conventional mouse.

The mouse is put at the left-hand side of the subject. The foam tape is stuck on the left key of the mouse in order to separate the left key from the right key.

10

Conventional keyboard.



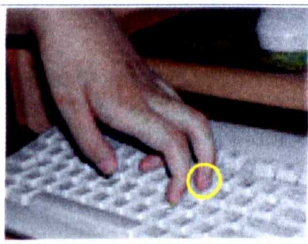
Special designed trackball mouse.

Right-hand finger extension support.

The substitute finger is worn on the subject's right index finger as an assistive device for inputting data. The wrist (the radial and ultar styloid processes) of his right hand is used for operating the trackball, left and right keys on the mouse.

The mouse is placed at the right-hand side of the keyboard. The right and left keys were separated to assist their operation.

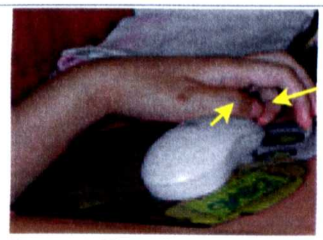
11



Left hand.

The computer operating mode of the subject is to use the middle fingertip of his left hand for inputting data on the keyboard and to use the IP joint of the left thumb and MCP joint of the little finger for operating a mouse.

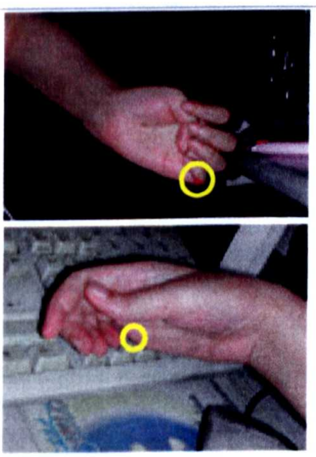
Conventional keyboard.



Conventional mouse.

The keyboard is put on the desk at the left-hand side of the subject.

12



Both hands.

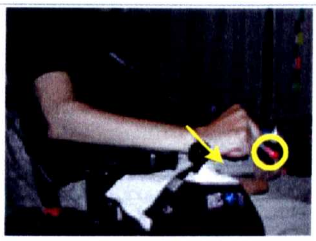
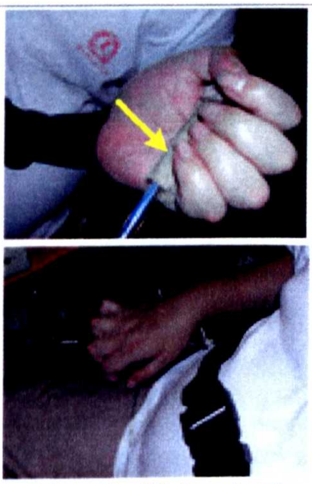
Accessing a mouse is the principal computer operation of the subject.

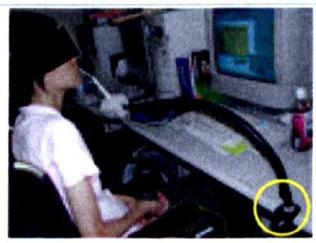
Conventional keyboard+ On-screen keyboard.

Due to the limited motion ability of both hands, the subject uses the on-screen keyboard for the majority of keyboard operations.
The normal keyboard is used only when the subject has to operate the computer keys such as Ctrl, Alt and Shift, for computer graphic drawing.

Conventional mouse.

The mouse is placed on the desk and operated by both hands.

	The left key on the mouse is operated by the PIP joint of the left-hand's little finger; the mouse's right key is pressed by the MCP joint of the little finger of her right hand.		
13	 **Left hand with an input pen.** Accessing the computer is performed by the input pen which is gripped by the left hand. The rubber attached to the head of a pen assists in stabilising the operation.	 **Conventional keyboard.** The keyboard is put on the subject's thigh.	**No mouse use.** The subject infrequently uses a mouse because of the operating difficulties.
14	 **Left hand with handstrip with the input pen.** With the subject's limited functional ability of his right hand, the computer operation is conducted by the left hand. He wears the handstrip on the left hand for holding the inputting pen tightly.	**Conventional keyboard.** The subject is used to putting the keyboard on his thigh.	**No mouse use.** The subject infrequently uses a mouse because of the operating difficulties.

15	 **Right hand.** Operating a computer only by the index and middle fingertips of the right hand.	**Conventional wireless keyboard.**	**Conventional wireless mouse.**
16	  **Breath and Mouth control.** Both hands are paralysed. The breath and mouth control mouse is used for the subject to operate a computer. The subject has to control the mouse by breathing in and out through her mouth through the straw/joystick of the device. The YES function is clicked by the right key of the mouse which can be operated when she inhales through the device. In addition, the left key of the mouse which operates the Function Menu can be used when she exhales.	**On-screen keyboard.** The on-screen keyboard is operated by the breath and mouth control mouse.	 **Specially designed Breath and Mouth control mouse.** The input device is adjustable and installed on the right hand side of the subject.

17

Right hand.

The subject uses only his single right hand which has a better function ability than the left hand to access a mouse.

The mouse is worked with the IP joint of the right thumb and MCP joint of the right little finger.

On-screen keyboard.

The on-screen keyboard is operated by the mouse.

Conventional mouse.

The mouse is set up on the right-hand side of the subject. The sleeve worn over the arm is for stablising operational movements.

18

Left hand.

The subject accesses a keyboard and a mouse only by using the index fingertip of his left hand.

Conventional keyboard.

Conventional mouse.

The mouse is placed on the left-hand side of the keyboard.

19

Conventional wireless Keyboard.

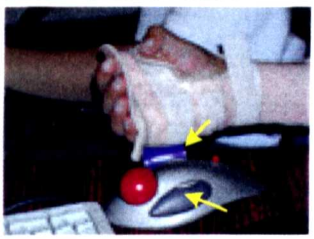
Conventional wireless mouse.

The mouse is put in front of the keyboard and the subject.

Right-hand finger orthosis + Left hand.

The subject can input data into the keyboard by using finger orthosis of his right hand. The MCP joint in the thumb of left the hand is used to support the mouse operation.

20

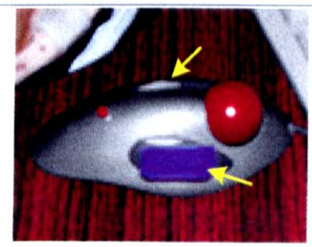


Right-hand finger and wrist orthosis.

Accessing a computer only by using the right-hand finger and wrist orthosis as a substitute finger.
The mouse is also operated with the subject's right hand.

Conventional Keyboard.

The keyboard is placed on the wheelchair table which is used as a computer desk.



Conventional Mouse.

The mouse is also set on the wheelchair table. The right key of the mouse is separated from the left key by two big purple buttons.

APPENDIX D: THE TSI / LSI SUBJECTS' ADOPTED INPUT DEVICE, HABITUAL PRACTICE AND PREFERENCE (STUDY A)

	OPERATING MODE	KEYBOARD	MOUSE
23	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
24	Both hands work without any difficulties.	Conventional keyboard. All computer devices are set up at the higher floor level. The subject has to relocate the keyboard to be on his thigh every time when using it.	Conventional mouse. All computer devices are set up at the higher floor level. The subject has to relocate the mouse to be on his thigh every time when using it.
25	Both hands work without any difficulties.	Conventional keyboard. The subject is used to operating the keyboard on his thigh.	Conventional mouse. The mouse is put on the desk.
26	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
27	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
28	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
29	Both hands work without any difficulties.	Laptop keyboard.	Conventional mouse.
30	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
31	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
32	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
33	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
34	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
35	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.
36	Both hands work without any difficulties.	Conventional keyboard.	Conventional mouse.

APPENDIX E: THE WORKPLACE SET-UP AND ARRANGEMENT OF THE 14 CSI SUBJECTS (STUDY C)

No.	COMPUTER EXPERIENCE	WORKPLACE	COMPUTER SEATING	COMPUTER DESK
01	3 yrs	Home	Manual wheelchair.	Conventional office desk.
03	15 -16 yrs	Home	Conventional computer chair; Because of the limited indoor space, the subject uses a walking aid in the house. A conventional computer chair is adopted when operating a computer. However, the use of a walking aid and computer chair may impose strain on his body and bring high risk of falling down.	General computer desk.
04	3 yrs	Home	Manual wheelchair.	Specially designed workstation; The special workstation allows the wheelchair to slide under it and lessen the distance between the computer and the subject.
05	3 yrs	Home	Lying on bed; Subject used to perform his computer activities seating in the manual wheelchair. Due to his decubitus ulcer, which involves slow recovery, he switched the working area to his bed from early 2004.	The keyboard and the input mouthstick are held by the specially designed frame and installed on the bed. The monitor is also propped up by a metal frame and set next to the bed.
06	8 - 9 yrs	Office	Powered wheelchair.	Conventional office desk; Because the wheelchair cannot pull up to the desk, it results in the distance between the input devices and the subject. As a result, the keyboard is used to be placed on the subject's thigh.

07	4 - 5 yrs	Office	Powered wheelchair.	Conventional office desk.
09	9 -10 yrs	Home	Lying on bed; The subject performs all usual activities on the bed, except going outdoors with his powered wheelchair.	General computer desk; Either the computer desk or keyboard is arranged next to the bed. However, the keyboard is barely operated but displayed most of time.
10	2 ½ yrs	Office	Powered wheelchair.	Conventional office desk.
11	10 -11 yrs	Home	Manual wheelchair.	General computer desk.
12	6 - 7 yrs	Home	Powered wheelchair with a belt support.	Conventional office desk.
13	8 - 9 yrs	Office	Powered wheelchair with a belt support.	Conventional office desk; Because the wheelchair cannot pull up to the desk, it results in distance between the input devices and the subject. As a result, the keyboard is placed on the subject's thigh.
14	3 yrs	Office	Powered wheelchair.	Conventional office desk; Because the wheelchair cannot pull up to the desk, it results in distance between the input devices and the subject. As a result, the keyboard is placed on the subject's thigh.
15	8 yrs	Home	Manual wheelchair.	General office desk; With the adjustment of height, the desk allows the wheelchair to slide under it.
20	2 yrs	Home	Manual wheelchair with a neck and back cushion support.	Wheelchair table; The specialised desk which is designed to accommodated to the wheelchair.

APPENDIX F: THE 14 CSI SUBJECTS' NORMAL OPERATING MODES (STUDY C)

	OPERATION MODE		
NO.	KEYBOARD	MOUSE	GROUP ATTRIBUTION
01	Specially designed keyboard (approximately 32 cm in width and 12 cm in height). Operated by the left hand. The handstrip on the left hand is used to support the assisted input pen. In addition, the right thumb is used only for some specific keys.	Conventional mouse put at the right-hand side of the keyboard. The mouse is operated with the 2nd PIP and 5th MCP joints of her right hand.	Group 2
03	Conventional keyboard. Operated only by the middle fingertip (left hand) and his index fingertip (right hand).	Conventional mouse placed on the right-hand side. The mouse is activated only by the index fingertip of the right hand.	Group 3
04	Conventional keyboard. The keyboard is operated by the left hand with finger orthosis and the right hand with wrist and finger orthosis. Besides, the function of the left hand is better than that of the right hand. Hence, his left hand operates mainly computer inputs.	Conventional mouse at the left-hand side of the keyboard. Operated by the left-hand finger orthosis.	Group 1
05	Conventional keyboard held by metal frames on the bed. The subject's arms and legs are paralysed as a tetraplegia. As a result, the keyboard is activated by his mouth using a mouthstick.	No mouse use. The subject cannot operate a mouse.	Group 1
06	Conventional keyboard raised by a bag on the subject's thigh. The index fingertip of subject's left hand is used to operate the keyboard.	Conventional mouse set up on the subject's thigh. The MCP joint of the little finger of his right hand operates the mouse.	Group 2
07	Conventional keyboard. The main operating mode of a keyboard is carried out by	Conventional mouse placed at the right-hand side of the keyboard. The mouse is worked with the	Group 2

	subject's middle fingertip of the left hand; the index fingertip of the right hand provides an additional support of the left-hand operation.	index fingertip of the subject's right hand.	
09	On-screen keyboard. The subject cannot operate a conventional keyboard. An on-screen keyboard is employed as a substitute keyboard for data input. The mobility of the subject's right hand is limited, hence, the subject's left hand operates the on-screen keyboard with a mouse.	Conventional mouse placed at the left-hand side of the subject on the bed. Operated only by the left hand. The right button on the mouse is worked with the PIP joint of index finger; the left button on the mouse is activated by the MCP joint of little finger.	Group 2
10	Conventional keyboard. Due to the paralysis of the left hand, the keyboard is operated only by a right-hand finger extension support. The substitute finger is worn on the subject's right index finger and is used to perform all keying-in operations.	Special designed trackball mouse placed at the right-hand side of the keyboard. The left and right buttons on the mouse are operated by the subject's wrist on the right hand.	Group 1
11	Conventional keyboard. The subject performs all computing operations with his left hand. The middle fingertip of left hand is used to operate the keyboard.	Conventional mouse put on the left-hand side of the desk. The mouse is worked with the IP joint of the left thumb and MCP joint of the left little finger.	Group 2
12	Conventional keyboard+ On-screen keyboard. The on-screen keyboard is adopted for conducting the majority of keyboard operations. However, the conventional keyboard is used only for some specific keys especially when graphic drawing. The on-screen keyboard has to be operated by the mouse.	Conventional mouse placed in the middle of the desk in front of the subject. Accessing a mouse is the principal computer operation for the subject and operated with her both hands. The left button on the mouse is worked with the PIP joint of her left little finger; the mouse's right button is pressed by the MCP joint of the right little finger.	Group 3
13	Conventional keyboard frequently put on the subject's thigh. The keyboard is accessed only by the input pen grasped by the subject's left hand.	No mouse use.	Group 2
14	Conventional keyboard placed on his thigh.	No mouse use.	Group 2

	The keyboard operation is conducted only by the input pen by the left hand. Also, in order to hold the pen tightly, a handstrip is worn on the left hand.		
15	Conventional wireless keyboard. The subject's left hand is paralysed. As a result, the keyboard is operated only by the index and middle fingertips of the right hand.	Conventional wireless mouse set on the right-hand side of keyboard. Operating a mouse by the index and middle fingertips of the right hand.	Group 2
20	Conventional Keyboard placed on the wheelchair table. The keyboard is accessed only by the right hand by the finger and wrist orthosis.	Specially designed trackball mouse placed on the right-hand side of the keyboard. The trackball and two buttons on the mouse are operated by the finger and wrist orthosis wore on the right hand.	Group 1

APPENDIX G: THE DEVICE SET-UPS AND ADJUSTMENTS OF THE 14 CSI SUBJECTS (STUDY C)

NO.	5.7-INCH PROTOTYPE	9-INCH PROTYTYPE	GROUP ATTRIBUTION
01	 The 5.7 inch prototype is set in the place of keyboard. In addition, due to the light reflection of the touchscreen surface, the device is uplifted by a document holder.	 The 9-inch prototype is placed at the place of keyboard.	**Group 2** (handstrip + an input pen)
03	 The 5.7-inch device is put on the keyboard tray.The document holder is used to raise the device to lessen the problem of light reflection of the touchscreen.	 The 9-inch device is unable to put at the place of keyboard because of its bigger size. Hence, the device is set on the subject's thigh and tilted against the computer desk.	**Group 3** (the right index finger)
04	 The 5.7-inch device is set in the normal position of the keyboard on the computer desk.	 The 9-inch device is set in the normal position of the keyboard on the computer desk.	**Group 1** (the left hand orthosis)
05			**Group 1** (a mouthstick)

The subject's keyboard is fixed on a metal frame. The 5.7-inch device is put on the keyboard and taped on the metal frame for stabilising.

Because of illness, the subject has transferred his workplace to the bed. The mouthstick is twofold lengthened compared to the original length. A mouthstick rest is designed as shown in the upper image.

Similarly, the 9-inch device has to be taped down and put on the place of keyboard.

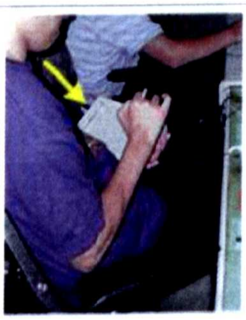
06

Following the subject's normal practice, the 5.7-inch prototype is set on the subject's thigh. A packsack (or a cushion) is used to raise the touchscreen device for lessening the distance between the user and the device.

In parallel, the 9-inch prototype is put on the subject's thigh on the packsack (or a cushion).

Group 2
(an input pen)

07



The subject is placed the 5.7-inch device between his left arm and the stomach.

The 9-inch device is set on the computer desk in the normal position of the keyboard.

Group 2
(an input pen)

09

In order to accommodate to the subject's lying-on-bed operation, the 5.7-inch device is put next to the subject and adjusted to fit the subject's viewing angle-height.

The 9-inch device is tilted and set next to the subject like the 5.7-inch device.

Group 2
(an input pen)

10

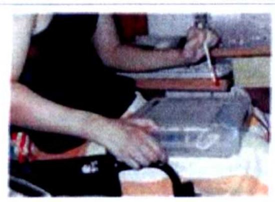
The 5.7-inch touchscreen is set in the same position as the keyboard on the office desk.

The 9-inch touchscreen is placed in the same position as the keyboard on the office desk.

Group 1
(the right-hand finger orthosis)

11

The height of the touchscreen device would lead to awkward wrist, arm and shoulder postures to the subject if the 5.7-inch touchscreen device were placed on the desk. Hence, the 5.7-inch device is put on the subject's thigh.

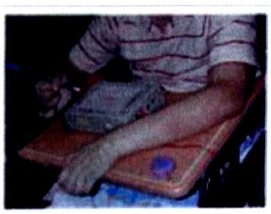


In parallel, the 9-inch touchscreen device is set on the subject's thigh similar to the 5.7-inch portable device.

Group 2
(an input pen)

12

Group 3
(the left little finger)

	It the touchseen device is set on the desk, it would cause the subject to work with the arms and shoulders in awkward postures. As a result, the 5.7-inch touchscreen device is placed on the subject's thigh.	Following the subject's preference, the 9-inch device is put on the subject's thigh.	
13	 According to the subject's normal practice, that the keyboard is frequently put on his thigh, the 5.7-inch prototype is put in the same place as the keyboard and also tilted by some rigid material for adjusting the viewing distance and angle between the device and the user.	 The 9-inch prototype is set on the subject's thigh in the same place as the keyboard used to be.	**Group 2** (an input pen)
14	 The 5.7-inch prototype is placed in place of the keyboard. Also, the device is tilted by some rigid material for matching the viewing angle of the subject.	 The 9-inch device is set on the subject's thigh and tilted against the desk.	**Group 2** (an input pen)
15	 The 5.7-inch device may cause the subject strain in his left arm and shoulders when arranging the device on the computer desk. Hence, the subject prefers to set the 5.7-inch device on the wheelchair's table which is used only for eating and reading.	 The 9-inch device is placed on the wheelchair table to avoid awkward postures when operating it.	**Group 2** (an input pen)
20	Following the subject's normal practice, the 5.7-inch device is placed on the wheelchair table.	The keyboard and mouse is used on the wheelchair's table. The 9-inch device is put at the same position as the keyboard.	**Group 1** (the finger and wrist orthosis)

APPENDIX H: USER'S EXPERIENCES OF DEVICE UTILISATION AT THE INTRODUCTORY PHASE (STUDY C)

NO.	SUBJECT PERSPECTIVES
01	The size of 5.7-inch for a portable touchscreen prototype could reduce repetitive operating strain because of its limited surface zone. However, the smaller keys presented on the limited touchscreen surface can easily cause eye fatigue and dryness when viewing the 5.7-inch device for long periods of time. The 9-inch touchscreen device is easy to use and diminishes the operating tiredness because of its smaller surface which is smaller than the conventional keyboard and allows the easy sliding of the finger across the screen. In terms of the device function, the touch operating mode brings a brand-new experience, and the inclusion of PDA function enhances its value.
03	Due to the very limited upper-limb function, the keys on the 5.7-inch device are too small to key in correctly with a single finger. For that reason, it may require an additional input support, such as an input pointer. The 9-inch device has the same strength (i.e. operated only by lightly tapping or sliding on the surface, hence, minimum operating fatigue) like the 5.7-inch device. Besides, the QWERTY standard keyboard layout that has been provided on the 9-inch touchscreen device is well accepted by an experienced computer user like the subject himself. Compared to the current conventional keyboard, the subject assumes that the touchscreen alternative input is easier to use and can improve his input effectiveness.
04	The function ability of the left hand is better than that of the right hand. Thus, the subject is used to accessing a keyboard or mouse mostly by his left hand by the finger orthosis. The right hand with the finger and wrist orthosis is used only for some specific keys, such as SPACE, ENTER, BACKSAPCE, etc. With the use of touchscreen input device, it lessens the repetitive keying strain, in addition, even the lower-functioning right hand can operate on the surface. The key size and layout of 9-inch device are displayed as the adopted conventional keyboard, further, there is a reduction of eyestrain while viewing the surface for a prolonged time compared to the 5.7-inch device. Moreover, the combining of keyboard and mouse functions in a device brings advantages for the users, like the subject, who have upper-limb disorders and who cannot properly use either a keyboard or a mouse.
05	The subject used to perform his computer activities when seated in the wheelchair before the illness. The mobility of mouthstick operation is more restrained from the lying-on-bed performance compared to the wheelchair-seating when access a computer. After testing both touchscreen devices, the subject preferred the 9-inch prototype because of its appropriate sizes of the surface and keys. For a mouthstick operator, the touchscreen device could reduce fatigue and strain more effectively than a conventional keyboard. However, the 5.7-inch device for the subject seemed to be too small and require more concentration when operating it.

In brief, the 9-inch device is well accepted, further, the requirement of longer-term use is proposed by this subject.

06 With the assistance of an inputting pen, the 5.7-inch touchscreen device is easier to use than operating a device with a single finger. To operate with an assisted pen is also recommended by the subject even when using a 9-inch device.

The 9-inch device could be more suitable to those users with severe upper-limb disorders than the 5.7-inch device. The touch-operating mode could complement the users' functional limitation and provide a labour-save means of accessing a computer. In terms of device function, the power switch of the touchscreen device which is on the side of the device is unable to turn on/off independently for most CSI users. In addition, the mouse function and ergonomic concern should bring a further improvement.

The subject has pointed out that the integrated touchscreen input devices are presented in easier way to access a computer and he expected to replace his existing conventional keyboard and mouse.

07 The 5.7-inch device is smaller and portable. The operating mode of the 5.7-inch touchscreen device is similar to the conventional PDA. For instance, the device can be set between his left arm and stomach and be activated by his right hand. From the subject's viewpoint, the portable input device is a proper idea for the wheelchair users, such as spinal cord injury. However, the sizes of the surface and keys are applicable to a touchscreen device. The depth and weight of this portable device should be thinner and lighter. Besides, the operation with an input pen is an effective way for touchscreen utilisation than inputting data with a single finger.

For the 9-inch device, the subject deems that it is easier to operate and more labour-saving than the conventional keyboard for a users with cervical spinal injury such as himself. As a result, the 9-inch device has the potential to replace the conventional input devices.

09 The habitual practice for this bedridden subject is to access a computer only by a mouse. The subject cannot operate a conventional keyboard because of his very limited finger function, hence, he adopts an on-screen keyboard as an alternative data key-in. In addition to his lower-functioning fingers, he has an ability to grasp a pen. With the assistance of an input pen, the subject can easily to operate both 5.7-inch and 9-inch touchscreen devices.

Due to the subject's lying-in-bed, the device has to be placed next to him in the same place as his adopted mouse. The keys on the 5.7-inch device are too small because of the viewing distance, but the key size of the 9-inch touchscreen is suitable for the subject. The PDA is the significant idea involved in the input device and enhances the attraction of the device. Following his habitual practice, the 9-inch touchscreen device can match the user's needs and replace the use of a mouse and on-screen keyboard. Some suggestions were also made for functional improvements, such as the installation of wireless and electronic books.

10 The operating mode of the subject is to access a keyboard and mouse only by his right substitute finger (i.e. the wearing of finger orthosis). The touchscreen operating mode brings to the subject a novel experience. The lightly sliding and tapping operating mode is user-friendly, the smaller workplace surface reduces the repetitive keying fatigue, as well as the integration of both keyboard and mouse functions benefiting the users.

Longer-term practice is required for the familiarization with a novel device such as the touchscreen prototype.

11	The users can sense the rebound effect when accessing a conventional keyboard. On the contrary, the touchscreen device has a stationary and smooth surface, and can be easier to operate for users with severe hand movement disorders. To operate a touchscreen device by an input pen is more effective than with his left middle fingertip. The touchscreen requires less labour force and reduces the tiredness caused by prolonged keying in actions. Besides, the assisted support (e.g. handstrip) for stabilising input operation is required for the subject. Further ergonomic considerations require more attention, such as the touchscreen holder for adjusting the viewing angle.
12	The subject has a very limited upper-limb function – she can neither spread her hands nor grasp things. As a result, she can operate both touchscreen prototypes only by her hand joints rather than an assisted input pen. Because of her very limited finger force, the touchscreen cannot function properly and requires repetitive attempts. As she is a graphic designer, the mouse tasks, such as dragging, dropping, and pointing, are well used. However, the mouse performance of the novel touchscreen devices cannot properly match the needs of a graphic designer. There needs to be hundreds of attempts, failures, adjustments, and a great deal of practice time to develop the current operating mode for the subject. The operating of a touchscreen input device is a novel experience for her. It may require a long-term adaptation, adjustments, and attempts for overcoming the operating difficulties and become familiar with the device utilisation.
13	Following the subject's habitual practice and the concerns of viewing angle, the touchscreen device is placed on his thigh and operated by an input pen. From the subject's viewpoint, the 5.7-inch device is suitable for portable use for the wheelchair chair user such as himself. The additional improvements have been proposed, such as the wireless installation, the thinner and lighter construction, and a device holder set on the wheelchair. The 9-inch device is applicable to those users with cervical spinal cord injury and easier to use than the conventional keyboard. The design improvements, such as the power switch design and the vertical position of the touchscreen device are pointed out.
14	The subject is used to operate a keyboard with an input pen supported by the handstrip. Similarly, the touchscreen device functions by an input pen and is placed on the subject's thigh. Compared to his currently used conventional keyboard, both touchscreen devices reduce finger force, keying fatigue, and are easier to use. The inclusion of the PDA function is novel and benefits the SCI users. The subject deems himself a slow learner, but the touchscreen devices allows him to operate an input device at the introductory stage. Therefore, he believes that users can operate it easily and achieve familiarisation with its functions in the near future.
15	The subject frequently operates a keyboard and a mouse only with his right index and middle fingers. With the remaining upper-limb function, such as grasp a pen, the subject is able to activate the touchscreen device with an assisted input pen. Following the subject's perspectives, the designs, such as the lightly sliding and tapping operating mode, hot keys, the integration of keyboard and mouse, and the PDA function, can benefit the single key-in operators such as himself. Moreover, the touchscreen alternative input has a potential to take the place of the conventional input devices. The subject has been working with a computer for 8 years. As a computer user with the high level of spinal lesion, the subject has tried hard to adapt himself to the conventional input devices. After time-after-time adjusts and practices, the subject can operate a

	computer and work as a computer worker. If the touchscreen device were provided at the first stage of computer use for those with upper-limb difficulties, it would reduce a length of time spent on adaptation.
20	The key size of the 5.7-inch portable device is too small for the subject, therefore, the problems, such as ease to hit the wrong keys, are found during the 5.7-inch device operation. In contrast, the desktop use 9-inch touchscreen device is applicable and well worked with the subject's assistive input device (i.e. finger and wrist orthosis). However, the embedded mouse function, such as dragging and dropping, is suggested for further *improvements*.

APPENDIX I: TESTING RESUTLS ON SHORT-TERM USE AND TRAINING (STUDY D)

Complete Report on 2005/8/15 by TypingMaster — Page 1

Subject 21

Group	
Current Course	No course started
Studying Time	3 h 40 min
Last Used	2005/8/15 下午 02:26
Usage	11 times
Created	2005/8/3

Typing Tests

Rules of baseball (from 1889)

Date:	2005/8/15 下午 02:05	Gross speed:	2 wpm	Gross hits:	225
Duration:	20 min.	Accuracy:	84%	Error hits:	35 (7 errors * 5)
Done:	20 min.	Net speed:	2 wpm	Net hits:	190

Observations of the "Father of Computing" (1791-1871)

Date:	2005/8/14 下午 02:07	Gross speed:	3 wpm	Gross hits:	250
Duration:	20 min.	Accuracy:	80%	Error hits:	50 (10 errors * 5)
Done:	20 min.	Net speed:	2 wpm	Net hits:	200

Netiquette

Date:	2005/8/13 下午 02:09	Gross speed:	2 wpm	Gross hits:	221
Duration:	20 min.	Accuracy:	82%	Error hits:	40 (8 errors * 5)
Done:	20 min.	Net speed:	2 wpm	Net hits:	181

Legends of Abraham Lincoln

Date:	2005/8/12 下午 02:10	Gross speed:	2 wpm	Gross hits:	229
Duration:	20 min.	Accuracy:	75%	Error hits:	55 (11 errors * 5)
Done:	20 min.	Net speed:	2 wpm	Net hits:	174

Hubble Space Telescope

Date:	2005/8/11 下午 02:09	Gross speed:	2 wpm	Gross hits:	231
Duration:	20 min.	Accuracy:	74%	Error hits:	60 (12 errors * 5)
Done:	20 sec.	Net speed:	2 wpm	Net hits:	171

History of Photography

Date:	2005/8/10 下午 02:07	Gross speed:	2 wpm	Gross hits:	218
Duration:	20 min.	Accuracy:	68%	Error hits:	70 (14 errors * 5)
Done:	20 min.	Net speed:	1 wpm	Net hits:	148

Extract from The Adventures of Pinocchio

Date:	2005/8/7 下午 02:10	Gross speed:	2 wpm	Gross hits:	222
Duration:	20 min.	Accuracy:	50%	Error hits:	110 (22 errors * 5)
Done:	20 min.	Net speed:	1 wpm	Net hits:	112

DNA Research -- the Human Genome Project

Date:	2005/8/6 下午 02:08	Gross speed:	3 wpm	Gross hits:	282
Duration:	20 min.	Accuracy:	53%	Error hits:	130 (26 errors * 5)
Done:	20 min.	Net speed:	1 wpm	Net hits:	152

Behind the scene: Movie credits

Date:	2005/8/5 下午 02:10	Gross speed:	1 wpm	Gross hits:	90
Duration:	20 min.	Accuracy:	44%	Error hits:	50 (10 errors * 5)
Done:	20 min.	Net speed:	0 wpm	Net hits:	40

Astronauts

Date:	2005/8/4 下午 02:08	Gross speed:	2 wpm	Gross hits:	155
Duration:	20 min.	Accuracy:	6%	Error hits:	145 (29 errors * 5)
Done:	20 min.	Net speed:	0 wpm	Net hits:	10

Aesop's fables

Date:	2005/8/3 下午 02:08	Gross speed:	1 wpm	Gross hits:	100
Duration:	20 min.	Accuracy:	39%	Error hits:	60 (12 errors * 5)
Done:	20 min.	Net speed:	0 wpm	Net hits:	40

Subject 22

Group	
Current Course	No course started
Studying Time	3 h 40 min
Last Used	2005/8/27 [illegible] 02:56
Usage	11 times
Created	2005/8/15

Typing Tests

Rules of baseball (from 1889)

Date:	2005/8/27 [illegible] 02:36	Gross speed:	8 wpm	Gross hits:	805
Duration:	20 min.	Accuracy:	94%	Error hits:	50 (10 errors * 5)
Done:	20 min.	Net speed:	8 wpm	Net hits:	755

Observations of the "Father of Computing" (1791-1871)

Date:	2005/8/26 [illegible] 02:40	Gross speed:	8 wpm	Gross hits:	797
Duration:	20 min.	Accuracy:	92%	Error hits:	60 (12 errors * 5)
Done:	20 min.	Net speed:	7 wpm	Net hits:	737

Netiquette

Date:	2005/8/25 [illegible] 02:36	Gross speed:	8 wpm	Gross hits:	781
Duration:	20 min.	Accuracy:	93%	Error hits:	55 (11 errors * 5)
Done:	20 min.	Net speed:	7 wpm	Net hits:	726

Legends of Abraham Lincoln

Date:	2005/8/24 [illegible] 02:36	Gross speed:	7 wpm	Gross hits:	727
Duration:	20 min.	Accuracy:	92%	Error hits:	60 (12 errors * 5)
Done:	20 min.	Net speed:	7 wpm	Net hits:	667

Hubble Space Telescope

Date:	2005/8/23 [illegible] 02:40	Gross speed:	7 wpm	Gross hits:	731
Duration:	20 min.	Accuracy:	96%	Error hits:	30 (6 errors * 5)
Done:	20 min.	Net speed:	7 wpm	Net hits:	701

History of Photography

Date:	2005/8/22 [illegible] 02:35	Gross speed:	6 wpm	Gross hits:	651
Duration:	20 min.	Accuracy:	91%	Error hits:	60 (12 errors * 5)
Done:	20 min.	Net speed:	6 wpm	Net hits:	591

Extract from The Adventures of Pinocchio

Date:	2005/8/19 [illegible] 02:37	Gross speed:	7 wpm	Gross hits:	665
Duration:	20 min.	Accuracy:	86%	Error hits:	90 (18 errors * 5)
Done:	20 min.	Net speed:	6 wpm	Net hits:	575

DNA Research -- the Human Genome Project

Date:	2005/8/18 [illegible] 02:37	Gross speed:	6 wpm	Gross hits:	633
Duration:	20 min.	Accuracy:	87%	Error hits:	80 (16 errors * 5)
Done:	20 min.	Net speed:	6 wpm	Net hits:	553

Behind the scene: Movie credits

Date:	2005/8/17 下午 02:38	Gross speed:	5 wpm	Gross hits:	492
Duration:	20 min.	Accuracy:	85%	Error hits:	75 (15 errors * 5)
Done:	20 min.	Net speed:	4 wpm	Net hits:	417

Astronauts

Date:	2005/8/16 下午 02:39	Gross speed:	5 wpm	Gross hits:	544
Duration:	20 min.	Accuracy:	89%	Error hits:	60 (12 errors * 5)
Done:	20 min.	Net speed:	5 wpm	Net hits:	484

Aesop's fables

Date:	2005/8/15 下午 02:36	Gross speed:	3 wpm	Gross hits:	320
Duration:	20 min.	Accuracy:	68%	Error hits:	100 (20 errors * 5)
Done:	20 min.	Net speed:	2 wpm	Net hits:	220

APPENDIX J: PUBLISHED WORKS BY CANDIDATE

1. Chen, R., Tsai, D. Chang, L. and Higget, N. (2004). "An Assessment into Touch Screen Input Devices for Cervical Spinal Injured Computer Users". Proceedings of ICCHP 2004, the 9th International Conference on Computers Helping People with Special Needs, 7-9 July, Paris, pp 873-879.
2. Chen, R. and Tsai, D. (2006). "A Usability Assessment of an Alternative Computer Input Device for Users with Cervical Spinal Injuries". Proceedings of EST 2006, the 13th Annual Meeting Ergonomics Society of Taiwan, Universal Human Technology: Interfacing Welfare and Design, 2-4 March, Kaohsiung, Taiwan.