EFFECTS OF SITTING TAI CHI ON SITTING BALANCE CONTROL AND QUALITY OF LIFE IN COMMUNITY-DWELLING PERSONS WITH SPINAL CORD INJURIES

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Effects of sitting Tai Chi on sitting balance control and quality of life in community-dwelling persons with spinal cord injuries

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CERTIFICATE OF ORIGINALITY

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

_____________ (Signed)

GAO Li Kelly____ (Name of student)

ABSTRACT

Background Context: Control of sitting balance is associated with the level of injury in people with spinal cord injury (SCI). Balance control is an important ability for functional activities, especially for wheelchair users. However, the measurement of the dynamic sitting balance is lacking. Tai Chi is a mind-body exercise which has been documented as improving balance. Traditional Tai Chi is performed in standing, which is not suitable for wheelchair users. Sitting Tai Chi may be an appropriate exercise for people with SCI. The benefits of sitting Tai Chi for people with SCI have not been demonstrated scientifically.

Study 1:

Purpose: Study 1 aimed to develop a reliable and valid tool for measuring the dynamic sitting balance of wheelchair users with SCI.

Study Design/Setting: This was a cross-sectional study.

Patient Sample: Convenience sampling from the community.

Outcome Measures: Limits of stability (LOS) and sequential weight shifting (SWS) were designed in this study. The tests measured participants' volitional weight shifting in multiple directions within their base of support. Their mobility scores on the Spinal Cord Independence Measure III (SCIM III) were correlated with the balance test results. The LOS outcome measures were reaction time, maximum excursion and directional control; for the SWS they were total time and directional control.

Methods: Nine participants with chronic SCI (average of 17.2 years post-injury) between levels C6 and L1 performed the tests while sitting in their own wheelchairs and on a standardized stool (unsupported sitting) twice, seven days apart.

Results: The sitting LOS results showed moderate to excellent test-retest reliability (ICC ranged from 0.673-0.990) with both the wheelchair and the unsupported sitting. The SWS results showed moderate to excellent reliability (ICC ranged from 0.688–0.952). Only the LOS results in unsupported sitting correlated significantly with the SCIM III mobility scores, but the SWS test results had significant correlation in both sitting conditions.

Conclusions: The sitting LOS and SWS tests provide a reliable and valid tool for assessing the dynamic sitting balance control of subjects with SCI.

Study 2:

Purpose: Study 2 aimed to investigate the effect of sitting Tai Chi exercise on handgrip strength, balance control and quality of life among people with SCI.

Study Design/Setting: This was a prospective intervention study.

Patient Sample: Convenience sampling from the community.

Outcome Measures: Dynamic sitting balance tests were evaluated with the subjects sitting in their own wheelchairs using the LOS test and the SWS test. Handgrip strength was tested. Quality of life was self-reported using the brief form of the World Health Organization’s quality of life questionnaire (WHOQOL-BREF).

Methods: Nineteen subjects with SCI between injury levels C6 and L1, 2 to 48 years post-injury participated in the study. Eleven subjects participated in sitting Tai Chi training (90 minute/session, 2 times/week for 12 weeks). Eight joined education and social activities as controls.

Results: Repeated measures MANCOVA showed significant group by time interaction effects on sitting balance control. Post hoc analysis demonstrated that the Tai Chi practitioners achieved significant improvements in their reaction time (p=0.042); maximum excursion (p=0.046) and directional control (p=0.025) in the LOS test. In the SWS test, they significantly improved their total time to sequentially hit 12 targets (p=0.035) and directional control (p=0.033). These improvements were significantly greater than those of the controls. Significant improvement in handgrip strength was also found among the Tai Chi practitioners (p= 0.049).

Conclusions: Twelve weeks of sitting Tai Chi training can improve the dynamic sitting balance and handgrip strength of community-dwelling SCI survivors. Clinicians might use sitting Tai Chi as an exercise for people with SCI who can continue to practice the exercise even after being discharged from hospital as a means to maintain health.

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LIST OF ABBREVIATIONS

ADL: activity of daily living

ANOVA: analysis of variance

APA: American Psychological Association

ASIA: American Spinal Injury Association

COG: center of gravity

COP: centre of pressure

DC: directional control

EMG: electromyography

FICSIT: Frailty and Injuries: Cooperative Studies of Intervention Techniques

ICC: intraclass correlation coefficient

LOS: limits of stability

MANOVA: multivariate analysis of variance

MANCOVA: multivariate analysis of covariance

ME: maximum excursion

METs: metabolic equivalents

P: Significance level

QOL: quality of life

RT: reaction time

SCI: spinal cord injury

SCIM III: Spinal Cord Independence Measure III

SWS: sequential weight shifting

WHOQOL-BREF: brief form of the World Health Organization's quality of life questionnaire

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CHAPTER 1

INTRODUCTION

1.1 Epidemiology of spinal cord injury

The annual incidence of spinal cord injury (SCI) worldwide was 14.5–39.4/million people over the past several decades (Burke, Linden, Zhang, Maiste, & Shields, 2001; O'Connor, 2002; Shingu, Ikata, Katoh, & Akatsu, 1994). Recently, the number of incidences has increased dramatically to 23.1–60/million people, and the highest rate was reported in China (Couris et al., 2010; Li et al., 2004). The main reason for fall accidents from heights is a lack of education in occupational safety. Also, there has been a rapid growth of vehicles in China which has considerably increased the number of road traffic accidents. Falling from heights and road traffic accidents are the major causes of the rapid increase of spinal cord injuries in China. The age of people with SCI ranges from 29.3 to 46.1 years in developing countries (Chiu et al., 2010). With improved therapeutic techniques, a recent survey reported that there has been remarkable progress in reducing the length of stay in acute hospital care, from an average of 24.7 days decreased to 16 days (Kattail, Furlan, & Fehlings, 2009; Sekhon & Fehlings, 2001). Suffering an injury to the spinal cord is often a life-altering event. Even after discharge from hospital, individuals still need long-term and comprehensive care for re-entry into the community and to resume habitual patterns of living.

1.2 Definition and classification of spinal cord injury

<u>Definition</u>

An SCI is the damage to the spinal cord due to trauma or disease which results in the loss of important mechanisms that carry signals going to and coming from the brain resulting in either temporary or permanent disruption of motor, sensory, and autonomic functions (Field-fote, 2009). Such an injury results in impairments of function that have a tremendous impact on an individual's life. There is a close relationship between the level and severity of injury with the residual motor, sensory, and autonomic functions.

Classification of spinal cord injury

The International Standards for Neurological and Functional Classification is the most reliable and valid method to assess people with SCI. It is the most frequently accepted method of describing the level and extent of injury based on a standardized physical examination (Kirshblum & Donovan, 2002). The classification is previously referred to as the American Spinal Injury Association (ASIA) guidelines. In 1969, Frankel and colleagues introduced a five-grade system of classifying traumatic SCI, with a division into complete and incomplete injuries. The classification was replaced by ASIA in 1992. The ASIA scores allow the examiner to determine the motor, sensory, and the neurological level of injury, the degree of completeness of the injury, and to determine the ASIA Impairment scale (refer to Appendix A). Twenty-eight key dermatome are used for the sensory examination (i.e., C2 to S4–5), each separately tested by a pinprick with a safety pin and light touch with a cotton-tipped applicator. A numerical scale is used, with 0 representing absent sensation; 1 representing impaired sensation, which is defined as partial or altered sensation including hyperesthesia; and 2 representing normal sensation, with the face being the normal reference point. The required elements of the motor examination consist of testing 10 key muscles on each side of the body, five in the upper limb and five in the lower limb. All muscles are tested with the graded on a numerical scale from 0 to 5.

A complete injury is defined as the absence of motor or sensory function in the lowest sacral segments. An incomplete injury is defined as preservation of motor function or sensation below the neurological injury level that includes the lowest sacral segments. Sensory function is tested by light touch and pinprick at the anal mucocutaneous junction (S4 to S5 dermatome), on both sides, and testing voluntary anal contraction and deep anal sensation. If any of these are present, it indicates that the individual has a neurologically incomplete injury. According to this definition, a person with cervical SCI can have sensory and motor function in the trunk or even in the lower limbs.

1.3 Sitting balance control and spinal cord injury

1.3.1 Falls in people with spinal cord injuries

Approximate 70% to 80% of people with SCI are permanently dependent on using a wheelchair for mobility. In a prospective study of 659 community-dwelling wheelchair users who suffered with SCI (age 54.8±12.6 years), 31% of subjects reported 553 fall events (Nelson et al., 2010). In a retrospective study by Nelson and colleagues (2003), a review of 45 individuals with SCI showed that 24 (53%) of them had 27 fall episodes. The major factor contributing to falls was loss of balance during functional activities (Nelson et al., 2003). The activities contributed to falls arose from more than one wheelchair activity including transfer (44%), reaching (11%), propelling (15%), moving in bed (22%), transferring or riding in a vehicle (30%), and showering (8%). Wheelchair users with SCI have been found to have decreased or absent trunk control leading to poor sitting balance and stability which may cause falls during transfer (Bernard, Peruchon, Micallef, Hertog, & Rabischong, 1994).

1.3.2 Sitting balance control

The level of injury will affect trunk control and balance, which are important for activity of daily living (ADL) and functional activities. Individuals with a high level of SCI have demonstrated decreased balance control (Chen et al., 2003; Lynch, Leahy, & Barker, 1998). People with high thoracic injuries have difficulty in sitting balance control. Often, people with SCI employ the short-sitting position (hips and knees are approximately 90°) when performing the ADL. However, the base of support is small in the short-sitting position because only part of the thighs are in contact with the supporting surface. As a result, the short-sitting position is less stable and maintaining balance is more difficult.

1.3.2.1 Sitting balance control and activities of daily living

Good sitting balance control is essential for people with SCI because they are often confined to the sitting position when performing the ADL. When performing ADL, from quiet sitting (such as feeding, grooming, and bathing) to dynamic activities (such as propelling the wheelchair up or down a ramp), all levels of activity require different degrees of sitting balance control. When ascending a ramp, people with SCI should lean forward as far as possible to prevent the wheelchair from tipping backward. When descending a ramp, they should lean as far back as possible to prevent falling forwards (Sisto, Druin, & Sliwinski, 2009). These techniques require individuals to perform maximal postural excursion in either the forward or backward direction. The ability to initiate voluntary weight shifting to certain positions without losing stability is important for individuals with SCI. Several articles focusing on balance control in the SCI population employed the maximal postural sway as the outcome measure. Moreover, SCI individuals are comparatively young and often participate in sport activities which demand an even higher sitting balance ability. Other than that, sitting balance heavily influences wheelchair skills, and especially wheelie mastery which is required to ascend or descend a curb.

1.3.2.2 Sitting balance and transfer

Sitting posture and balance directly affect transfer performance (Bolin, Bodin, & Kreuter, 2000). An appropriate sitting position is fundamental in providing a stable base of support for transfer activities. A sense of position in space is another crucial factor when attempting a transfer. The ability to precisely and accurately control intentional movements of the centre of pressure (COP) in different directions is important. Better directional control provides an accurate controlling ability to perform a variety of transfer activities. When individuals perform a transfer from a short-sitting position to an unsupported position, they require better directional control, for example, transferring from a wheelchair to a bathtub.

A few studies showed that SCI persons with a higher level injury try to compensate for their loss of postural muscle function of the erector spine through increased use of different non-postural muscles (Seelen, Potten, Huson, Spaans, & Reulen, 1997; Seelen et al., 1998a; Seelen, Potten, Drukker, Reulen, & Pons, 1998b; Seelen, Janssen-Potten, & Adam, 2001). They tend to use latissimus dorsi, upper trapeizus, pectoralis major, and serratus anterior to restore sitting balance. Effective balance training can achieve a significant contribution to preserving upper extremity joint integrity.

1.4 The assessment of sitting balance control

Sitting balance control is complex and it involves the integration of sensory, motor, and central nervous systems within the biomechanical constrains in an environment for a specific task. Sitting balance is defined as the ability to remain sitting upright without using an external support in a quiet or dynamic sitting posture (Boswell-Ruys et al., 2009; Lynch et al., 1998).

There are two main methods of measuring sitting balance: clinical and laboratory perspectives.

1.4.1 Clinical methods

The clinical methods include shifting of body position in different directions, time to complete certain daily activities, and arm reaching (Boswell-Ruys et al., 2009; Chen et al., 2003; Lynch et al., 1998). Modified functional reach test (Lynch et al., 1998) is similar to the functional reach test. It uses a yardstick to measure the forward distance in sitting and is commonly used due to its simplicity. It was reported, however, that the test cannot detect a slightly improved balance (Bolin et al., 2000). Furthermore, sitting balance is complex and not restricted to the ability to reach forward, but also requires moving the center mass in multiple directions (Boswell-Ruys et al., 2009), as required in ADL tasks. In a cross-sectional study on a paraplegia population, the maximal postural excursions in four directions (forward, backward, left and right) were measured by a ruler. Despite the addition of spatial directions, the prediction of functional performance from the view of sitting balance control is inadequate, as the test involves only orthogonal directions and the time and smoothness to complete the task are unknown.

In measuring the time to complete certain daily activities, a stopwatch was employed to time both the upper and lower body dressing/undressing, and transfer between a wheelchair and a mat table (Chen et al., 2003). Later, Boswell-Ruys and his colleagues (2009) combined the aforementioned tests with the addition of a coordinated stability task during an unsupported sitting position. The tests consist of a tape and a stopwatch to measure the distance of upper-body sway, maximal balance range, and seated reach distance; time dressing/undressing of the upper body and alternating arm reach as well as errors made during a coordinated stability task. Although dressing activity is a necessity in ADL and the time needed for dressing/undressing of the upper body is functional, different subjects may have their respective ways to get dressed/undressed which may make inter-subject comparison difficult. Also, dressing/undressing performance does not depend only on sitting balance, but also on coordination, endurance and the type of clothing.

1.4.2 Laboratory methods

The laboratory methods consist of force plate analysis, motion-analysis, and electromyography (EMG) measurements.

Force plate measures the resultant vertical ground reaction force and can represent the neuromuscular responses to imbalance of the body's COP (Chen et al., 2003; Grigorenko et al., 2004). The mechanism uses a strain-gauge type load cell mounted on four precision strain elements. It records changes of COP displacement from the force plate signals. The data are often used to measure maximal postural sway in sagittal and coronal planes. Longer displacement achieved during leaning indicates better sitting balance control. However, only four directions were measured in previous studies on subjects with SCI. The data cannot truly reflect the ability required in performing the ADL. For example, when transferring from the wheelchair to the bed, the wheelchair is positioned at approximately 30° to the bed. Individuals need to go in a diagonal direction in either right-forward or left-forward to the target position depending on the subjects' habits.

The motional analysis system consists of a video camera and an infra-red light emitting diodes. The data are used to calculate the angular and linear displacement of the trunk segments. Shirado (Shirado et al., 2004) and colleagues investigated the change of pelvic tilt and lumbar lordosis in the sagittal plane during long sitting of subjects (with hips flexed and knees extended). They found that people with SCI kept their pelvis posteriorly and the lumbar spine was less lordotic during long sitting. Mean pelvic tilt was also used to postulate the sitting balance ability in the Janssen-Potten's, Kukke's and Seelen's study (Seelen et al., 1997; Seelen et al., 1998a; Seelen et al., 1998b; Seelen et al., 2001). The investigators used the ability of pelvic tilt to delineate the weight shifting capability of subjects with spinal cord injury.

EMG was also used in Seelen's team to examine people with thoracic SCI (Seelen et al., 1997; Seelen et al., 1998a; Seelen et al., 1998b; Seelen et al., 2001). They found that subjects with higher thoracic SCI actively maintain sitting balance through the use of non-postural muscles. The latissimus dorsi and the upper part of the trapezius are used to compensate for the function loss of the erector spinae. Similarly, Janssen-Potten's team used EMG to monitor the trunk, hip and leg muscles which contribute to the active control of sitting balance for people with lower SCI and lumbar SCI because they have less sensory-motor dysfunction (Janssen-Potten, Seelen, Drukker, & Reulen, 2000; Janssen-Potten, Seelen, Drukker, Huson, & Dorst, 2001; Janssen-Potten, Seelen, Drukker, Spaans, & Dorst, 2002). The investigators found that people with lumber SCI showed less rectus femoris activity during rest, and less tibialis anterior activity during the forward-reaching in those with thoracic SCI.

1.5 Exercise for sitting balance control in people with spinal cord injury

With the advancement of rehabilitation strategies, people with SCI can benefit from various interventions that restore their functional capacity and ability to re-enter the community. There is evidence to state that people with chronic SCI can achieve functional gains if the appropriate intervention is given. Little is known, however, about the exercise program on sitting balance in people with SCI. Grigorenko and his colleagues (2004) conducted an 8-week open sea kayak training on 12 individuals with SCI and 12 able-bodied subjects. Subjects seated with knees slightly bent on a specific chair which was also designed for kayak training. The setup was mounted onto a force plate. The standard deviation and mean velocity of the COP displacement and the median frequency of the acceleration of the COP in the sagittal and frontal planes were measured in quiet sitting with eyes open over a 30-second period. The results showed that kayak training had relatively small effects on balance in quiet sitting. A significant training effect was seen only on a decrease in median frequency in the sagittal plane. In fact, this specific sitting position was similar to the long sitting position which was not functional in ADL when compared with a short and unsupported sitting. In a later study, 10 persons with SCI underwent a 10-week kayak arm ergometer training (Bjerkefors, Carpenter, & Thorstensson, 2007). The kayak ergometer was modified to adjust the balance demand in the medial-lateral direction. This balance demand was individually adapted to each subject's initial ability to cope with the instability during the paddling movement. Balance control was tested on their own wheelchair fixed to a wooden platform under predicted and unpredicted perturbations. Markers were mounted on the trunk and movement data were recorded in a 3D system. Postural stability was improved after training. After training, the participants achieved smaller rotational and linear displacements of the trunk observed during both predicted and unpredicted perturbations in anterior, posterior and lateral directions. However, the reliability of the outcome measurements of the perturbation test was lacking. Furthermore, kayak training is instrumentation and space dependent. The training is difficult to continue in long-term practice for community-dwelling people with SCI.

A case study on COP-controlled video game-based program was conducted on two subjects with spinal cord injury and head injury, respectively. The results showed improvement in their dynamic short-sitting balance (Betker, Desai, Nett, Kapadia, & Szturm, 2007). Balance training was more effective on an unstable surface when compared with a stable surface. However, only one person with a spinal cord injury was studied and the results were not conclusive.

1.6 Quality of life in people with spinal cord injury

Good quality of life (QOL) is related to good relationships, maximizing functions, engaging in activities and the ability to access one's environment (Kennedy and Rogers, 2000). Charlifue and Gerhart (2004) reported that 24.7% of people with SCI rated their QOL as fair to poor which indicated that the QOL was regarded as low in this group. The goal of rehabilitation is to improve the QOL in people with SCI. Hence, QOL becomes an essential outcome in determining the success of rehabilitation program. There are several factors influencing QOL in people with SCI. Functional losses have a great impact on QOL. Ville and colleagues (2001) pointed out that the functional independence is directly linked to QOL (Ville & Ravaud, 2001). Perhaps it is more accurate to say that the impact of limited functional status on social activities could reduce QOL. Participation in the community has a direct effect on QOL through increased opportunities for meaningful activity and social connection.

1.7 Background of Tai Chi

Tai Chi is a Chinese martial art which is regarded as a gentle, relaxing, yet invigorating form of exercise. Tai Chi is both an integrated exercise and an enjoyable sport for all kinds of people: strong and weak, young and old, male and female. Weather does not inhibit its practice indoors. Requirements of travelling time and space are minimal (Tsao, 1995). Studies show that the movements involved in Tai Chi provide a stimulus for increased flexibility, strength, balance, vascular health and body awareness (Levandoski & Leyshon, 1990; Lumsden, Baccala, & Martire, 1998; Ross & Presswalla, 1998). Tai Chi movements are not difficult to learn. They exercise the major joints of the body, and involve low-impact and low-risk movements (Levandoski & Leyshon, 1990; Lumsden et al., 1998). Tai Chi can produce an average of 50% increase in heart rate and has a metabolic demand of 4 to 5 metabolic equivalents (METs) (Fu & Fung, 1996). Hence, it is recommended as a form of exercise suitable for older adults, subjects suffering from arthritis, stroke or Parkinsonism.

1.8 Effects of Tai Chi on balance control

It is a common belief that practicing Tai Chi can improve a person's mental and physical status (Jin , 1992; Kutner, Barnhart, Wolf, Mcneely, & Xu , 1997). Some qualitative reports on the benefits of Tai Chi began to be published in China in the mid 1970s, and in the Western literature in the 1980s (Vandeusen & Harlowe, 1987; Zhou, Shephard, Plyley, & Davis, 1984). These initial investigations focused on joint range of motion, cardiorespiratory and metabolic responses (Vandeusen & Harlowe, 1987; Zhou et al., 1984).

Studies of Tai Chi and balance control began in the 1990s (Lan, Lai, & Chen, 2002; Li, Hong, & Chan,2001; Wu, Zhao, Zhou,& Liu, 2002). In 1992, Tse and Bailey were the first to evaluate the influence of Tai Chi on balance control. In a cross-sectional study, they found that elderly people with more than one year of Tai Chi practice had better balance control than their sedentary counterparts in right and left leg standing with the eyes open. In 2000, Hong and colleagues found that practitioners with more than 10 years of Tai Chi experience could maintain single-leg standing with their eyes closed for a significantly longer period than non-Tai Chi practitioners.

In 1993, the Atlanta Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) group evaluated two types of interventions, namely, Tai Chi and computerized balance training, with an education group serving as the control (Wolf, Kutner, Greenwood, & Mcneely, 1993). After 15 weeks of intervention, only the subjects in the Tai Chi group had reduced their fear of falling and the risk of multiple falls (by 47.5%) when compared with the education group (Wolf et al., 1996). This article has been regarded as playing a major role in the acceptance of Tai Chi as a means to improve balance and decrease fall risk in the Western world (Lavery & Studenski, 2003). According to Lavery and Studenski (2003), a search of PubMed revealed about 10 publications on Tai Chi before the FICSIT study and more than 90 articles since then. However, these early FICSIT findings were contradicted by objective balance measurements in the FICSIT group's own subsequent study in 1997 (Wolf, Barnhart, Ellison, & Coogler, 1997). The results in that study showed significantly reduced maximum sway amplitude after toe-up perturbations in the computerized balance training group, but not in the Tai Chi group. The use of toe-up perturbation as an outcome in a Tai Chi study was criticized by other researchers as being either inappropriate (Horak, 1997) or not challenging enough to the balance control system (Wong, Lin, Chou, Tang, & Wong, 2001). Postural control involves complex mechanisms requiring close interactions between the musculoskeletal and various neural systems (Shumway-Cook & Woollacott, 2001). Tsang and his colleagues use the sensori-motor model to investigate Tai Chi's underlying mechanism in improving balance control. In 2001, they (Tsang, Wong, & Hui-Chan, 2001) compared the sway amplitude of older Tai Chi practitioners to that of an older healthy control group, when they stood under six combinations of visual (eyes open, eyes closed, sway-referenced) and support surface (fixed, sway-referenced) conditions in the sensory organization test. Their findings demonstrated that older Tai Chi practitioners swayed significantly less when they stood under sensory conditions that demanded an increased reliance on the visual and vestibular systems than the healthy control group similar in age, sex and physical activity level. Of particular interest is that older Tai Chi practitioners attained the same level of balance control performance in the sensory organization test as young, healthy subjects when standing under reduced or conflicting somatosensory, visual and vestibular conditions (Tsang, Wong, Fu, & Hui-Chan, 2004). Using the limits of stability test, Tsang et al. (Tsang & Hui-Chan, 2003) showed that Tai Chi practitioners initiated voluntary shifting of their weight to different spatial positions within their base of support more quickly, leaned further without losing their stability, and showed better control of their leaning trajectory than those of the control subjects. However, traditional Tai Chi forms pose difficulty for older adults with poor standing balance or who are physically dependent, and may increase the risk of falling or injuries. In view of this, different kinds of modified Tai Chi have been proposed for the frail or individuals with disabilities (Chen, Chen, & Huang, 2006 ; Li, Fisher, Harmer, & Shirai, 2003; Wolf, Coogler, & Xu, 1997). Sitting Tai Chi is commonly accepted in these populations.

1.9 Previous clinical research of sitting Tai Chi

Recent attention has been paid by researches for the therapeutic benefits of sitting Tai Chi (a modified Tai Chi practiced in the seated position) (Cheung, Tsai, Fung, & Ng, 2007; Lu et al., 2009). A randomized, single-blinded clinical trial was conducted by Tsang and colleagues in 2007 (Cheng, Ku, Tsui, Tsang, & Tsang, 2007) which involved 101 frail older adults. Most of them used walking aids and were recruited from four care and attention homes. A 12-form sitting Tai Chi routine was used which focuses on enhancing the participants' eye-hand coordination and sitting balance. The investigators demonstrated that three months of sitting Tai Chi training ($3 \times wk^{-1}$) could significantly improve eye-hand coordination (Lu et al., 2009) which is one of the fitness components strongly associated with the functional performance of institutionalized elderly. For balance control, significant improvements of forward reaching in the sitting position was found when Tai Chi practitioners were compared with control subjects (Cheng et al., 2007). However, the effect of sitting Tai Chi on the balance control of people with SCI is unknown.

This thesis describes two studies: (1) to develop a reliable and valid tool for measuring the dynamic sitting balance of wheelchair users with SCI; and (2) to investigate the effect of sitting Tai Chi exercise on handgrip strength, balance control and quality of life among people with SCI. The rationales and objectives are summarized below. The Methodology section and the two studies are presented from chapters 2 to 4. The thesis ends with a Summary and Conclusion section in chapter 5. The two studies follow the format of the submitted journal, *The Spine Journal*. However, the reference system of the whole thesis followed the American Psychological Association (APA) system with the reference list presented after chapter 5. There will be a slight replication of Methodology and the Method sections in the two studies as not to disturb the flow of presentation. We hope that through the development of new dynamic sitting balance control tests and the investigation of the effectiveness of a Tai Chi intervention, subjects with SCI living in the community could benefit from the findings of this study.

1.10 Rationales

A supported or unsupported short-sitting position is commonly adopted by people with SCI when handling ADL; however, most of the previous studies in assessing sitting balance control focus on the maximal COP displacement in the long-sitting position which is relatively less functional. Also, the assessment of sitting balance control should include diagonal movement which is commonly required in transfer. The time domain and the movement control to achieve different excursion directions are not investigated in previous studies which constitute important factors in sitting balance control.

An effective exercise on sitting balance in community-dwelling people with SCI is lacking. Sitting Tai Chi can be performed in any place and at any time. Whether sitting Tai Chi improves sitting balance and quality of life remains to be answered.

1.11 Hypotheses and Objectives

Hypotheses of Study 1:

H_0: Reliability of dynamic sitting balance control tests (limits of stability test and sequential weight shifting test) was zero.

H_0 : There exists no correlation between the dynamic sitting balance tests and functional mobility scores.

Objectives of Study 1:

(1) To develop laboratory-based tests for use in a clinical setting that assess sitting balance control in people with SCI.

(2) To examine the reliability of the sitting balance control tests.

(3) To assess the correlation of the sitting balance control performance with functional activities in people with SCI.

Hypotheses of Study 2:

H_0 : There is no difference in the dynamic sitting balance and quality of life between sitting Tai Chi group and control group

Objectives of Study 2:

(1) To investigate the effects of sitting Tai Chi on sitting balance control and quality of life in people with SCI.

Alternative hypotheses

We hypothesize that the test-retest reliability of the sitting balance control tests are from moderate to excellent values. There is a relationship between sitting balance performance and functional activities in people with SCI. We also hypothesize that sitting Tai Chi could improve the sitting balance control and quality of life in people with spinal cord injury.

CHAPTER 2

METHODOLOGY

2.1 Study design

This study involved both a cross-sectional sample study investigating the reliability and correlation of dynamic sitting balance tests for wheelchair users with chronic spinal cord injury and a prospective study evaluating the effectiveness of sitting Tai Chi on balance control of community-dwelling persons with spinal cord injuries.

The outline of the reliability study and the intervention protocol are shown in Figure 2.1.

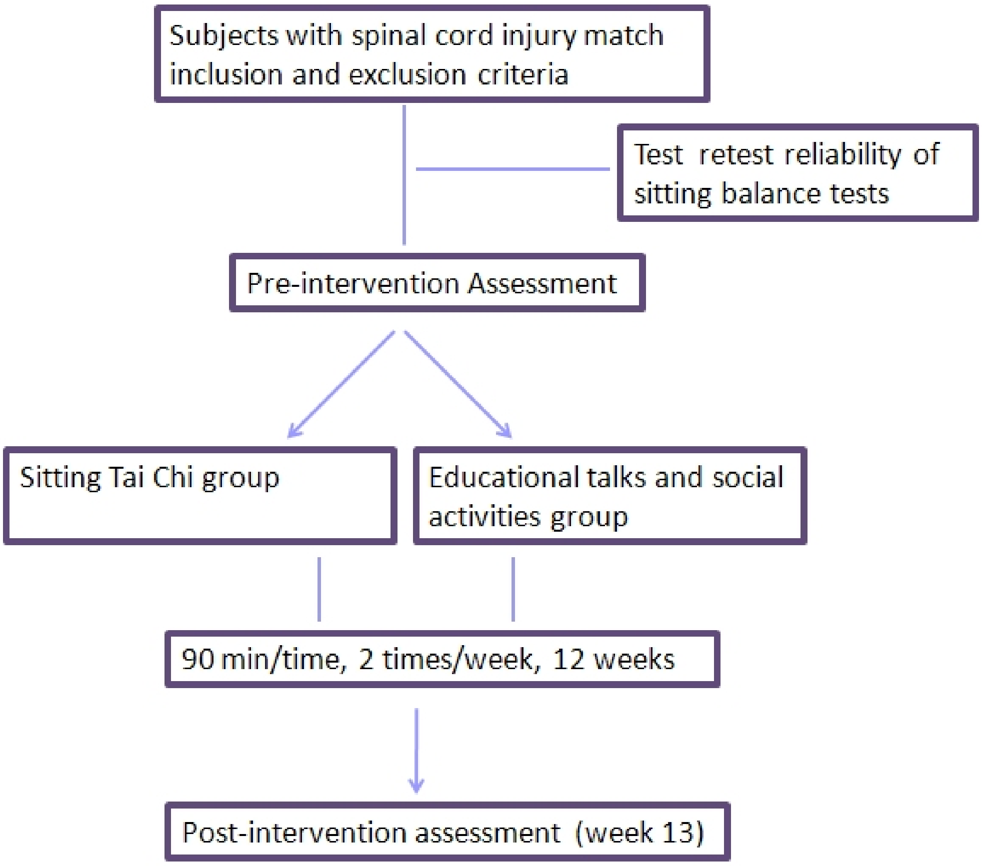


Figure 2.1 Flow chart of subjects' recruitment, assessment, and intervention processes.

2.2 Subjects recruitment

The participants were recruited from the Hong Kong Sports Association for the Physically Disabled, Direction Association for the Handicapped, and Paraplegic & Quadriplegic Association. The written consent forms were obtained from all participants before the study started. They were free to withdraw from the study at any time. The inclusion and exclusion criteria used for the present study were as follows:

Inclusion criteria:

1. at least post-injury 1 year
2. Incomplete injury according to the American Spinal Injury Association Impairment scale (ASIA) (Refer to Appendix A for the classification)
3. aged 18 years or above
4. able to communication and following instructions

Exclusion criteria:

1. unstable cardiopulmonary disease
2. serious complications related to the SCI, such as pressure ulcers
3. contracture and marked hypertonicity of muscles
4. poorly controlled hypertension
5. metastatic cancer

The project was approved by the Ethics Committee of The Hong Kong Polytechnic University. The procedures were fully explained to all subjects who met the criteria and informed consent in Chinese (Appendix B) or in English (Appendix C) was obtained from all eligible participants.

2.3 Experimental procedure

2.3.1 Study 1-The reliability of dynamic sitting balance tests and their correlations with functional mobility for wheelchair users with chronic spinal cord injury

Subjects were invited to the laboratory and repeated the sitting balance tests in the same order with the same examiner seven days apart. Two dynamic sitting balance control tests were investigated — a limits of stability (LOS) test and a sequential weight shifting (SWS) test. Subjects performed the two tests either in supported or unsupported conditions.

2.3.1.1 Instrumentation

The setup consisted of a tailor-made wooden force platform (90 cm x 76 cm) and an adjustable-height screen placed 1.5 m in front of the participants on which the COP was continuously displayed (Figure 2.2). Subjects' COP was measured by 4 load cells (SBDEG, Measurement Specialties Inc., Schaevitz) mounted in the platform. The measurement range of the load cells was 40-400 pounds force. All movement data from the force platform was sampled and digitized via a Multifunction Data Acquisition USB

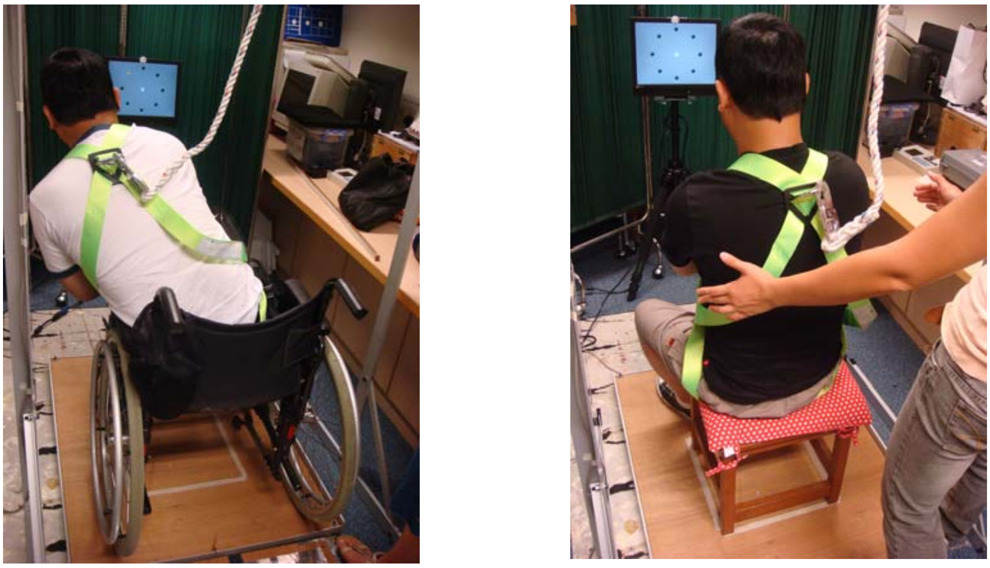
(National Instrument NI USB-6009, USA) with an 8-channel analog-to-digital converter at a sample rate of 1000 Hz. It was connected to a computer that was programmed using tailored LabView (version 8.6, National Instruments, USA) software to display and store in real time motion of the COP during the sitting balance tests.

Figure 2.2 The tailor-made force platform for sitting balance control assessment

2.3.1.2 Limits of stability

Supported sitting was defined as seated in the subject's own wheelchair without resting on the back support for paraplegia or both back and head support for tetraplegia at the beginning of the balance tests. Subjects might get support from wheelchair when they moved their center of gravity (COG) close to limits of stability. Unsupported sitting was on a standardized stool without support but with adjustable seat height. The participant’s hips, knees and ankles were kept at approximately 90° of flexion, the feet shoulder width apart while resting on the platform. A cushion was placed on the stool for comfort and to reduce the risk of generating pressure sores during testing. Each participant had practice trials for familiarization before the actual balance test (Figure 2.3).

The LOS test in sitting adopted the traditional standing protocol which has been widely used in both research and clinical studies (Tsang & Hui-Chan, 2003). The test measured the intentional weight shifting ability in multiple directions within their base of support. The initial COP was displayed in the center of the screen together with eight target positions in front, right front, right, right back, back, left back, left, and left front. The participants were required to move the COP trace on the screen toward one of eight selected target positions by shifting their weight within their limits of stability as quickly and as smoothly as possible when one of the visual targets appeared. There was a 20 second rest period between trials to minimize fatigue which might affect performance. The participants wore a safety harness which was connected to an overhead suspension frame during the unsupported sitting tests. The investigator was beside the participant for safety. There was a two second baseline measurement of COP sway before the visual target appeared. Each direction was repeated three times and the results were averaged.



a. b.

Figure 2.3 A subject underwent limits of stability test a. support sitting condition and b. unsupported sitting condition.

A computer program was developed to record the following parameters: (1) Reaction time (RT) - the time from the appearance of a target to the onset of the voluntary shifting of the COP (Figure 2.4); (2) Maximum excursion (ME) - the maximum displacement of the COP in the target direction; (3) Directional control (DC) - a comparison of the amount of movement of the COP in the on-target direction with the amount of off-target displacement (Figure 2.5).

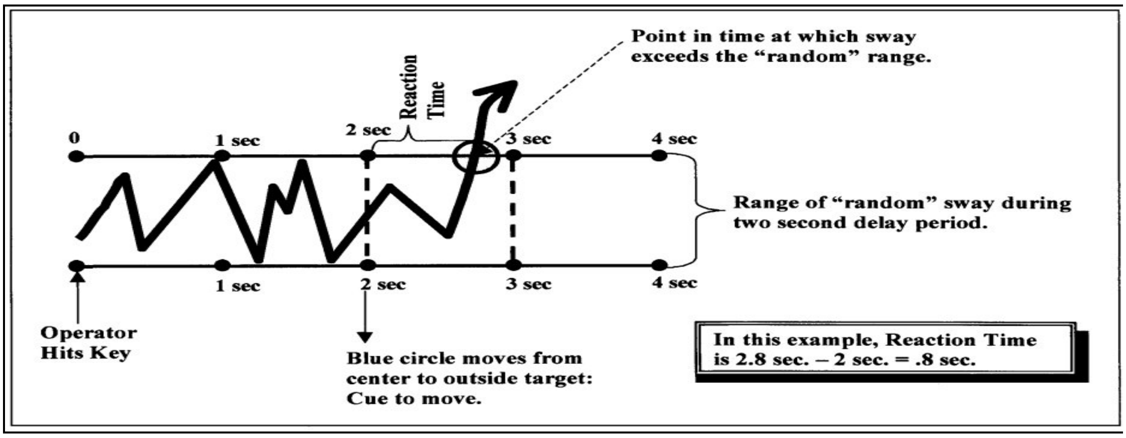


Figure 2.4 The determination of reaction time of the limits of stability test (adopted from NEUROCOM. *Smart EquiTest® System Operators Manual (Version8).* Clackamas, OR: NeuroCom International Inc., 2002).

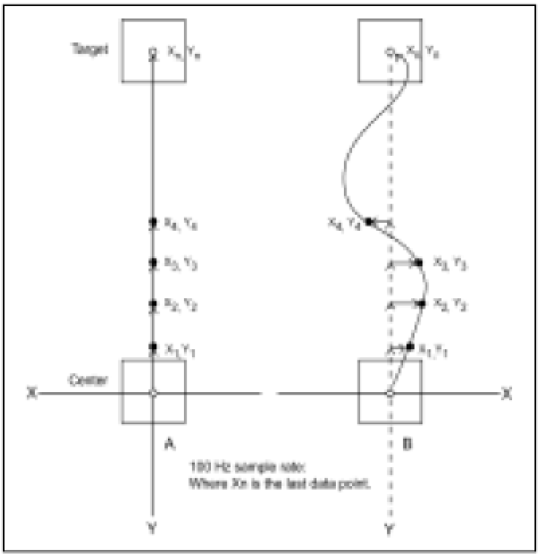


Figure 2.5 A diagram shows the on-target direction with the amount of off-target displacement (adopted from NEUROCOM. *Smart EquiTest® System Operators Manual (Version8).* Clackamas, OR: NeuroCom International Inc., 2002).

In the supported trials, both the data from the eight directions, and also the ‘combined forward’ which consisted of data in forward, right forward and left forward targets only were captured for data analysis. The ‘combined forward’ was analyzed because the other five directions could to some extent be affected by the wheelchair's arm rests and back support.

2.3.1.3 Sequential weight shifting

The sitting positions were the same as those used in the LOS test. As soon as a target appeared, participants were asked to shift their COP to move the screen trace to the target as quickly as possible without losing their balance. Twelve targets appeared sequentially. When each target was hit, it disappeared and another appeared. The 12 targets appeared above, left, below, and right to the center (Figure 2.6). The distance from the center to each target was 75% of that subject’s maximal excursion as determined in the LOS test. The trajectory is shown in Figure 2.6. The participants had continuous visual feedback about the position of their COP from the screen as they performed the weight shifts. The total time and directional control for subjects to hit the 12 targets sequentially was computed.

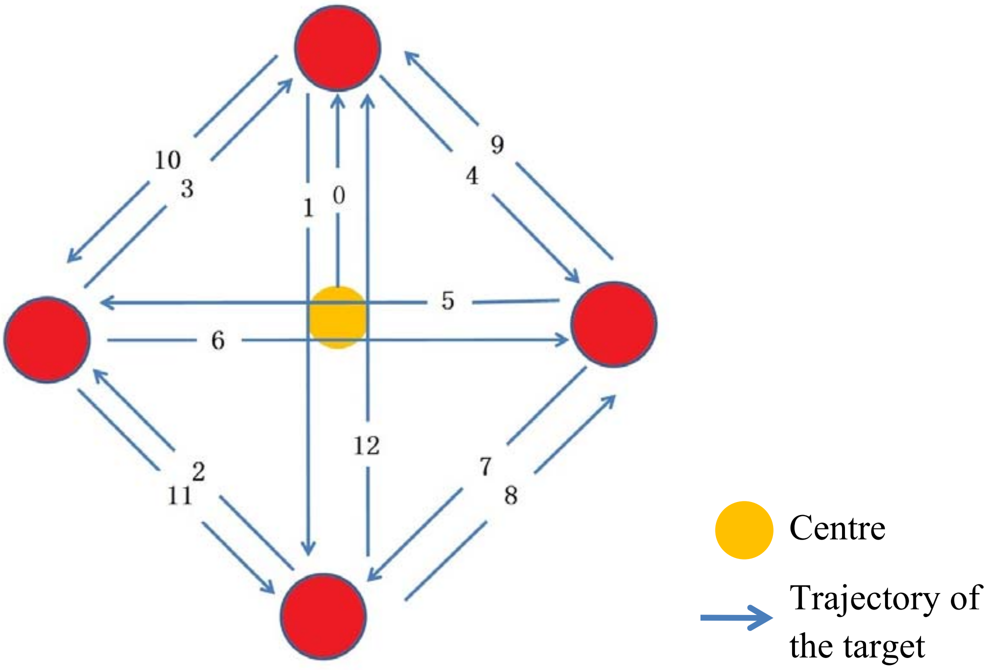


Figure 2.6. The trajectory of the targets in the SWS test.

2.3.1.4 Correlation assessments

The correlation assessments which included 1) modified functional reach test, and 2) functional assessment – the Spinal Cord Independence Measure III are presented as follows.

Modified functional reach test

The modified functional reach test used (Lynch, Leahy, & Barker, 1998) has been shown to have excellent test-retest reliability (ICC 0.85–0.94). The subjects were seated in their own wheelchairs. A ruler was placed across subject's shoulder at the level of the acromion. Their hips, knees, and ankles were positioned in approximately 90° of flexion. There was 5 cm of clearance between the popliteal fossa and the wheelchair. Subjects were instructed to sit erect initially with both arms flexed to 90°. The anatomical landmark used to measure functional reach was the ulnar styloid process. This landmark was used in this study instead of the 3rd metacarpal with a fist because the ulnar styloid process is a prominent protrusion not affected by the wrist angle, which varies among different subjects. The subjects were instructed to reach forward as far as possible without losing their balance. They were allowed to use the non-reaching arm for counter-balance, but not for weight bearing or to hold on to surrounding objects (Figure 2.7). The difference between the starting position and maximum distance reached was recorded. An average of three trials was calculated for data analysis.

Figure 2.7. Modified functional reach test

Functional assessment

The Spinal Cord Independence Measure III (SCIM III) has been used for rating the comprehensive ability of those with SCI in performing basic everyday tasks (Appendix D & E). It is an efficient and objective instrument for functional assessment devised by Catz's group at the Loewenstein Rehabilitation Hospital (Catz & Itzkvoich, 2007). This version has been shown to be highly reliable (ICC=0.94) and sensitive to changes in function for people with SCI (Itzkovich et al., 2007; Zhang, Wang, Liang, 2009). The Chinese version has also been found to have good internal consistency and reliability (Wang et al., 2007). The scale consists of three subscales: 'self-care' with 4 items and scores ranging from 0 to 20; 'respiration and sphincter management' with 4 items and scores ranging from 0 to 40; and 'mobility' involving 9 items relevant to indoor and outdoor transfers with scores ranging from 0 to 40. The total score therefore ranges from 0 to 100, with a higher score indicating greater independence in functional activity. Each SCIM III item is scored through direct observation by a physiotherapist except bathing, bladder and bowel management. Those are self-reported.

2.3.2 Study 2 - Sitting Tai Chi improves the balance control of community-dwelling persons with spinal cord injuries

2.3.2.1 Tai Chi training protocol

The sitting Tai Chi intervention involved two 90-minute sessions, 2 times per week for 12 weeks. A 12-form sitting version of Yang's Tai Chi style was designed for the experiment. The subjects in the control group were involved in educational talks and social activities of equivalent duration and frequency. Before and after measurements of sitting balance control, handgrip strength, and QOL were conducted.

A 12-form sitting Tai Chi routine (Figure 2.8) was designed for the needs of people with SCI based on the traditional forms of Yang style Tai Chi. The principle investigator of this study, Dr. William Tsang and a Tai Chi master, Ms Wong Lin Ying who have 13 years of Tai Chi research experience and 30 teaching Tai Chi experience, respectively designed these Tai Chi forms. The physical functions and training foci of each form are described in Table 2.1. Shifting of weight while sitting, trunk rotation, upper limb joint mobilization and muscle strengthening were emphasized in an attempt to counteract loss of strength in the lower limb and trunk muscles and unstable sitting balance (Lee et al., 2011). The training was safe and simple for the participants to perform sitting in a wheelchair. A Tai Chi master and a physiotherapist conducted the training. Each session included a 5 minute warm up and 5 minute cool down with rests as necessary. The Tai Chi training was held in the sport laboratory of the Department of Rehabilitation Sciences, the Hong Kong Polytechnic University. Participants were either transported to the venue by Rehab Bus or own driving. Attendance was recorded. The subjects were encouraged to also practice at home for 90 minutes each week. A logbook was used to monitor home exercise by self recording.

Form 1

Commencing

(起式)

Form 2

White crane spreads its wings

(白鶴亮翅)

Form 3

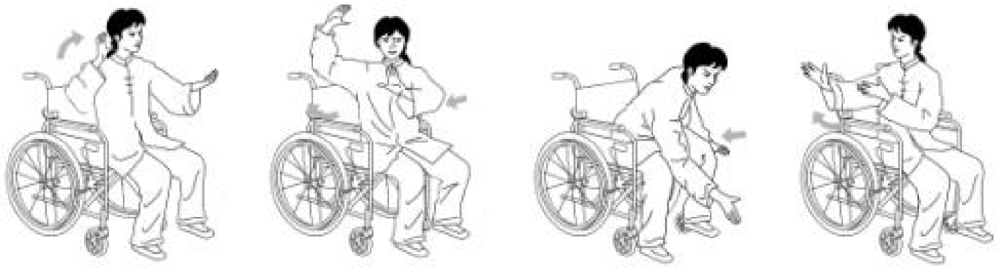
Brush knee and twist step

(左右摟膝步)

Form 4

Hand strums the lute

(手揮琵琶)



Form 5

Step back and whirl arms

(倒卷肱)

Form 6

Work at shuttles on both sides

(左右穿梭)

Form 7

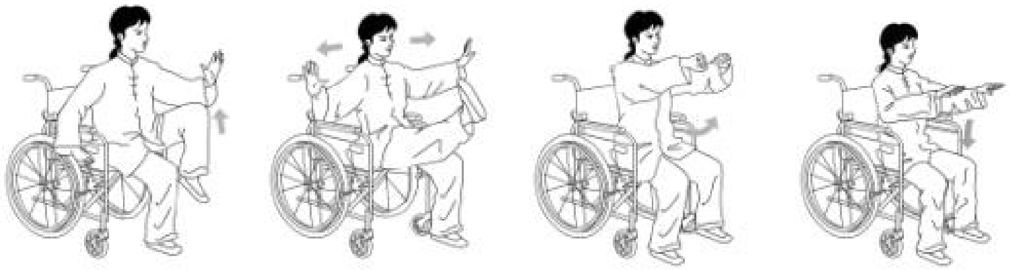
Needle at sea bottom

(海底針)

Form 8

Wave hands as clouds

(雲手)



Form 9

Push down and lift one leg

(金雞獨立)

Form 10

Turn and kick with right heel

(左右蹬腳)

Form 11

Strike ears with both fists

(雙峰貫耳)

Form 12

Closing

(收式)

Figure 2.8. The 12 modified forms of Yang’s style Tai Chi

Table 2.1 The features, physical functions and training foci of the 12-form sitting Tai Chi.

Form No.	Name	Features	Physical Functions	Training foci
1	Starting 起式	- Sitting - Lowering of centre of mass	1. To prepare and relax whole body 2. Mind concentration 3. Correct posture 4. Breathing	Relaxation, attention, posture and breathing
2	White crane spreads its wings 白鶴亮翅	- Weight shift backward - Arms hanging in the air	1. Weight shifting 2. Arm mobilizing	Weight shifting in anterior-posterior direction, Directional control (right forward)
3	Brush knee and twist step 左右摟膝步	- Weight shift forward & backward - Trunk rotates forward	1. Antero-posterior balance 2. Trunk rotation	Muscle strength Balance (anterior-posterior)
4	Playing the Lute 手揮琵琶	- Eyes follow the hands movement - Trunk rotation - Lift upper limb	1. Trunk rotation 2. Upper limb mobilizing 3. Eye-hand coordination	Muscle strength Balance (anterior-posterior)

5	Repulse monkey 倒卷肱	- Trunk rotation - Weight shifted backwards - Lift upper limb	1. Trunk rotation 2. Weight shift right back and left back 3. Eye-hand coordination	Upper limb muscle endurance, Prevent falls when leaning back, Eye-hand coordination
6	Work at shuttles on both sides 左右穿梭	- Weight shift left and right - Trunk rotation - Lift upper limb - Eyes follow the hands movement	1. Weight shifting 2. Trunk rotation 3. Upper limb 4. Eye-hand coordination	Eye head hand coordination, Directional control in left and right forward, Upper limb muscle endurance
7	Needle at sea bottom 海底針	- Weight shift in anterior-posterior balance - Eyes follow the hands movement	1. Anterior-posterior balance 2. Eye-hand coordination	Weight shifting in anterior-posterior direction, Directional control (anterior-posterior), Eye-hand coordination
8	Wave hands as clouds 雲手	- Weight shift left and right - Trunk rotation - Eyes follow the hands movement	1. Weight shifting 2. trunk rotation 3. Upper limb 4. Eye-hand coordination	Weight shifting in left and right direction, Directional control (mediolateral), Eye-hand coordination, Muscle endurance

9	Push down and lift one leg 金雞獨立	- Lift upper limb - Lift the thigh and leg upwards	1. Trunk rotation 2. Lower limb training 3. Upper and lower body coordination training	Directional control left and right forward
10	Turn and kick with right 左右蹬腳	- Extend the knee straight and upward - Lift upper limb - Eyes follow the hands movement	1. Lower limb strength training 2. Upper limb strength training	Directional control left back and right back, Muscle strength
11	Strike ears with both fists 雙峰貫耳	- Lift upper limb - Eyes follow the hands movement	1. Upper limb 2. Eye-hand coordination	Muscle strength, Directional control Left forward, Eye-hand coordination, Reaction fast
12	Close 收式	- Relax	1. Completion of all the forms 2. Posture correction	Relaxation

2.3.2.2 Control group activities

The content of the control group took place in different venues depending on the nature of the activities. The activities included two categories. The educational talks consisted of complications management (4 sessions); wheelchair maintenance (1 session); Photoshop software (2 sessions) and the art of paper clay (4 sessions). The social activities consisted of BBQ (1 session); touring in the Peak (1 session); movie show (1 session); Lantau island (1 session); barrier free cultural tours (6 sessions); Lavender garden tour (1 session); Nanliang garden tour (1 session) and Dim sum (1 session). Participants were either transported to the venue by Rehab Bus or own driving.

2.3.2.3 Outcome measures

The outcome measure consisted of handgrip strength, limits of stability and sequential weight shifting balance tests and quality of life questionnaire. The dynamic balance control tests had been described in sections 2.3.1.2 and 2.3.1.3. The handgrip strength and quality of life questionnaire are described as follows:

Handgrip strength

Handgrip strength has been regarded as a significant indicator of overall body strength (Rantanen et al., 2003). A Jamar hydraulic hand dynamometer (Sammons Preston, Ability One Co, Bolinbrook, IL) was used to measure handgrip strength. The Jamar dynamometer is widely used for measuring isometric grip force from 0-200 lb (90 kg) and has shown excellent reproducibility (Linstrom-Hazel, Kratt, & Bix, 2009; Mathiowetz, Weber, Volland, & Kashman, 1984). Subjects were instructed to sit in their own wheelchair with the test shoulder adducted and rotated neutrally and the elbow flexed at 90°, the forearm in a neutral position, and the wrist between 0 and 30 degrees of extension and between 0 and 15 degrees of ulnar deviation (Mathiowetz et al., 1984) (Figure 2.9). Familiarization trials were allowed before the results of three measurements were averaged for comparison.

Quality of life

The brief version of the World Health Organization's Quality of Life scale (WHOQOL-BREF) (Appendix F & G) has been demonstrated to be an acceptable and validated questionnaire to assess the QOL of people with SCI (Hill, Noonan, Sakakibara, & Miller, 2010; Jang, Hsieh, Wang, & Wu, 2004). The Chinese version of the WHOQOL-BREF was used to measure QOL in this study. It has previously been shown to have high intra-rater reliability (ICC= 0.84-0.98) (Lin, Hwang, Chen, & Chiu, 2007) and its validity as a tool for measuring the QOL of Chinese individuals with SCI has been established (Jang et al., 2004).


[redacted]

Figure 2.9. Handgrip strength measurement

WHOQOL-BREF is a self-reporting questionnaire which consists of 26 questions. There are 2 general questions (about overall QOL and overall health perceptions) and more detailed questions about four QOL domains. Seven query the physical domain (D1), 6 the psychological domain (D2), 3 the social relationship domain (D3), and 8 questions probe the environmental domain (D4). All questions solicit ratings on a five-point Likert scale. The scores were first summarized for the 4 domains (physical health, psychological health, social relationships and environment) according to the WHOQOL-BREF guidelines by taking the mean score for the questions addressing that domain and multiplying by 4. So each domain score could range from 4 to 20. A higher score indicates better QOL.

2.3.3 Statistical analysis

All data were analyzed using SPSS version 17 (SPSS Inc., Chicago, IL). For study 1, intraclass correlation coefficients (ICC3,k) were employed to assess the test-retest reliability of the sitting LOS test and the sequential weight shifting test. An ICC3 model was used for assessing intra-rater reliability, with "k" denoting the number of trials used in the different tests (Portney & Watkins, 2009). Correlation between the sitting balance test results and SCIM III mobility scores were analyzed using Pearson's product-moment coefficient of correlation.

For study 2, the age, sitting height, and weight between the two groups were compared using independent t-tests. Chi-square test was applied for between-group comparison of the gender distribution and injury levels. After testing for normality and equal variance, independent t-test were employed to analyze any inter-group difference in the baseline values between the Tai Chi group and the control group. If a significant difference was found in any of the baseline values it was treated as a co-variate in the subsequent statistical analysis. Two-way repeated measures MANOVA with an intent-to-treat design was employed for analysis with one factor of between groups (control vs. intervention groups) and another factor of repeated measure involving 2 time points (pretest and posttest). Intent-to-treat was employed in this study as it is “a more conservative approach, which means that data are analyzed according to the original random assignments, regardless of the treatment subjects actually received; that is, we analyze data according to the way we intended to treat the subjects. (Portney and Watkins 2009; p. 167) Post hoc paired t-tests were conducted to investigate whether there was any within-group difference in the assessment intervals with the baseline values. Independent t-tests were conducted to compare the Tai Chi and control groups at the 2 time points. A significance level (α) of 0.05 was chosen for the statistical comparisons.

CHAPTER 3

THE RELIABILITY OF DYNAMIC SITTING BALANCE TESTS AND THEIR CORRELATIONS WITH FUNCTIONAL MOBILITY FOR WHEELCHAIR USERS WITH CHRONIC SPINAL CORD INJURY

Publications:

1. Gao, K. L., Purves, S., Chan, K. M., & Tsang, W. W. N. (2011). The reliability and validity of a dynamic sitting balance test for people with spinal cord injury. World Confederation for Physical Therapy, 16th International WCPT Congress, 20-23 June 2011, Amsterdam Holland, RR-PO-207-14.
2. Gao, K. L., Purves, S., Chan, K. M., & Tsang, W. W. N. (2012). The reliability and validity of a temporal-spatial sitting balance assessment for wheelchair users with spinal cord injury. Joint World Congress of ISPGR and Gait & Mental Function, 24-28 June 2012, Norway, in press.
3. Gao, K. L., Chan, K. M., Purves, S., & Tsang, W. W. N. The reliability of dynamic sitting balance tests and their correlations with functional mobility for wheelchair users with chronic spinal cord injury. The Spine Journal (under review)

3.1 Abstract

Background Context: Dynamic sitting balance control is essential for persons with spinal cord injury (SCI) in many activities of daily living.

Purpose: It aimed to develop a reliable and valid tool for measuring the dynamic sitting balance of wheelchair users with SCI.

Study Design/Setting: This was a cross-sectional study.

Patient Sample: Convenience sampling from the community.

Outcome Measures: Limits of stability (LOS) and sequential weight shifting (SWS) were designed in this study. The balance tests measured participants' volitional weight shifting in multiple directions within their base of support. The modified functional reach test was also measured. Their mobility scores on the Spinal Cord Independence Measure III (SCIM III) were correlated with the balance test results. The LOS outcome measures were reaction time, maximum excursion and directional control; for the SWS they were total time and directional control.

Methods: Nine participants with chronic SCI (average of 17.2 years post-injury) between levels C6 and L1 performed the tests while sitting in their own wheelchairs and on a standardized stool (unsupported sitting) twice, seven days apart.

Results: The sitting LOS results showed moderate to excellent test-retest reliability (ICC ranged from 0.673-0.990) with both the wheelchair and the unsupported sitting. The SWS results showed moderate to excellent reliability (ICC ranged from 0.688–0.952). Only the LOS results in unsupported sitting correlated significantly with the

SCIM III mobility scores, but the SWS test results had significant correlation in both sitting conditions. However, the modified functional reach test shows no correlation with the SCIM III mobility scores.

Conclusions: The sitting LOS and SWS tests provide a reliable and valid tool for assessing the dynamic sitting balance control of subjects with SCI.

Key words: Sitting balance; Mobility; Spinal cord injury; Reliability; Correlation

3.2 Introduction

Approximately 70% to 80% of people with spinal cord injury (SCI) are dependent for life on using a wheelchair for mobility (Post, vanAsbeck, vanDijk, & Schrijvers, 1997). Good sitting balance control is essential for such people because they are often confined to sitting position when performing the activities of daily living (ADL). From quiet sitting such as feeding, grooming and bathing to dynamic activities like propelling their wheelchair up or down ramps, ADL require different degrees of sitting balance control. When ascending a ramp, people with SCI lean forward as far as possible to prevent the wheelchair from tipping backward. When descending they lean as far back as they can to prevent falling (Sisto, Druin, & Sliwinski, 2009). These techniques require maximal postural excursions. That is why investigators studying balance control with a SCI population employ maximal postural sway as one outcome measure.

Sitting balance control directly affects transfer performance (Bolin, Bodin, & Kreuter, 2000). An appropriate sitting position is fundamental to providing a stable base of support for transfer activities. A sense of position in space is another crucial factor when attempting a transfer. Also, the ability to precisely and accurately control intentional movements of the center of gravity (COG) in different directions is important. Better directional control provides more accurate control in performing a variety of transfer activities. When individuals transfer from short sitting (with the hips and knees at approximately 90°) to an unsupported position, they require good directional control. Transferring from a wheelchair to a bathtub is a common example.

Falls are a major problem for SCI sufferers. In a prospective study of 659 community-dwelling wheelchair users who suffered from SCI (age 54.8±12.6 years), 31% of the subjects reported a total of 553 fall events (Nelson et al., 2010). In a retrospective study by the same group (2003), a review of 45 individuals with SCI showed that 24 (53%) of them had experienced a total of 27 fall episodes. The major factor contributing to falls was found to be loss of balance during functional activities (Nelson et al., 2003). Falls most often occurred during transfer (44%), reaching (11%), propelling a wheelchair (15%), moving in bed (22%), transferring to or riding in a vehicle (30%), and showering (8%). Wheelchair users with SCI have been found to have decreased or absent trunk control, leading to poor sitting balance and stability, which in turn may cause falls during transfer (Bernard et al. 1994).

A supported or unsupported short sitting position is commonly adopted by people with SCI when handling ADL. However, most previous studies assessing sitting balance control have focused on the maximum displacement of center of pressure (COP) when sitting with knees straight which are relatively less functional. Also, the assessment of sitting balance control should include the diagonal movements commonly required in transfer. The time and the movement control to achieve different excursions have not been investigated in previous studies, but they are important factors in dynamic sitting balance control. When performing transfer, people with SCI usually lean trunk forward to lift their buttocks off the initial surface and quickly pivot their buttocks to the target surface using a twisting motion (Gagnon, Nadeau, Noreau, Eng, & Gravel, 2008). Moreover, the functional activities do not end in a single direction, but in sequence of movements. The present study was therefore designed to develop laboratory-based tests for use in a clinical setting to assess the dynamic sitting balance control of wheelchair users with SCI.

3.3 Methods

3.3.1 Participants

Nine persons with SCI participated in this study—6 females and 3 males (please refer to Table 3.1). The participants were between 35 and 63 years old (mean ± S.D., 50.6 ± 10.7 years). Time since injury averaged 17.2 years (from 2 year to 48 years). Their level of injury ranged from C6 to L1 according to the International Standards for Neurological and Functional Classification of SCI. One year post-injury is commonly classified as the chronic stage because neural recovery plateaus at approximately 12 months post-injury (Burns & Ditunno, 2001). The inclusion criteria for the study were at least 1 year post-injury; incomplete injury according to the American Spinal Injury

Association (ASIA) impairment scale; aged 18 years or above; and able to communicate and following instructions. The exclusion criteria were unstable cardiopulmonary disease; serious complications related to the SCI, such as pressure ulcers; contracture or marked hypertonicity of the muscles; poorly controlled hypertension; and metastatic cancer. Written consent forms were obtained from all participants before the study started. The study was approved by the Ethics Committee of the Hong Kong Polytechnic University.

3.3.2 Testing Procedure

Two dynamic sitting balance control tests were conducted—a limits of stability test and a sequential weight shifting test. Subjects performed the two tests either in supported or unsupported conditions. The order of the testing procedures was the same in the two testing days starting with limits of stability test with supported and unsupported conditions, followed by sequential weight shifting test with supported and unsupported conditions.

3.3.2.1 Instrumentation

The setup consisted of a tailor-made wooden force platform (90 cm x 76 cm) and an adjustable-height screen placed 1.5 m in front of the participants on which the COP was continuously displayed. Subjects' COP was measured by 4 load cells (SBDEG, Measurement Specialties Inc., Schaevitz) mounted in the platform. The measurement range of the load cells was 40-400 pounds force. All movement data from the force platform was sampled and digitized via a Multifunction Data Acquisition USB (National Instrument NI USB-6009, USA) with an 8-channel analog-to-digital converter at a sample rate of 1000 Hz. It was connected to a computer that was programmed using tailored LabView (version 8.6, National Instruments, USA) software to display and store in real time motion of the COP during the sitting balance tests.

3.3.2.2 Limits of stability (LOS)

Supported sitting was defined as seated in the subject's own wheelchair without resting on the back support for paraplegia or both back and head support for tetraplegia at the beginning of the balance tests. Subjects might get support from wheelchair when they moved their COG close to limits of stability. Unsupported sitting was on a standardized stool without support but with adjustable seat height. The participant's hips, knees and ankles were kept at approximately 90° of flexion, the feet shoulder width apart while resting on the platform. A cushion was placed on the stool for comfort and to reduce the risk of generating pressure sores during testing. Each participant had practice trials for familiarization before the actual balance test.

The LOS test in sitting adopted the traditional standing protocol which has been widely used in both research and clinical studies (Tsang & Hui-Chan, 2003). The test measured the intentional weight shifting ability in multiple directions within their base of support. The initial COP was displayed in the center of the screen together with eight target positions in front, right front, right, right back, back, left back, left, and left front.

The participants were required to move the COP trace on the screen toward one of eight selected target positions by shifting their weight within their limits of stability as quickly and as smoothly as possible when one of the visual targets appeared. There was a 20 second rest period between trials to minimize fatigue which might affect performance. The participants wore a safety harness which was connected to an overhead suspension frame during the unsupported sitting tests. The investigator was beside the participant for safety. There was a two second baseline measurement of COP sway before the visual target appeared. Each direction was repeated three times and the results were averaged.

Table 3.1: Characteristics of the participants

Subject	Age (years)	Time since injury (years)	Injury level	ASIA grade
1	35	22	T1	B
2	36	10	T1	B
3	57	11	T1	B
4	63	48	T1	C
5	61	2	T1	C
6	58	13	L1	D

7	55	10	C7	D
8	48	10	T12	D
9	42	29	C6	B

A computer program was developed to record the following parameters: (1) Reaction time (RT) - the time from the appearance of a target to the onset of the voluntary shifting of the COP; (2) Maximum excursion (ME) - the maximum displacement of the COP in the target direction; (3) Directional control (DC) - a comparison of the amount of movement of the COP in the on-target direction with the amount of off-target displacement.

In the supported trials, both the data from the eight directions, and also the 'combined forward' which consisted of data in forward, right forward and left forward targets only were captured for data analysis. The 'combined forward' was analyzed because the other five directions could to some extent be affected by the wheelchair's arm rests and back support.

3.3.2.3 Sequential weight shifting

The sitting positions were the same as those used in the LOS test. As soon as a target appeared, participants were asked to shift their COP to move the screen trace to the target as quickly as possible without losing their balance. Twelve targets appeared sequentially. When each target was hit, it disappeared and another appeared. The 12 targets appeared above, left, below, and right to the center (Figure 2.6). The distance from the center to each target was 75% of that subject's maximal excursion as determined in the LOS test. The trajectory is shown in Figure 2.6. The participants had continuous visual feedback about the position of their COP from the screen as they performed the weight shifts. The total time and directional control for subjects to hit the 12 targets sequentially was computed.

3.3.2.4 Modified functional reach test

The modified functional reach test used (Lynch, Leahy, & Barker, 1998) has been shown to have excellent test-retest reliability (ICC 0.85–0.94). The subjects were seated in their own wheelchairs. A ruler was placed across subject's shoulder at the level of the acromion. Their hips, knees, and ankles were positioned in approximately 90° of flexion. There was 5 cm of clearance between the popliteal fossa and the wheelchair. Subjects were instructed to sit erect initially with both arms flexed to 90°. The anatomical landmark used to measure functional reach was the ulnar styloid process. This landmark was used in this study instead of the 3rd metacarpal with a fist because the ulnar styloid process is a prominent protrusion not affected by the wrist angle, which varies among different subjects. The subjects were instructed to reach forward as far as possible without losing their balance. They were allowed to use the non-reaching arm for counter-balance, but not for weight bearing or to hold on to surrounding objects. The difference between the starting position and maximum distance reached was recorded. An average of three trials was calculated for data analysis.

3.3.2.5 Functional assessment

The Spinal Cord Independence Measure III (SCIM III) has been used for rating the comprehensive ability of those with SCI in performing basic everyday tasks. It is an efficient and objective instrument for functional assessment devised by Catz's group at the Loewenstein Rehabilitation Hospital (Catz & Itzkvoich, 2007). This version has been shown to be highly reliable (ICC=0.94) and sensitive to changes in function for people with SCI (Itzkovich et al., 2007; Zhang, Wang, Liang, 2009). The Chinese version has also been found to have good internal consistency and reliability (Wang et al., 2007). The scale consists of three subscales: 'self-care' with 4 items and scores ranging from 0 to 20; 'respiration and sphincter management' with 4 items and scores ranging from 0 to 40; and 'mobility' involving 9 items relevant to indoor and outdoor transfers with scores ranging from 0 to 40. The total score therefore ranges from 0 to 100, with a higher score indicating greater independence in functional activity. Each SCIM III item is scored through direct observation by a physiotherapist except bathing, bladder and bowel management. Those are self-reported.

3.3.3 Statistical Analysis

Intraclass correlation coefficients (ICC3,k) were employed to assess the test-retest reliability of the sitting LOS test and the sequential weight shifting test. An ICC3 model was used for assessing intra-rater reliability, with "k" denoting the number of trials used in the different tests (Portney & Watkins, 2009). The ICC values were interpreted according to a rating system suggested by Shrout and Fleiss (Shrout & Fleiss, 1979) (< 0.40 poor reliability, 0.40-0.75 fair to good reliability, > 0.75 excellent reliability). Correlation between the sitting balance test results and SCIM III mobility scores were analyzed using Pearson's product-moment coefficient of correlation. A significance level (α) of 0.05 was chosen for the statistical comparisons.

3.4 Results

3.4.1Test-retest reliability of the limits of stability and sequential weight shifting tests

The nine participants repeated the sitting balance tests in the same order with the same examiner seven days apart. The LOS test showed excellent reliability (ICCs ranging from 0.751–0.990) in terms of reaction time, maximum excursion and directional control in supported sitting (Table 3.2), and moderate to excellent reliability (ICCs 0.673–0.955) in the combined forward directions (average of the forward, left forward and right forward directions). Only seven participants could complete the unsupported sitting trials, but their results also showed excellent reliability (ICCs 0.817–0.947). The SWS results in supported sitting also exhibited moderate to excellent test-retest reliability (ICCs ranging from 0.688–0.952). The unsupported sitting trials showed excellent test-retest reliability (ICC=0.788–0.846).

Table 3.2: Test-retest reliability for the limits of stability and sequential weight shifting tests with spinal cord injury subjects

	Combined forward in supported sitting (n=9)	Supported sitting (n=9)	Unsupported sitting (n=7)
Limits of stability			
- reaction time	0.818	0.751	0.885
- maximum excursion	0.955	0.990	0.817
- directional control	0.673	0.863	0.947
Sequential weight shifting			
- total time		0.688	0.788
- directional control		0.952	0.846

3.4.2 Correlation between sitting balance control results and Spinal Cord Independence Measure III

In supported sitting, neither the results of the modified reach test nor the results of the LOS test (reaction times, maximum excursions and directional control) correlated with the SCIM III scores (Table 3.3). In unsupported sitting, instead, the 3 aforementioned measures from the LOS test showed significant correlations with SCIM III scores. Finally, the total time and directional control in the SWS test in both supported and unsupported sitting were significantly correlated with the SCIM III scores (Table 3.3).

3.5 Discussion

The LOS and SWS tests in sitting were developed to measure both the supported and unsupported dynamic sitting balance control of wheelchair users with chronic SCI. The tests encompass temporal and spatial domains and involve both diagonal and orthogonal displacements. The fast reactions, maximal weight shifting, and accurate movement control are required for the functional aspects of daily living.

Table 3.3: Correlations between the sitting balance tests and SCIM III mobility scores

	Correlation with mobility score of SCIM III (*p* value)
Modified functional reach test	0.459 (0.252)
Combined forward in supported sitting	
Limits of stability - reaction time	-0.489 (0.219)
Limits of stability - maximum excursion	0.311 (0.453)
Limits of stability - directional control	0.250 (0.550)
Supported sitting	
Limits of stability - reaction time	-0.433 (0.284)
Limits of stability - maximum excursion	0.278 (0.505)

Limits of stability - directional control	0.313 (0.451)
Sequential weight shifting - movement time	-0.829 (0.011*)
Sequential weight shifting - directional control	0.849 (0.033*)
Unsupported sitting	
Limits of stability - reaction time	-0.852 (0.015*)
Limits of stability - maximum excursion	0.813 (0.026*)
Limits of stability - directional control	0.889 (0.007*)
Sequential weight shifting - movement time	-0.823 (0.044*)
Sequential weight shifting - directional control	0.927 (0.024*)

* denotes a statistically significant difference at the $p<0.05$ confidence level

<u>3.5.1 Reliability of the tests</u>

These dynamic sitting balance tests were found to have moderate to excellent test-retest reliability. The maximum excursions determined in these tests were similar to the values with the modified functional reach test as reported by Lynch's group in forward reach (average ICC = 0.91; Lynch et al., 1998). These tests, however, also include diagonal displacements (right forward, right backward, left forward and left backward) along with the forward, rightward, backward and leftward directions. The ability to shift their weight forward and backward is essential for wheelchair users when propelling their wheelchairs up or down ramps (Sisto et al., 2009), but the diagonal pathways are also required for good transfer performance. Beyond measuring maximum weight shifting, the test requires the wheelchair user with SCI to lean as quickly and as smoothly as possible toward the eight targets, and the reaction time and the smoothness of the trajectory are also taken into consideration in the two tests.

In the sequential weight shifting test, the distance from the center to each target were set at 75% of the limits of stability. This provided sufficient challenge to avoid any ceiling effect, but it allowed the participants to complete the test, as 100% of the limits of stability might not be achieved, especially in the diagonal directions. The 75% distance was also suitable for avoiding excessive fatigue.

3.5.2 Correlation of the sitting balance control results with functional assessments

The modified functional reach test results were not correlated with results on the mobility scale of the SCIM III functional assessment (Table 3.3). The reason may be that during the performance of ADL the movements involved are multi-directional, so forward body movement alone cannot properly reflect ADL ability.

Though eight directions of movement were tested in supported sitting, the results still did not correlate significantly with results on the mobility scale of the SCIM III. On the other hand, the unsupported sitting measurements correlated well with the functional assessment scores (Table 3.3). The reaction times had a negative correlation with the mobility scale (r = -0.852), so subjects able to react more quickly also had better mobility scores in the functional assessment. Similarly, the further participants could lean and the better their directional control, the better they performed in functional mobility testing. The question arises as to why only the unsupported sitting results show these correlations. In the mobility assessment of the SCIM III, the tests involve lots of transfer activities (Catz & Itzkovich, 2007), such as from a wheelchair to a tub or car and vice versa. These transfers involve lots of unsupported sitting. This may explain why the better correlations for the unsupported sitting results.

The sequential weight shifting results, both supported and unsupported, correlated well with the mobility scores of the SCIM III (Table 3.3). In ADL, shifting the body's center of mass controllably in all directions is often important. In transfer and mobility particularly, wheelchair users have to control the acceleration and deceleration of the trunk in diagonal directions with the right timing. The traditional sitting balance test, like the modified functional reach test, and even the limits of stability test is not able to assess such functional related performance. All these may contribute to the high correlation between the sitting balance test results and functional ability as reflected in the mobility scores of the SCIM III.

This study mainly focused on the reliability and correlation of the dynamic sitting balance tests for the general population of wheelchair users with spinal cord injury. A future study might profitably amplify these findings by looking into more homogenous groups— older and younger (Curtis et al., 1995), sub-acute and chronic, higher and lower injury level (Chen et al., 2003; Lynch et al., 1998). Also, the testing order of the two dynamic sitting balance tests under supported and unsupported conditions could be randomized to minimize the order effect.

CHAPTER 4

SITTING TAI CHI IMPROVES THE BALANCE CONTROL OF COMMUNITY-DWELLING PERSONS WITH SPINAL CORD INJURIES

Publication

1. Gao, K. L., Purves, S., Chan, K. M., & Tsang, W. W. N. (2012). Effect of sitting Tai Chi on dynamic sitting balance control in community-dwelling people with spinal cord injury: A pilot study. Joint World Congress of ISPGR and Gait & Mental Function, 24-28 June 2012, Norway, in press.
2. Gao, K. L., Chan, K. M., Purves, S., & Tsang, W. W. N. Sitting Tai Chi Improves the Balance Control of Community-dwelling Persons with spinal cord injuries. The Spine Journal (under review)

4.1 Abstract

Background Context: Control of sitting balance is associated with the level of injury in people with spinal cord injury (SCI). Balance control is an important ability for functional activities, especially for wheelchair users. Tai Chi is a mind-body exercise which has been documented as improving balance. However, traditional Tai Chi is performed in standing, which is not suitable for wheelchair users. Sitting Tai Chi may however be an appropriate exercise for people with SCI. The benefits of sitting Tai Chi for people with SCI have not been demonstrated scientifically.

Purpose: The effect of sitting Tai Chi exercise on handgrip strength, balance control and quality of life was tested among people with SCI.

Study Design/Setting: This was a prospective intervention study.

Patient Sample: Convenience sampling from the community.

Outcome Measures: Dynamic sitting balance tests were evaluated with the subjects sitting in their own wheelchairs using a limits of stability test and a sequential weight shifting test. Handgrip strength was tested. Quality of life was self-reported using the brief form of the World Health Organization’s quality of life questionnaire (WHOQOL-BREF).

Methods: Nineteen subjects with SCI between injury levels C6 and L1, 2 to 48 years post-injury participated in the study. Eleven subjects participated in sitting Tai Chi training (90 minute/session, 2 times/week for 12 weeks). Eight joined education and social activities as controls. The research was supported by the Hong Kong Polytechnic

University, grant 09902245R. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Results: Repeated measures MANCOVA showed significant group by time interaction effects on sitting balance control. Post hoc analysis demonstrated that the Tai Chi practitioners achieved significant improvements in their reaction time (p=0.042); maximum excursion (p=0.046) and directional control (p=0.025) in the limits of stability test. In the sequential weight shifting test, they significantly improved their total time to sequentially hit 12 targets (p=0.035) and directional control (p=0.033). These improvements were significantly greater than those of the controls. Significant improvement in handgrip strength was also found among the Tai Chi practitioners (p= 0.049).

Conclusions: Twelve weeks of sitting Tai Chi training can improve the dynamic sitting balance and handgrip strength of community-dwelling SCI survivors. Clinicians might use sitting Tai Chi as an exercise for people with SCI who can continue to practice the exercise even after being discharged from hospital as a means to maintain health**.**

Key words: spinal cord injury, sitting Tai Chi, sitting balance control

4.2 Introduction

Good sitting balance control is essential for people with spinal cord injury (SCI) because they are often confined to a sitting position when performing activities of daily living (ADL). The ability to shift their weight voluntarily in different directions without losing stability is important. Sitting balance heavily influences wheelchair skills, especially for performing the wheelies required to ascend or descend a curb or other obstacle. Sitting posture and balance also directly affect transfer performance (Bolin, Bodin, & Kreuter, 2000) where the ability to precisely and accurately control intentional movements of the center of pressure (COP) in different directions is important. Better directional control provides more accurate controlling of a variety of transfer activities. In a recent survey, thirty-one percent of 659 community-dwelling wheelchair users with SCI reported a total of 553 fall events (Nelson et al., 2010). The major factor contributing to falls is often a loss of balance during transfers (Nelson et al., 2003).

Wheelchairs users with SCI have decreased or no control of their trunk, leading to poor sitting balance and stability which may cause falls during transfer (Bernard, Peruchon, Micallef, Hertog, & Rabischong, 1994). With advances in rehabilitation strategies, people with SCI can benefit from various interventions that restore their functional capacity and ability to re-enter the community, but little has been published describing exercise programs to improve the sitting balance control of people with SCI who live in the community.

Good quality of life (QOL) is related to good relationships, maximizing functioning, engaging in activities and the ability to access one's environment (Kennedy & Rogers, 2000). There are several factors influencing QOL in people with SCI. Functional losses have a great impact on QOL. Ville and Ravaud (2001) pointed out that the functional independence is directly linked to QOL. In another words, the impact of limited functional status on social activity could reduce QOL. Participation in the community has a direct effect on QOL through increased opportunities for meaningful activity and social connections. After discharge from the hospital, regular exercise is not readily available. A new approach is needed to improve the functional status and QOL of community–dwelling people with SCI. Tai Chi is a Chinese martial art which is regarded as a gentle, relaxing, yet invigorating form of exercise. Tai Chi is both an integrated exercise and an enjoyable sport for all kinds of people: strong and weak, young and old, male and female. Weather does not inhibit its practice, as it can be performed indoors. Traveling time and space requirements are minimal (Tsao, 1995).

Previous academic work has shown that Tai Chi practice improves balance control, muscle strength, functional status, aerobic capacity, arterial compliance and decreases fall risk (Chen, Fu, Chan & Tsang, 2012; Gyllensten, Hui-Chan & Tsang, 2010; Lu, Hui-Chan & Tsang, 2012; Tsang, Wong, Fu & Hui-Chan, 2004; Wolf, Barnhart, Ellison & Coogler, 1997; Wolf, Sattin, Kutner, O'Grady, Greenspan & Gregor, 2003). Using the limits of stability test, Tsang & Hui-Chan (2003) showed that Tai Chi practitioners could initiate voluntary shifting of their weight to different spatial positions within their base of support more quickly than control subjects, leaned further without losing stability, and showed better control of their leaning trajectory. However, the traditional Tai Chi forms poses difficulty for older adults with poor standing balance or who are physically dependent, and may increase the risk of falling or injuries. In view of this, different modifications have been proposed for the frail or individuals with disabilities (Chen, Chen & Huang, 2006; Li, Fisher, Harmer, & Shirai, 2003; Wolf, Coogler & Xu, 1997).

Community-dwelling people with SCI lack an effective exercise to improve their sitting balance. Sitting Tai Chi could be performed easily without time and venue constraints. Could practicing sitting Tai Chi improve sitting balance and QOL? This study was designed to investigate the effects of practicing sitting Tai Chi on the handgrip strength, sitting balance control and QOL of people with SCI.

4.3 Methodology

4.3.1 Subjects and study design

Nineteen wheelchair users with SCI (11 males and 8 females aged 47.9 ± 10.7 years) participated in this study. The participants were recruited from the Hong Kong Sports Association for the Physically Disabled, the Direction Association for the Handicapped, and the Paraplegic & Quadriplegic Association. They were given both written and verbal information about the study before giving their informed consent to participation. The inclusion criteria were at least 1 year post-injury, incomplete injury according to the American Spinal Injury Association Impairment scale (ASIA) (Ditunno, Young, Donovan, & Creasey, 1994), aged 18 years or above, and able to communicate and follow instructions. People with unstable cardiopulmonary disease, serious complications related to the SCI (e. g. pressure ulcers), contracture or marked muscle hypertonicity, poorly controlled hypertension or metastatic cancer were excluded. The study protocol was approved by the Ethics Committee of the Hong Kong Polytechnic University and written consent was obtained from all participants before the study started.

4.3.2 The Tai Chi intervention

The sitting Tai Chi intervention involved two 90-minute sessions, 2 times per week for 12 weeks. A 12-form sitting version of Yang's Tai Chi style was designed for the experiment. The subjects in the control group were involved in educational talks and social activities of equivalent duration and frequency. Before and after measurements of sitting balance control, handgrip strength, and QOL were conducted. An outline of the trial is shown in Figure 4.1.

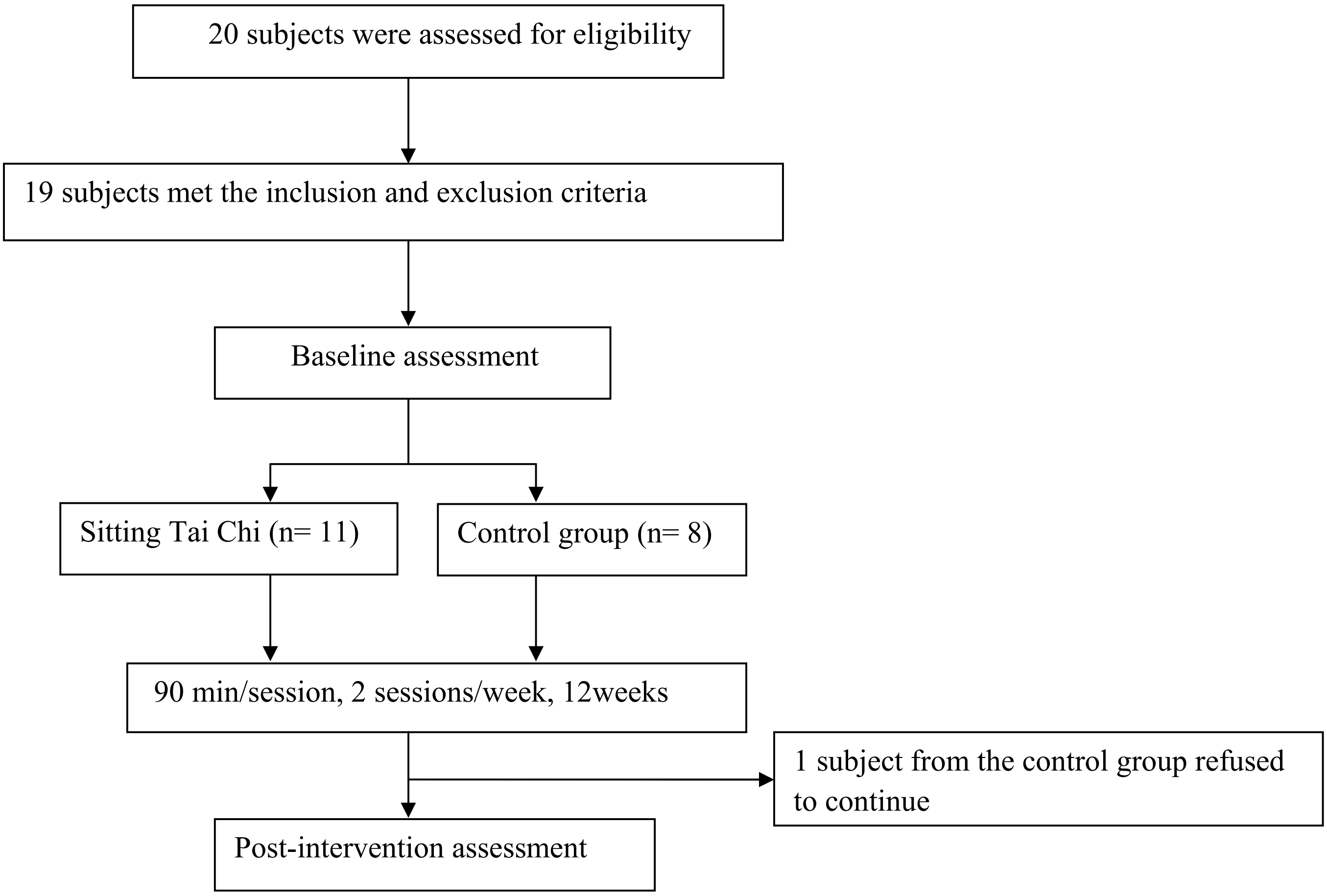


Figure 4.1. Flowchart of study 2

A 12-form sitting Tai Chi routine (Figure 2.8) was designed for the needs of people with SCI based on the traditional forms of Yang style Tai Chi. Shifting of weight while sitting, trunk rotation, upper limb joint mobilization and muscle strengthening were emphasized in an attempt to counteract loss of strength in the lower limb and trunk muscles and unstable sitting balance. The training was safe and simple for the participants to perform sitting in a wheelchair. A Tai Chi master and a physiotherapist conducted the training. Each session included a 5 minute warm up and 5 minute cool down with rests as necessary. Attendance was recorded. The subjects were encouraged to also practice at home for 90 minutes each week. A logbook was used to monitor home exercise by self recording.

4.3.3 Outcome measurements

4.3.3.1 Handgrip strength

Handgrip strength has been regarded as a significant indicator of overall body strength (Rantanen et al., 2003). A Jamar hydraulic hand dynamometer (Sammons Preston, Ability One Co, Bolinbrook, IL) was used to measure handgrip strength. The Jamar dynamometer is widely used for measuring isometric grip force from 0-200 lb (90 kg) and has shown excellent reproducibility (Linstrom-Hazel, Kratt, & Bix, 2009; Mathiowetz, Weber, Volland, & Kashman, 1984). Subjects were instructed to sit in their own wheelchair with the test shoulder adducted and rotated neutrally and the elbow flexed at 90°, the forearm in a neutral position, and the wrist between 0 and 30 degrees of extension and between 0 and 15 degrees of ulnar deviation (Mathiowetz et al., 1984).

Familiarization trials were allowed before the results of three measurements were averaged for comparison.

4.3.3.2 Sitting balance control

The sitting balance tests were performed supported in the subject's own wheelchair. They involved a limits of stability test and a sequential weight shifting test. Both were performed on a wooden force platform (90 cm x 76 cm) in front of an adjustable-height screen 1.5 m away on which the COP was continuously displayed. The subject's COP was measured by 4 load cells (SBDEG, Measurement Specialties Inc., Schaevitz VA, USA) under the platform. The measurement range of the load cells was 40-400 pounds of force. All movement data from the force platform were converted and digitized using a Multifunction Data Acquisition device (National Instrument NI USB-6009, USA) and an 8-channel analog-to-digital converter at a sampling rate of 1000 Hz. A computer running tailored LabVIEW (version 8.6, National Instruments, USA) software displayed and stored the COP data in real time during the sitting balance tests.

4.3.3.2.1 Limits of stability

Supported sitting was defined as seated in the subject's own wheelchair but without resting on the back support for the paraplegics or with both back and head support for the tetraplegics at the beginning of testing. The participant's hips, knees and ankles were kept at approximately 90° of flexion, and the feet were shoulder width apart resting on the platform. Each participant had practice trials for familiarization, followed by three trials of each balance test.

The limits of stability (LOS) test measured their intentional weight shifting ability in multiple directions within their base of support. The initial COP position was displayed in the center of the screen together with eight target positions in front, right front, right, right back, back, left back, left, and left front. The participants were required to move the COP trace on the screen toward one of the eight target positions by shifting their weight within their limits of stability as quickly and as smoothly as possible when a visual signal indicated a target. There was a 20 second rest period between trials to minimize any fatigue which might affect performance. For each target, the mean of three trials was calculated for comparison. The investigator was beside the participant for safety. There was a two second baseline measurement of COP sway before each target was indicated.

The outcome measures of the LOS test were: (1) reaction time (RT) - the time from the appearance of a target to the onset of the voluntary shifting of the COP; (2) maximum excursion (ME) - the maximum displacement of the COP in the target direction; (3) directional control (DC) - a comparison of the amount of movement of the COP in the on-target direction with the amount of off-target displacement. This LOS test protocol has been shown in a previous study to have moderate to excellent reproducibility (ICC=0.751-0.990) (Gao, Purves, Chan, & Tsang, 2011).

4.3.3.2.2 Sequential weight shifting

A temporal-spatial task was involving diagonal COP shifting was used to measure sequential weight shifting (SWS) ability. The sitting position was the same as in the LOS test. As soon as a visual target appeared, participants were asked to shift their COP to move the screen trace to the target as quickly as possible without losing their balance. Twelve targets appeared sequentially. When each target was hit, it disappeared and another appeared. The 12 targets appeared above, left, below, and to the right of the center (Figure 2.6). The distance from the center to each target was 75% of that subject's maximal excursion as determined in the LOS test. The trajectory is shown in Figure 2.6. The participants had continuous visual feedback about the position of their COP from the screen as they performed the weight shifts. The total time for the subject to hit the 12 targets sequentially and directional control were computed. The SWS test has been shown to have moderate to excellent reproducibility (ICC=0.688-0.952) in a previous study (Gao, Purves, Chan, & Tsang, 2012).

4.3.3.3 Quality of life

The brief version of the World Health Organization's Quality of Life scale (WHOQOL-BREF) has been demonstrated to be an acceptable and validated questionnaire to assess the QOL of people with SCI (Hill, Noonan, Sakakibara, & Miller, 2010; Jang, Hsieh, Wang, & Wu, 2004). The Chinese version of the WHOQOL-BREF was used to measure QOL in this study. It has previously been shown to have high intra-rater reliability (ICC= 0.84-0.98) (Lin, Hwang, Chen, & Chiu, 2007) and its validity as a tool for measuring the QOL of Chinese individuals with SCI has been established (Jang et al., 2004).

WHOQOL-BREF is a self-reporting questionnaire which consists of 26 questions. There are 2 general questions (about overall QOL and overall health perceptions) and more detailed questions about four QOL domains. Seven query the physical domain (D1), 6 the psychological domain (D2), 3 the social relationship domain (D3), and 8 questions probe the environmental domain (D4). All questions solicit ratings on a five-point Likert scale. The scores were first summarized for the 4 domains (physical health, psychological health, social relationships and environment) according to the WHOQOL-BREF guidelines by taking the mean score for the questions addressing that domain and multiplying by 4. So each domain score could range from 4 to 20. A higher score indicates better QOL.

4.3.4 Statistical analysis

The average age, sitting height, weight, and years of injury of the experimental and control groups were compared using independent t-tests. The sitting height was defined as the vertical distance from vertex of the head to the seat of the wheelchair. Chi-square tests were applied for between-group comparison of the gender distribution and injury levels. After testing for normality and equal variance, independent t-tests were employed to analyze any inter-group differences in the baseline values between the Tai Chi group and the control group. If a significant difference was found in any of the baseline values it was treated as a co-variate in the subsequent statistical analysis. Two-way repeated measures MANOVA with an intent-to-treat design was employed to analyze any inter-group differences in the outcome measures between before and after the intervention. Post hoc paired t-tests were conducted to investigate whether there was any within-group difference in the assessment intervals with the baseline values. Independent t-tests were conducted to compare the Tai Chi and control groups at the 2 time points. A significance level (α) of 0.05 was chosen for the statistical comparisons.

4.4 Results

4.4.1 Subjects

The neurological level of the participants' injuries ranged from C6 to L1 according to the International Standards for the Neurological Classification of Spinal Cord Injury from the American Spinal Injury Association. The time since injury averaged 16 years (from 2 to 48 years). Nineteen subjects had lesions incomplete to varying degrees (11 subjects with ASIA grade B, 3 with grade C, 5 with grade D impairments). The participants were categorized into 2 groups depending on their level of injury. The high-level injury group (n=12) grouped those with injuries between C6 and T7. The remaining subjects made up the low-level group (n=7), having injuries between T8 and L1 (Bowel-Ruys, et al., 2009). Eleven subjects with SCI participated in the sitting Tai Chi training while 8 subjects with SCI participated in the educational talks and social activities as controls. Only one subject in the control group dropped out due to loss of interest (i.e., 87.5% completed). The average attendance of the face-to-face Tai Chi training sessions was 90%, while that of the controls was 87%. No adverse events were reported during the training period. The self-reported sitting Tai Chi home exercise compliance rate was 100%.

The demographics of the two groups are summarized in Table 4.1. There was no significant difference in the gender distribution, nor in average age, sitting height, weight, injury level or time since injury between the two groups.

4.4.2 Handgrip strength

Two-way repeated measures MANOVA test of the handgrip strength results showed an overall significant time by group interaction ($P = 0.049$; Table 4.2), and a significant time by group interaction ($P = 0.019$) in terms of dominant handgrip strength. Paired t-tests showed that only the experimental group had a significant improvement in dominant hand strength ($P = 0.008$) after three months of training. No significant change was found in the control group ($P = 0.441$). No significant time by group interaction was found involving non-dominant hand strength ($P = 0.318$), however paired t-tests revealed that the Tai Chi group had significant improvement ($P = 0.027$) after three months of training. No significant change was found in the control group ($P = 0.624$).

Table 4.1: Characteristics of the participants

	Control group (n=8)	Sitting Tai Chi group (n=11)	*P* value
Age, years	46.2 ± 11.8	49.1 ± 10.3	0.761
Gender (male/female), n	7/1	4/7	0.062
Sitting height, cm	83.7 ± 5.5	75.5 ± 11.1	0.122
Weight, kg	65.4 ± 14.6	60.4 ± 24.3	0.064
Injury level (high/low), n	5/3	7/4	0.968
Time since injury, years	17.3 ± 7.8	14.7 ± 13.7	0.258

4.4.3 Sitting balance control

The two-way repeated measures MANCOVA of the sitting balance results showed an overall significant time by group interaction (*P* = 0.035; Table 4.2). Since the average baseline maximum excursions of the two groups were significantly different, this was treated as a co-variate in the analysis.

4.4.3.1 Changes in the limits of stability

Univariate repeated measures ANOVA indicated differences in the groups' average reaction time, maximum excursion and directional control. A significant time by group interaction effect (*P* = 0.042) was found in the reaction time. Paired t-tests revealed that only the sitting Tai Chi group had significantly better reaction time performance (*P* = 0.025) after three months of training. No significant change was found in the control group over time (*P* = 0.469).

Moreover, a significant time by group interaction (*P* = 0.016) was found in the average maximum excursion. Paired t-tests revealed that only the sitting Tai Chi group achieved an improvement in the COP distance travelled (*P* = 0.006) after three months of training. No significant change was found in the control group (*P* = 0.613).

Furthermore, a significant time by group interaction (*P* = 0.025) was found in the average directional control. The sitting Tai Chi trainees showed a significant improvement (*P* = 0.047) after three months of training while there was no significant change in the control group (*P* = 0.076) over time.

4.4.3.2 Changes in sequential weight shifting performance

The total time to complete the sequential weight shifting test showed a significant time by group interaction (*P* = 0.035; Table 4.2). Paired t-tests showed that only the Tai Chi group showed a significant average improvement (*P* = 0.012) after the three months of training. No significant change was found in the control group (*P* = 0.399). Between-group comparisons demonstrated that the difference between the two groups was statistically significant after the intervention (*P* = 0.001).

Table 4.2: Comparison of outcome measurements between and within groups

	Control group	(n=8)	Sitting Tai Chi group	(n=11)	p value		
Measurements	pretest	post-test	pretest	post-test	Pre-test (Group effect)	Post-test (Group effect)	Group x time effect
Limits of stability test							Overall *P* = 0.035
Reaction time, msec	717.9 ± 265.8	832.0 ± 422.0	1028.9 ± 326.1	757.2 ± 155.1[e]	0.580	0.144	0.042[a]
Maximum excursion, mm	61.9 ± 53.6	60.6 ± 50.1	35.4 ± 19.8	44.4 ± 21.7[f]	0.005[d]	0.015[c]	0.016[a]
Directional control	0.68 ± 0.1	0.65 ± 0.12	0.70 ± 0.11	0.77 ± 0.09[e]	0.725	0.555	0.025[a]
Sequential weight shifting test							Overall *P* = 0.016
Total time, msec	50789.0 ± 16605.8	59160.5 ± 27533.9	54978.5 ± 8693.3	41475.3 ± 7797.4[e]	0.190	0.001[d]	0.035[a]
Directional control	0.64 ± 0.09	0.61 ± 0.09	0.60 ± 0.07	0.64 ± 0.04	0.699	0.027[c]	0.033[a]
Handgrip strength							Overall *P* = 0.049
Right hand (kg)	32.8 ± 17.1	31.5 ± 14.8	21.4 ± 13.4	24.8 ± 15.2[f]	0.354	0.807	0.019[a]
Left hand (kg)	31.6 ± 15.4	32.4 ± 14.8	21.2 ± 11.8	23.8 ± 12.4[e]	0.473	0.924	0.318
Quality of life							

Physical	10.6 ± 1.7	10.6 ± 1.8	11.4 ± 1.3	10.8 ± 2.1	0.331	0.490	0.534
Psychological	12.5 ± 1.9	12.2 ± 1.8	11.3 ± 1.4	11.8 ±2.2	0.308	0.741	0.171
Social	12.3 ± 2.6	12.8 ± 2.4	13.9 ± 2.5	14.1 ± 2.5	0.584	0.924	0.736
Environmental	13.3 ± 2.3	12.7 ± 2.6	11.9 ± 2.4	13.4 ± 4.9	0.697	0.373	0.196

Note. Values are mean ± SD or *P* values.

Group by time interaction:

[a] Denotes a difference significant at the $p<0.05$ confidence level.

[b] Denotes a difference significant at the $p<0.01$ level of confidence.

Between groups:

[c] Denotes a difference significant at the $p<0.05$ confidence level.

[d] Denotes a difference significant at the $p<0.01$ level of confidence.

Within group (time effect):

[e] Denotes a difference significant at the $p<0.05$ level when compared with pretest values.

[f] Denotes a difference significant at the $p<0.01$ level when compared with pretest values.

A significant time by group interaction (*P* = 0.033) was also found in terms of directional control, but there was no significant change in either group after the three month intervention.

4.4.4 Quality of life

No significant time by group interaction was found in any domain of the WHOQOL-BREF results. There was no significant difference between the two groups before or after the intervention.

4.5 Discussion

Handgrip strength

The experimental group showed improved grip strength in both hands. To the extent that handgrip strength reflects overall body strength (Rantanen et al., 2003), the findings may indicate a general improvement in average muscle strength among the sitting Tai Chi trainees. Similar findings have been reported by Jones' group (Jones, Dean, & Scudds, 2005). In that study, fifty-one subjects inexperienced in Tai Chi learned 119 forms of Cheng's style Tai Chi in a community center for 1.5 hours, 3 times per week for 12 weeks. Handgrip strength improved significantly after the 3 months of training (average increase of 2.6%). The 12-form Tai Chi used in this study is much simpler and easier to learn, yet it too produced a significant improvement in average handgrip strength (average increase of 14.3%).

The key difference may be that Jones' subjects were not wheelchair bound. Previous studies have shown that persons with high level SCI compensate their loss of postural muscle function from the erector spinae through increased use of non-postural muscles such as the latissimus dorsi, upper trapeizus, pectoralis major, and serratus anterior (Seelen, Potte, Huson, Spaans, & Reulen, 1997; Seelen, et al., 1998a; Seelen, Potten, Drukker, Reulen, & Pons, 1998b; Seelen, Janssen-Potten, & Adam, 2001). If improved handgrip strength reflects better general muscle strength, that may lead to improved wheelchair maneuvering. However, further research is warranted.

Sitting balance control

Limits of stability

This has been the first published study to investigate the effects of sitting Tai Chi on the sitting balance control of community-dwelling people with SCI. The sitting Tai Chi practitioners showed improvements in the limits of stability test and were able to achieve significantly better reaction times, maximum excursions and directional control. The Tai Chi practitioners showed better dynamic balance control in self-initiated shifting of the COP to different spatial targets within their base of support. Reaction time in initiating movement depends on both neuromuscular control and cognitive factors (Shumway-Cook & Woollacott, 2001). The improved muscle strength found in this study and better balance control stabilize the body in advance of potentially destabilizing movements (Tsang & Hui-Chan 2003), which might explain why the Tai Chi practitioners had shorter reaction times in the voluntary leaning of their body to the eight target positions. The Tai Chi group also showed improved COP distance travelled after the intervention while no significant change was found in the control group. The kinematic characteristics of the sitting Tai Chi forms provide comparatively large anteroposterior and mediolateral COP displacements (as reported in Lee et al., 2011) which may explain these results.

When ascending a ramp, people with SCI lean forward as far as possible to prevent the wheelchair from tipping backward. When descending a ramp, they would lean as far back as possible to prevent falling (Sisto, Druin, & Sliwinski, 2009). These techniques require them to perform maximal postural excursions in either the forward or backward direction. Enhanced maximum excursion should therefore be beneficial in their ADL and transfer activities.

A previous Tai Chi study has shown that 4 weeks of intensive training (1.5 hr/session, 6 times per week for 24 sessions) significantly improves directional control in the limits of stability test for community-dwelling elderly who are standing. However, those older subjects did not improve their average reaction time or maximum excursion (Tsang & Hui-Chan 2004). The investigators in that study explained that Tai Chi movements require the practitioners to perform the forms in a smooth and coordinated manner, thus enhancing their directional control. Since the elderly participants were healthy and their initial maximum excursion levels were already considered high, the short-term intensive Tai Chi practice could not further enhance their average maximum excursion. In this present study the subjects lived in the community but felt that they lacked exercise after being discharged from the hospital. Practicing sitting Tai Chi may provide an alternative means of exercise which should be effective in improving their balance control.

Sequential weight shifting test

The sequential weight shifting assessment required the subjects to shift their weight shifting as quickly and accurately as possible. It demanded acceleration and deceleration of the trunk along both orthogonal and diagonal trajectories which are important in the ADL of those with SCI. Trunk angular displacements and velocity control are key elements in any transfer (Gangon et al., 2008). A group led by Forslund investigated the coordination of body movement during transfer from a table to a wheelchair among 13 people with SCI. They started with a weight shift from the buttocks to the hands by trunk flexion and rotation towards the trailing side (Forslund et al., 2007). Sitting Tai Chi involves sequential shifting with reciprocal arm movements and coordinated trunk flexion and rotation. In Tai Chi practice, one of the principles for able bodied individuals is to lead the movement with the “waist” (Yu, 2002). Also, the Tai Chi forms involve both orthogonal and diagonal movements (Wolf et al., 1997), which may explain the improvements in sequential weight shifting among the experimental group.

Generally, exercises to improve the sitting balance control of community-dwelling people with SCI are scarce. Kayak training has been investigated in a few studies (Bjerkefors, Carpenter, & Thorstensson, 2007; Grigorenko et al., 2004). Grigorenko and his colleagues (2004) conducted an 8-week open-sea kayak training program with 12 individuals with SCI and 12 able bodied subjects. The results showed a relatively small treatment effect on balance in the sagittal plane during quiet sitting test.

In the later study led by Bjerkefors (Bjerkefors et al., 2007), 10 subjects with thoracic SCI were given 10 weeks of kayak arm ergometer training and the investigators found less body sway in rotation and less linear displacement of the trunk during perturbations. These studies only demonstrated improved static posture control, not better dynamic balance control. In any case, neither open sea kayaks or kayak arm ergometers are easy to access for SCI survivors in the community.

Quality of Life

There was no significant change in the average scores in any of the four quality of life domains in either group. The question may thus arise as why there were improvements observed in handgrip strength and dynamic sitting balance control in the Tai Chi group but no change was reflected in the physical domain by the WHOQOL-BREF questionnaire. One possible reason is that all the participants were at the chronic stage and their social and environment domains had reached a steady state. It may take more time for improved strength and balance control to be reflected in improvements in daily life. In this connection, Hicks and his colleagues found that the quality of life of individuals with SCI was improved only after 9 months of twice-weekly exercise training, but not after three or six months (Hicks et al., 2003). Some subjects in this study did, however, mention that they had better access to their living environment after the Tai Chi training. For example, one subject reported that he could lean further to get a magazine from the newspaper stand and another Tai Chi participant commented that he had better mobility while accessing the mass transit railway.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 Rationale for the study

A supported or unsupported short-sitting position is commonly adopted by people with SCI when handling ADL. Also, the assessment of sitting balance control should include diagonal and sequential movements which are commonly required in transfer. The time domain and the directional control to achieve different excursion directions, which constitute the important factors in sitting balance control, have not been investigated in previous studies. Therefore, the objectives of study 1 included: (1) to develop laboratory-based tests for use in a clinical setting that assess dynamic sitting balance control in people with SCI; (2) to examine the reliability of the sitting balance control tests; and (3) to assess the correlations of the sitting balance control performance with functional activities in people with SCI.

Persons with SCI have been characterized as considerably sedentary. Often, individuals with SCI are physical de-conditioned (Dearwater, Laporte, Cauley, & Brenes, 1985; Noreau, Shephard, Simard, Paré, & Pomerleau, 1993) which contributes to serious of complications like pressure ulcers, autonomic dysreflexia, pneumonia, cardiovascular disease, urinary tract infections, osteoporosis and activity limitations (Brenes et al., 1986; Dearwater et al., 1986; Janssen et al., 1994; McKinley et al., 1999). This population can benefit greatly by participating in regular exercise activities (Jacobs & Nash, 2004) and various interventions that may restore their functional capacity and ability to re-entry into the community. Sitting balance is a critical part of functional activities in such individuals. However, an effective exercise on sitting balance in community-dwelling people with SCI is lacking. Sitting Tai Chi can be performed in any place and at any time. Whether sitting Tai Chi improve sitting balance, muscle strength, and quality of life remains to be answered. The objective of study 2 was to investigate the effects of sitting Tai Chi on sitting balance control, handgrip strength, and quality of life in community-dwelling people with SCI.

5.2 Summary of results

1) The limits of stability test in sitting was found to have excellent reliability under supported sitting, and moderate to excellent reliability in the combined forward directions. Excellent reliability was found under the unsupported sitting.
2) The sequential weight shifting test under supported sitting also exhibited moderate to excellent test-retest reliability. Under the unsupported sitting, this test showed excellent test-retest reliability.
3) The parameters of the limits of stability test, namely reaction time, movement time and directional control under unsupported sitting showed significant correlations with the mobility scores of Spinal Cord Independent Measurement III. Under both unsupported and unsupported sitting, the parameters of the sequential weight shifting test, namely total time and directional control were significantly correlated with the mobility scores of Spinal Cord Independent Measurement III.
4) A 12-form Yang style sitting Tai Chi routine can be practiced by community-dwelling people with SCI in a safe and enjoyable manner.
5) Twelve weeks of sitting Tai Chi training improves the handgrip strength of community-dwelling people with SCI.

6) After twelve weeks of sitting Tai Chi training, community-dwelling people with SCI showed improved dynamic sitting balance control in time and spatial domains.
7) Only twelve weeks training in this 12-form Yang style Tai Chi may not be enough to improve quality of life in the chronic stages of community-dwelling people with SCI.

5.3 Recommendations

There are several limitations in this study. The small sample size is common among studies on SCI, but that too limits generalizability. Further study of this topic should take steps to involve a large sample. The study on the reliability and correlation of the dynamic sitting balance tests focus mainly on the general population of wheelchair users with SCI. A future study might profitably amplify these findings by looking into more homogenous groups — older and younger (Curtis et al., 1995), sub-acute and chronic, higher and lower injury level (Chen et al., 2003; Lynch et al., 1998).

Only the supported sitting condition was employed to assess the dynamic sitting balance control of the participants since only 7 subjects in the Tai Chi group and 3 subjects in the control group could undergo the unsupported sitting condition. Also, the participants in the intervention Tai Chi study were heterogeneous in terms of age and gender, injury level and time since injury. The significant changes in the handgrip strength and sitting balance control in the Tai Chi subjects should, therefore, be generalized to others with SCI only with caution. The post assessment was conducted immediately after the intervention, so any long-term effect of Tai Chi training on sitting balance control and ADL was not ascertained. Moreover, the participants were not randomly allocated to the Tai Chi or control, so experimental bias might have occurred. Further study with a randomized clinical trial design is warranted.

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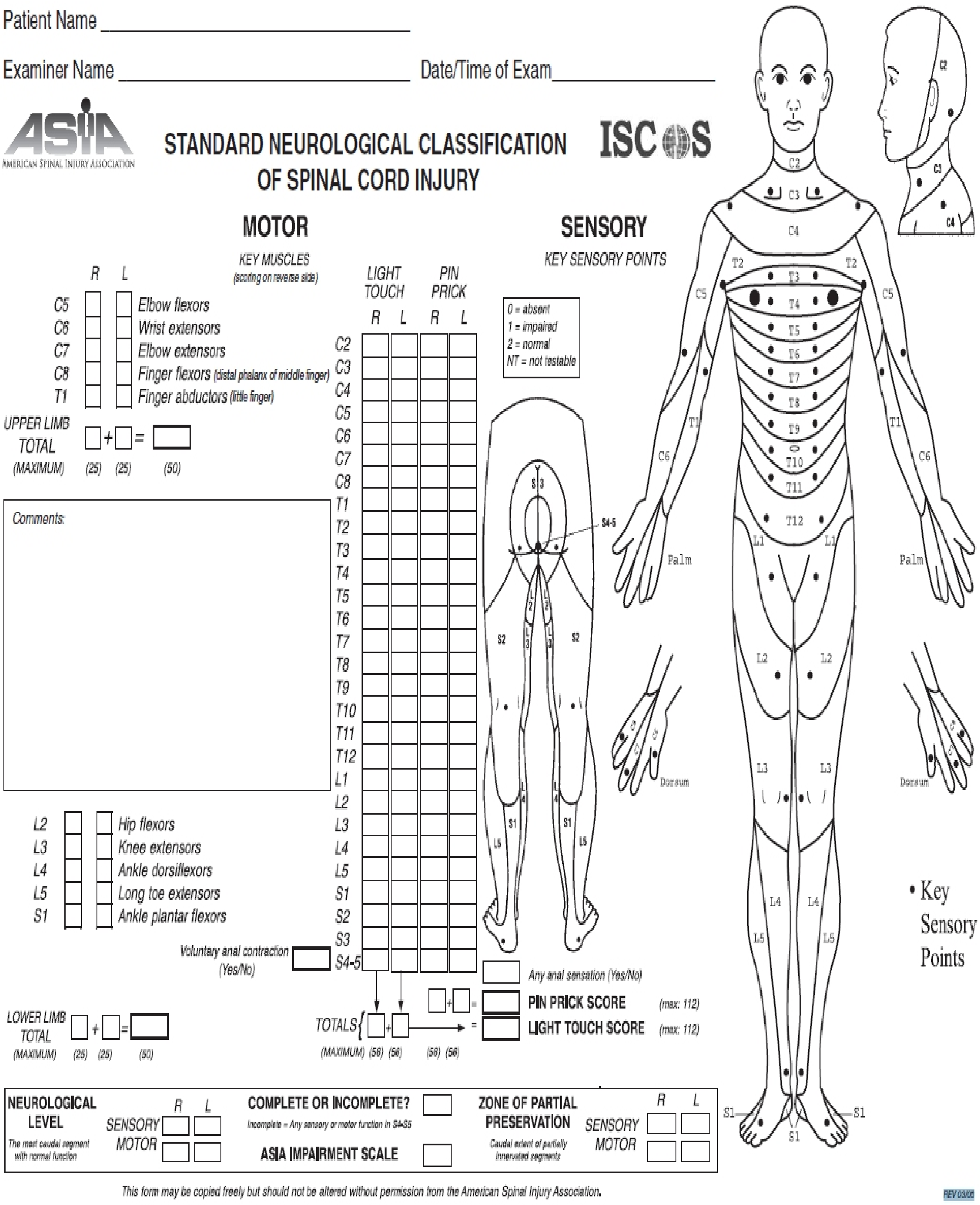
Appendix A



Patient Name ______________________________

Examiner Name ______________________________ Date/Time of Exam______________

AMERICAN SPINAL INJURY ASSOCIATION

STANDARD NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY

ISCoS

MOTOR

KEY MUSCLES (scoring on reverse side)

	R	L	
C5	☐	☐	Elbow flexors
C6	☐	☐	Wrist extensors
C7	☐	☐	Elbow extensors
C8	☐	☐	Finger flexors (distal phalanx of middle finger)
T1	☐	☐	Finger abductors (little finger)

UPPER LIMB TOTAL ☐ + ☐ = ☐

(MAXIMUM) (25) (25) (50)

Comments:

	R	L	
L2	☐	☐	Hip flexors
L3	☐	☐	Knee extensors
L4	☐	☐	Ankle dorsiflexors
L5	☐	☐	Long toe extensors
S1	☐	☐	Ankle plantar flexors

Voluntary anal contraction (Yes/No) ☐

LOWER LIMB TOTAL ☐ + ☐ = ☐

(MAXIMUM) (25) (25) (50)

SENSORY

KEY SENSORY POINTS

	LIGHT TOUCH R	LIGHT TOUCH L	PIN PRICK R	PIN PRICK L
C2	☐	☐	☐	☐
C3	☐	☐	☐	☐
C4	☐	☐	☐	☐
C5	☐	☐	☐	☐
C6	☐	☐	☐	☐
C7	☐	☐	☐	☐
C8	☐	☐	☐	☐
T1	☐	☐	☐	☐
T2	☐	☐	☐	☐
T3	☐	☐	☐	☐
T4	☐	☐	☐	☐
T5	☐	☐	☐	☐
T6	☐	☐	☐	☐
T7	☐	☐	☐	☐
T8	☐	☐	☐	☐
T9	☐	☐	☐	☐
T10	☐	☐	☐	☐
T11	☐	☐	☐	☐
T12	☐	☐	☐	☐
L1	☐	☐	☐	☐
L2	☐	☐	☐	☐
L3	☐	☐	☐	☐
L4	☐	☐	☐	☐
L5	☐	☐	☐	☐
S1	☐	☐	☐	☐
S2	☐	☐	☐	☐
S3	☐	☐	☐	☐
S4-5	☐	☐	☐	☐

0 = absent
1 = impaired
2 = normal
NT = not testable

☐ Any anal sensation (Yes/No)

TOTALS ☐ + ☐ → = ☐ **LIGHT TOUCH SCORE** (max: 112)

(MAXIMUM) (56) (56)

☐ + ☐ = ☐ **PIN PRICK SCORE** (max: 112)

(56) (56)

NEUROLOGICAL LEVEL
The most caudal segment with normal function

	R	L
SENSORY	☐	☐
MOTOR	☐	☐

COMPLETE OR INCOMPLETE? ☐
Incomplete = Any sensory or motor function in S4-S5

ASIA IMPAIRMENT SCALE ☐

ZONE OF PARTIAL PRESERVATION
Caudal extent of partially innervated segments

	R	L
SENSORY	☐	☐
MOTOR	☐	☐

This form may be copied freely but should not be altered without permission from the American Spinal Injury Association.

REV 03/00

MUSCLE GRADING

0 total paralysis

1 palpable or visible contraction

2 active movement, full range of motion, gravity eliminated

3 active movement, full range of motion, against gravity

4 active movement, full range of motion, against gravity and provides some resistance

5 active movement, full range of motion, against gravity and provides normal resistance

5* muscle able to exert, in examiner's judgement, sufficient resistance to be considered normal if identifiable inhibiting factors were not present

NT not testable. Patient unable to reliably exert effort or muscle unavailable for testing due to factors such as immobilization, pain on effort or contracture.

ASIA IMPAIRMENT SCALE

☐ A = **Complete**: No motor or sensory function is preserved in the sacral segments S4-S5.

☐ B = **Incomplete:** Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5.

☐ C = **Incomplete:** Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.

☐ D = **Incomplete:** Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.

☐ E = **Normal:** Motor and sensory function are normal.

CLINICAL SYNDROMES (OPTIONAL)

☐ Central Cord
☐ Brown-Sequard
☐ Anterior Cord
☐ Conus Medullaris
☐ Cauda Equina

STEPS IN CLASSIFICATION

The following order is recommended in determining the classification of individuals with SCI.

1. Determine sensory levels for right and left sides.
2. Determine motor levels for right and left sides.
   Note: in regions where there is no myotome to test, the motor level is presumed to be the same as the sensory level.
3. Determine the single neurological level.
   This is the lowest segment where motor and sensory function is normal on both sides, and is the most cephalad of the sensory and motor levels determined in steps 1 and 2.
4. Determine whether the injury is Complete or Incomplete (sacral sparing).
   If voluntary anal contraction **= No** *AND all S4-5 sensory scores* **= 0** *AND any anal sensation* **= No,** *then injury is COMPLETE. Otherwise injury is incomplete.*
5. Determine ASIA Impairment Scale (AIS) Grade:

Is injury <u>Complete</u>? If **YES,** AIS=A Record ZPP
(For ZPP record lowest dermatome or myotome on each side with some (non-zero score) preservation)

NO ↓

Is injury motor <u>incomplete</u>? If **NO,** AIS=B
(Yes=voluntary anal contraction OR motor function more than three levels below the motor level on a given side.)

YES ↓

Are <u>at least</u> half of the key muscles below the (single) <u>neurological</u> level graded 3 or better?

NO ↓ AIS=C

YES ↓ AIS=D

If sensation and motor function is normal in all segments, AIS=E
Note: AIS E is used in follow up testing when an individual with a documented SCI has recovered normal function. If at initial testing no deficits are found, the individual is neurologically intact; the ASIA Impairment Scale does not apply.

康復治療科學系

同意書

研究題目：太極拳對脊髓損傷患者的平衡控制及心肺功能的研究

研究者： 曾偉男博士

Sheila Purves 女士

陳啟明教授

高莉小姐

研究資料：

有研究表明脊髓損傷者損傷節段的不同，控制坐位平衡的能力也有所不同。而坐位平衡的控制是維持正常功能活動的一個重要能力，如上下臺階，進入巴士等都需要較好的平衡。此外因為活動能力受限，脊髓損傷者的戶外活動會減少，從而導致肌肉力量的下降，增加跌倒的機率及生活質素的下降。

太極拳是一種身心結合的運動，其動作舒緩，並且不受場地，器械，服裝的局限，不受氣候的影響，受到很多東方人的喜愛。但傳統太極都以站立為主，輪椅使用者因此受到限制，而坐式太極的出現恰好彌補了這項空白。研究證實，練習坐式太極能夠提高正常的老年人的坐位平衡力量，增強心肺功能及全身肌肉力量。但是，現有關坐式太極對脊髓損傷患者效益的研究還沒有結論。因此，通過這項研究，我們希望測試有關坐式太極對脊髓損傷患者的平衡能力，心肺功能及肌肉力量的影響。參與者會被隨機分配到為期三個月的太極班或興趣班，並與活動班舉行前及完成後進行測試。所有參與者會先填寫相關問卷，以作為鑒別其身體狀況是否適合參與該項研究。

甄選標准：

- 脊髓損傷節段在胸椎 2 以下
- 視力正常
- 輪椅使用者
- 不曾參加太極運動
- 無嚴重併發症
- 沒有下列病史: 內耳問題，整形外科（骨科）手術，神經科疾病。

運動班：

參與者會被隨機分配到太極班或興趣班。太極班的參與者會學習改良的楊式坐式太極拳。在興趣班，參與者主要是坐著進行各類興趣活動。兩種活動班都會持續三個月，每週三次課，每次課一個半小時（共 36 節）。參與者需於活動舉行的三個月間最少出席 75%（即 27 節）的活動班。

測試方法：

參與者將於 3 個月太極班或興趣班前及完成後參與測試，每次測試需要約 90 分鐘。所有測試均不會構成任何的危險。測試項目包括：

1. 坐位平衡測試 – 穩定限制性測試
2. 肌肉力量測試 –握力與軀幹肌肉力量測試
3. 心肺功能的測試 –心率與肺功能測試儀
4. 評估問卷 – 脊髓損傷獨立量表第三版

同意書：

本人_____________已瞭解此次研究的具體情況。本人願意參加此次研究，本人有權在任何時候、無任何原因放棄參與此次研究，而此舉不會導致我受到任何懲罰或不公平對待。本人明白參加此研究課題的潛在危險性以及本人的資料將不會洩露給與此研究無關的人員，我的名字或相片不會出現在任何出版物上。

本人可以用電話 27666717 來聯絡此次研究課題負責人，曾偉男博士或 6042 高莉小姐。若本人對此研究人員有任何投訴，可以聯系梁女士（部門科研委員會秘書），電話：27665397。本人也明白，參與此研究課題需要本人簽署一份同意書。

參加者簽署：__________________　　　　日期：__________________

見證人簽署：__________________　　　　日期：__________________

Appendix C

The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

Consent Form

Project title:

Effects of sitting Tai Chi on sitting balance and cardiopulmonary functions in persons with spinal cord injury.

Investigators: Dr. William W. N. Tsang

Ms. Sheila Purves

Professor K. M. Chan

Ms. Kelly Gao

Research information:

Previous researches have shown that control of sitting balance is associated with the level of injury in people with spinal cord injury. Balance control is an important ability for functional activities like up and down kerb and entering bus. In addition, because of limited physical ability, people with spinal cord injury have decreased physical activity which can cause decline in muscle strength, increased falls incidence and reduced quality of life.

Tai Chi is a mind-body exercise with slow, soft and fluid movements. It can be practiced at any time and in any place because it needs neither much space nor equipment. It is popular among Chinese persons. However, traditional Tai Chi in standing position is not suitable for wheelchair users. Sitting Tai Chi is an exercise which is appropriate for wheelchair users. A number of studies on elderly persons have proven that sitting Tai Chi can benefit their balance control, lower limb muscle strength, and cardiopulmonary function. However, the benefits of Tai Chi on people with spinal cord injury are not conclusive. Therefore, the objective of the study is to examine the effect of sitting Tai Chi exercise on balance control, cardiopulmonary function and muscle strength in people with spinal cord injury. Participants will be randomly allocated to either a 3-month Tai Chi or an interest class. There will be assessments before and after the intervention. All participants will be screened by questionnaires to ensure there are no medical contraindications.

Inclusion criteria:

- People with spinal cord injury level below T2.
- Normal vision.
- Wheelchair user.

- No previous Tai Chi experience.
- No serious complication.
- No history of inner ear problem, orthopaedic operation, neurological disease.

Intervention classes:

Participants will be allocated randomly into either sitting Tai Chi or an interest class. In sitting Tai Chi group, participant will practice modified Yang style sitting Tai Chi exercise course. In the interest group, participant will join activities which will involve sitting position. Both courses will be held for 3 months. Each course will be conducted three sessions per week, 1.5 hour for each session (36 sessions). Participants must attend at least 75% of the sessions (27 sessions) in order to take part in the assessment.

Assessment:

Each assessment will take around 90 minutes. There will be no harm caused during the process. Assessments include:

1) Sitting balance control test – limits of stability test
2) Cardiopulmonary function test – heart rate and spirometry tests
3) Muscle strength test – hand grip strength and trunk muscle strength test
4) Questionnaire - the Spinal Cord Independent Measure II

Consent

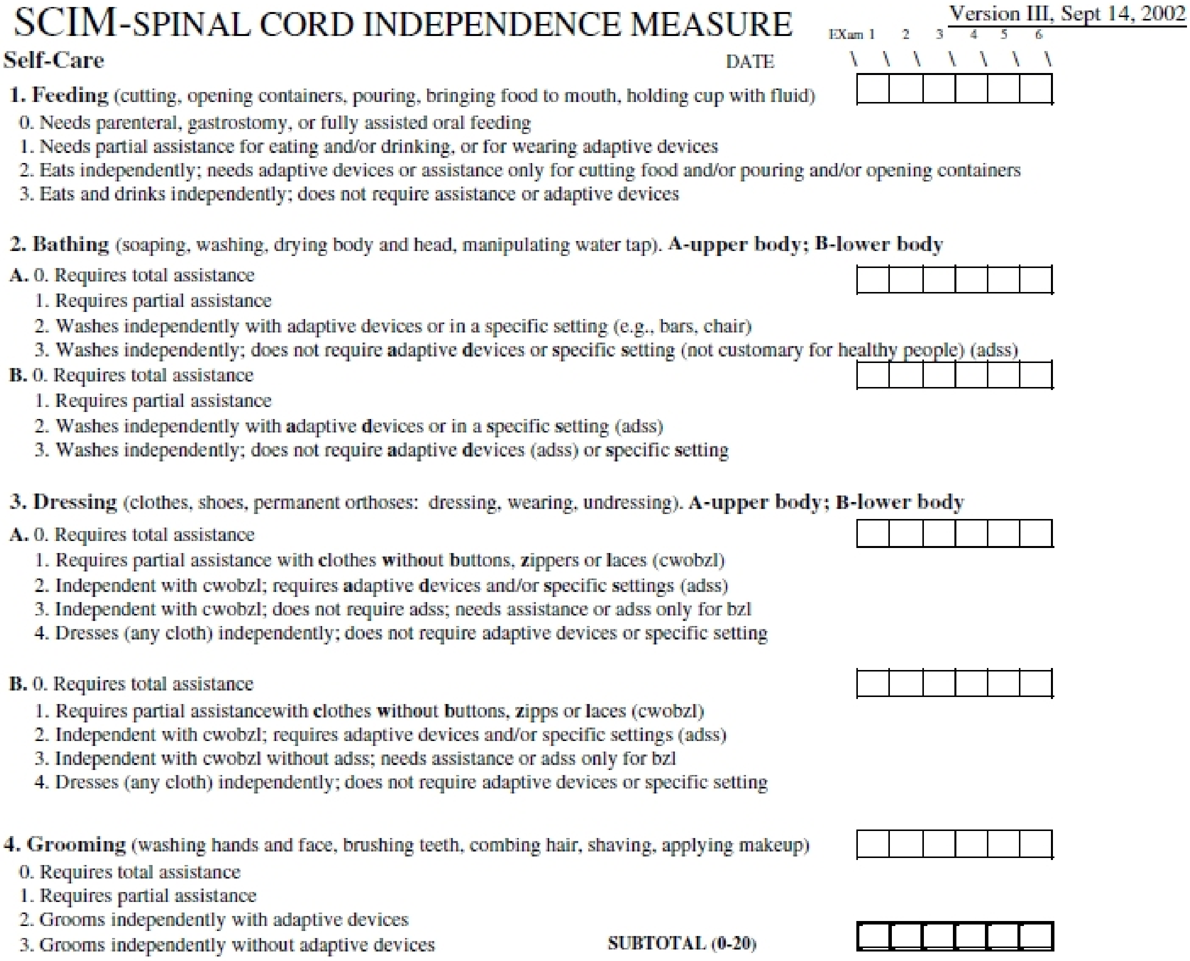
I, ___________________________, have been explained the details of this study. I voluntarily consent to participate in this study. I understand that I can withdraw from this study at any time without giving reasons, and my withdrawal will not lead to any punishment or prejudice against me. I am aware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

I can contact Dr. William Tsang at telephone 27666717 or Ms. Kelly Gao at 6042 for any questions about this study. If I have complaints related to the investigators, I can contact Ms. Michelle Leung, secretary of Departmental Research Committee, at 27665397. I know I will be given a signed copy of this consent form.

Signature (subject): ____________________ Date: _____________

Signature (witness): ______________________ Date: ______________

Appendix D



SCIM-SPINAL CORD INDEPENDENCE MEASURE

Version III, Sept 14, 2002

EXam 1 2 3 4 5 6

Self-Care DATE \ \ \ \ \ \ \

1. Feeding (cutting, opening containers, pouring, bringing food to mouth, holding cup with fluid) ☐☐☐☐☐☐

0. Needs parenteral, gastrostomy, or fully assisted oral feeding
1. Needs partial assistance for eating and/or drinking, or for wearing adaptive devices
2. Eats independently; needs adaptive devices or assistance only for cutting food and/or pouring and/or opening containers
3. Eats and drinks independently; does not require assistance or adaptive devices

2. Bathing (soaping, washing, drying body and head, manipulating water tap). **A-upper body; B-lower body**

A. 0. Requires total assistance ☐☐☐☐☐☐
   1. Requires partial assistance
   2. Washes independently with adaptive devices or in a specific setting (e.g., bars, chair)
   3. Washes independently; does not require **a**daptive **d**evices or **s**pecific **s**etting (not customary for healthy people) (adss)

B. 0. Requires total assistance ☐☐☐☐☐☐
   1. Requires partial assistance
   2. Washes independently with **a**daptive **d**evices or in a **s**pecific **s**etting (adss)
   3. Washes independently; does not require **a**daptive **d**evices (adss) or **s**pecific **s**etting

3. Dressing (clothes, shoes, permanent orthoses: dressing, wearing, undressing). **A-upper body; B-lower body**

A. 0. Requires total assistance ☐☐☐☐☐☐
   1. Requires partial assistance with **c**lothes **w**ith**o**ut **b**uttons, **z**ippers or **l**aces (cwobzl)
   2. Independent with cwobzl; requires **a**daptive **d**evices and/or **s**pecific **s**ettings (adss)
   3. Independent with cwobzl; does not require adss; needs assistance or adss only for bzl
   4. Dresses (any cloth) independently; does not require adaptive devices or specific setting

B. 0. Requires total assistance ☐☐☐☐☐☐
   1. Requires partial assistancewith **c**lothes **w**ith**o**ut **b**uttons, **z**ipps or **l**aces (cwobzl)
   2. Independent with cwobzl; requires adaptive devices and/or specific settings (adss)
   3. Independent with cwobzl without adss; needs assistance or adss only for bzl
   4. Dresses (any cloth) independently; does not require adaptive devices or specific setting

4. Grooming (washing hands and face, brushing teeth, combing hair, shaving, applying makeup) ☐☐☐☐☐☐

0. Requires total assistance
1. Requires partial assistance
2. Grooms independently with adaptive devices
3. Grooms independently without adaptive devices

SUBTOTAL (0-20) ☐☐☐☐☐☐

Respiration and Sphincter Management

5. Respiration

0. Requires tracheal tube (TT) and permanent or intermittent assisted ventilation (IAV)
2. Breathes independently with TT; requires oxygen, much assistance in coughing or TT management
4. Breathes independently with TT; requires little assistance in coughing or TT management
6. Breathes independently without TT; requires oxygen, much assistance in coughing, a mask (e.g., peep) or IAV (bipap)
8. Breathes independently without TT; requires little assistance or stimulation for coughing
10. Breathes independently without assistance or device

6. Sphincter Management - Bladder

0. Indwelling catheter
3. Residual urine volume (RUV) > 100cc; no regular catheterization or assisted intermittent catheterization
6. RUV < 100cc or intermittent self-catheterization; needs assistance for applying drainage instrument
9. Intermittent self-catheterization; uses external drainage instrument; does not need assistance for applying
11. Intermittent self-catheterization; continent between catheterizations; does not use external drainage instrument
13. RUV <100cc; needs only external urine drainage; no assistance is required for drainage
15. RUV <100cc; continent; does not use external drainage instrument

7. Sphincter Management - Bowel

0. Irregular timing or very low frequency (less than once in 3 days) of bowel movements
5. Regular timing, but requires assistance (e.g., for applying suppository); rare accidents (less than twice a month)
8. Regular bowel movements, without assistance; rare accidents (less than twice a month)
10. Regular bowel movements, without assistance; no accidents

8. Use of Toilet (perineal hygiene, adjustment of clothes before/after, use of napkins or diapers).

0. Requires total assistance
1. Requires partial assistance; does not clean self
2. Requires partial assistance; cleans self independently
4. Uses toilet independently in all tasks but needs adaptive devices or special setting (e.g., bars)
5. Uses toilet independently; does not require adaptive devices or special setting)

SUBTOTAL (0-40)

Mobility (room and toilet)

DATE \ \ \ \ \ \ \

0. Needs assistance in all activities: turning upper body in bed, turning lower body in bed, sitting up in bed, doing push-ups in wheelchair, with or without adaptive devices, but not with electric aids
2. Performs one of the activities without assistance
4. Performs two or three of the activities without assistance
6. Performs all the bed mobility and pressure release activities independently

10. Transfers: bed-wheelchair (locking wheelchair, lifting footrests, removing and adjusting arm rests, transferring, lifting feet).

0. Requires total assistance
1. Needs partial assistance and/or supervision, and/or adaptive devices (e.g., sliding board)
2. Independent (or does not require wheelchair)

11. Transfers: wheelchair-toilet-tub (if uses toilet wheelchair: transfers to and from; if uses regular wheelchair: locking wheelchair, lifting footrests, removing and adjusting armrests, transferring, lifting feet)

0. Requires total assistance
1. Needs partial assistance and/or supervision, and/or adaptive devices (e.g., grab-bars)
2. Independent (or does not require wheelchair)

Mobility (indoors and outdoors, on even surface)

12. Mobility Indoors ☐☐☐☐☐☐

0. Requires total assistance
1. Needs electric wheelchair or partial assistance to operate manual wheelchair
2. Moves independently in manual wheelchair
3. Requires supervision while walking (with or without devices)
4. Walks with a walking frame or crutches (swing)
5. Walks with crutches or two canes (reciprocal walking)
6. Walks with one cane
7. Needs leg orthosis only
8. Walks without walking aids

13. Mobility for Moderate Distances (10-100 meters) ☐☐☐☐☐☐

0. Requires total assistance
1. Needs electric wheelchair or partial assistance to operate manual wheelchair
2. Moves independently in manual wheelchair
3. Requires supervision while walking (with or without devices)
4. Walks with a walking frame or crutches (swing)
5. Walks with crutches or two canes (reciprocal walking)
6. Walks with one cane
7. Needs leg orthosis only
8. Walks without walking aids

14. Mobility Outdoors (more than 100 meters) ☐☐☐☐☐☐

0. Requires total assistance
1. Needs electric wheelchair or partial assistance to operate manual wheelchair
2. Moves independently in manual wheelchair
3. Requires supervision while walking (with or without devices)
4. Walks with a walking frame or crutches (swing)
5. Walks with crutches or two canes (reciprocal waking)
6. Walks with one cane
7. Needs leg orthosis only
8. Walks without walking aids

15. Stair Management ☐☐☐☐☐☐

0. Unable to ascend or descend stairs
1. Ascends and descends at least 3 steps with support or supervision of another person
2. Ascends and descends at least 3 steps with support of handrail and/or crutch or cane
3. Ascends and descends at least 3 steps without any support or supervision

16. Transfers: wheelchair-car (approaching car, locking wheelchair, removing arm- and footrests, transferring to and from car, bringing wheelchair into and out of car) ☐☐☐☐☐☐

0. Requires total assistance
1. Needs partial assistance and/or supervision and/or adaptive devices
2. Transfers independent; does not require adaptive devices (or does not require wheelchair)

17. Transfers: ground-wheelchair ☐☐☐☐☐☐

0. Requires assistance
1. Transfers independent with or without adaptive devices (or does not require wheelchair)

SUBTOTAL (0-40) ☐☐☐☐☐☐

TOTAL SCIM SCORE (0-100) ☐☐☐☐☐☐

Appendix E

脊髓獨立性評定（第3版）（SCIM-Spinal Cord Independence Measure III）

自我照顧(0-20 分)

1. 進 食（切、打開罐裝食物、倒、把食物送進嘴、握住裝液體的杯子）

0 分：需要照顧，胃造瘺術或完全幫助的口部進食）
1 分：需要部分帮助進食和/ 或喝、或穿戴適應性用具
2 分：獨立進食，需要幫助或適應性用具切食物和/ 或倒和/ 或開啟罐裝食物
3 分：獨立進食和喝，不需要幫助或適應性用具

2. 沐 浴（抹肥皂、洗、擦乾身體和頭、操縱水龍頭）

A（上半身）：0 分：完全依賴幫助
1 分：需要部分帮助
2 分：在特殊的環境（橫木或椅子等）下或使用適應性用具獨立洗
3 分：獨立洗；不需要使用適應性用具或特殊的環境（橫木或椅子等，對於健康者是不習慣的）

B（下半身）：0 分：完全依賴
1 分：需要部分帮助
2 分：在特殊的環境下（橫木或椅子等）或使用適應性用具獨立洗
3 分：獨立洗；不需要使用適應性用具或特殊的環境

3. 穿脫衣服（衣服、鞋、永久矯形器、敷料）

A（上半身）：0 分：完全依賴幫助
1 分：需要部分帮助穿脫沒有紐扣、拉鍊、花穗的衣服
2 分：獨立穿脫沒有紐扣、拉鍊、花穗的衣服；需要使用適應性用具或在 特殊的環境下
3 分：獨立穿脫沒有紐扣、拉鍊、花穗的衣服；不需要使用適應性用具或 特殊的環境；僅在穿脫有紐扣、拉鍊、花穗的衣服時需要幫助和適應性用具或特殊的環境
4 分：獨立穿脫任何衣服；不需要使用適應性用具或特殊的環境

B（下半身）：0 分：完全依賴幫助
1 分：需要部分帮助穿脫沒有紐扣、拉鍊的衣服和無鞋帶的鞋
2 分：獨立穿脫沒有紐扣、拉鍊的衣服和無鞋帶的鞋，需要使用適應性用具或在特殊的環境下
3 分：獨立穿脫沒有紐扣、拉鍊的衣服和無鞋帶的鞋；不需要使用適應 性用具或特殊的環境；僅在穿脫有紐扣、拉鍊的衣服和有鞋帶的鞋時需要幫助和適應性用具或特殊的環境
4 分：獨立穿脫任何衣服；不需要使用適應性用具或特殊的環境

4. 修飾（洗手和臉、刷牙、梳頭、刮鬍子、使用化妝品）

0 分：完全依賴
1 分：需要部分幫助
2 分：使用適應性用具獨立進行修飾
3 分：不需要使用適應性用具獨立進行修飾

呼吸和括約肌管理(0-40 分)

5. 呼吸

0 分：需要氣管插管和持續或間斷輔助通氣
2 分：氣管插管下獨自呼吸；需要氧氣和較多的帮助進行咳嗽和處理氣管插管
4 分：氣管插管下獨自呼吸；需要氧氣和較小的帮助進行咳嗽和處理氣管插管
6 分：不需要氣管插管獨立呼吸；需要氧氣、面罩或間斷輔助通氣和較多的幫助進行咳嗽
8 分：不需要氣管插管獨自呼吸；需要較少的帮助或刺激咳嗽
10 分：不需要幫助和輔助設施獨立呼吸

6. 括約肌管理—膀胱

0 分：內置導尿管
3 分：殘餘尿量> 100 ml；無規律的導尿或輔助的間歇導尿
6 分：殘餘尿量< 100 ml 或間歇自我導尿；在使用排尿用具上需要幫助
9 分：間歇自我導尿；使用外部排尿用具；不需要幫助使用排尿用具
11 分：間歇自我導尿；導尿期間能自我控制；不需要使用外部排尿用具
13 分：殘餘尿量< 100 ml；僅需要外部尿排除；不需要幫助排尿
15 分：殘餘尿量< 100 ml；能控制；不需要外部排尿用具

7. 括約肌管理—腸

0 分：腸活動節律紊亂或頻率減少（少於1 次／ 3 d）
5 分：腸活動規律，但需要幫助（如應用栓劑）；很少意外（失禁少於2 次／月）
8 分：規律的腸活動；不需要幫助，很少意外（失禁少於2 次／ 月）
10 分：規律的腸活動；不需要幫助，無意外（無失禁）

8. 使用廁所（會陰部清潔、便前便後衣服的整理、使用衛生紙或尿布）

0 分：完全依賴幫助
1 分：需要部分帮助；不能自我清潔
2 分：需要部分帮助；能自我清潔
4 分：能獨立使用廁所（完成所有的任務),但需要適應性用具和特殊的環境(如橫木)
5 分：能獨立使用廁所完成所有的任務，不需要適應性用具和特殊的環境

移動(室內和廁所內)(0-40 分)

9. 床上移動和預防壓瘡的活動

0 分: 所有活動均需要幫助, 在床上翻上身、下身、坐起、在輪椅上撐起, 需要或不需要適應性用具, 但不需要電動帮助

2 分: 不需要幫助完成上述1 項活動

4 分: 不需要幫助完成上述2-3 項活動

6 分: 獨立進行所有床上活動和減壓活動

10. 床-輪椅轉移 (鎖輪椅、抬起足托、移動和調節臂托、轉移、抬腳)

0 分: 完全依賴

1 分: 需要部分帮助和/ 或監護和/ 或適應性用具 (如滑板)

2 分: 獨立進行 (或不需要輪椅)

11. 輪椅-廁所-浴盆轉移 (如使用廁所輪椅: 轉移來或去; 使用普通輪椅: 鎖輪椅、抬起足托、移動和調節臂托、轉移、抬腳)

0 分: 完全依賴

1 分: 需要部分帮助和/ 或監護和/ 或適應性用具 (抓一橫木)

2 分: 自理 (或不需要輪椅)

12. 室內移動

0 分: 完全依賴

1 分: 需要電動輪椅或部分帮助去操縱手動輪椅

2 分: 在手動輪椅上獨立移動

3 分: 步行 (需要或不需要設施) 時需要監護

4 分: 借助步行架或拐杖步行 (擺動)

5 分: 借助拐杖或兩根手杖步行 (交替步行)

6 分: 借助一根手杖步行

7 分: 僅需要腿的矯形器進行步行

8 分: 不需要幫助進行步行

13. 適度距離的移動 (10-100 m)

0 分: 完全依賴

1 分: 需要電動輪椅或部分帮助去操縱手動輪椅

2 分: 在手動輪椅上獨立移動

3 分: 步行 (需要或不需要設施) 時需要監護

4 分: 借助步行架或拐杖步行 (擺動)

5 分: 借助拐杖或手杖步行 (交替步行)

6 分: 借助一根手杖步行

7 分: 僅需要腿的矯形器進行步行

8 分: 不需要幫助進行步行

14. 室外移動（超過100 m）

0 分：完全依賴
1 分：需要電動輪椅或部分帮助去操縱手動輪椅
2 分：在手動輪椅上獨立移動
3 分：步行（需要或不需要設施）時需要監護
4 分：借助步行架或拐杖步行（擺動）
5 分：借助拐杖或手杖步行（交替步行）
6 分：借助一根手杖步行
7 分：僅需要腿的矯形器進行步行
8 分：不需要幫助進行步行

15. 上下樓梯

0 分：不能上樓或下樓
1 分：在另一人的支持或監護下上下樓梯至少3 級
2 分：借助扶欄的支持和/ 或拐杖或手杖上下樓梯至少3 級
3 分：不需要任何支援和監護上下樓梯至少3 級

16. 轉移：輪椅-汽車間轉移（接近汽車、鎖輪椅、移去臂和足托、汽車與輪椅間的轉移、帶輪椅進出汽車）

0 分：完全依賴
1 分：需要部分帮助和/ 或監護和/ 或適應性用具
2 分：獨自轉移；不需要適應性用具或輪椅

17. 轉移：地面-輪椅間轉移

0 分：需要幫助
1 分：獨自轉移；需要或不需要適應性用具（或不需要輪椅）

總分:0-100 分 __

Appendix F

World Health Organization Quality of Life (WHOQOL-BRIEF) - English version

The following questions ask how you feel about your quality of life, health, or other areas of your life. I will read out each question to you, along with the response options. Please choose the answer that appears most appropriate. If you are unsure about which response to give to a question, the first response you think of is often the best one.

Please keep in mind your standards, hopes, pleasures and concerns. We ask that you think about your life in the last four weeks.

		Very poor	Poor	Neither poor nor good	Good	Very good
1.	How would you rate your quality of life?	1	2 3 4			5

		Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
2.	How satisfied are you with your health	1	2	3	4	5

The following questions ask about how much you have experienced certain things in the last four weeks.

		Not all	A little	A moderate amount	Very much	An extreme amount
3.	To what extent do you feel that physical pain prevent you from doing what you need to do?	5	4	3	2	1
4.	How much do you need any medical treatment to	5	4	3	2	1

	function in your daily life?					
5.	How much do you enjoy life?	1	2	3	4	5
6.	To what extent do you feel your life to be meaningful?	1	2	3	4	5

		Not at all	A little	A moderate amount	Very much	Extremely
7.	How well are you able to concentrate?	1	2	3	4	5
8.	How safe do you feel in your daily life	1	2	3	4	5
9.	How healthy is your physical environment?	1	2	3	4	5

The following questions ask about how completely you experience or were able to do certain thing in the last four weeks.

		Not at all	A little	Moderately	Mostly	Completely
10.	Do you have enough energy for everyday life?	1	2	3	4	5
11.	Are you able to accept your bodily appearance?	1	2	3	4	5
12.	Have you enough money to meet your needs?	1	2	3	4	5
13.	How available to you is the information that you need in your day-to-day life?	1	2	3	4	5
14.	To what extent do you	1	2	3	4	5

	have the opportunity for leisure activities?					

		Very poor	Poor	Neither poor nor good	Good	Very good
15.	How well are you able to get around?	1	2	3	4	5

		Very dissatisfied	Dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
16.	How satisfied are you with your sleep?	1	2	3	4	5
17.	How satisfied are you with your ability to perform your daily living activities?	1	2	3	4	5
18.	How satisfied are you with your capacity for work?	1	2	3	4	5
19.	How satisfied are you with yourself?	1	2	3	4	5
20.	How satisfied are you with your personal relationship?	1	2	3	4	5
21.	How satisfied are you with your sex life?	1	2	3	4	5
22.	How satisfied are you with the support you get from your friends?	1	2	3	4	5
23.	How satisfied are you with the conditions of y our	1	2	3	4	5

	living place?					
24.	How satisfied are you with your access to health services?	1	2	3	4	5
25.	How satisfied are you with your transport?	1	2	3	4	5

The following question refers to how often you have felt or experienced certain things in the last four weeks.

		Never	Seldom	Quite often	Very often	Always
26.	How often do you have negative feeling such as blue mood, despair, anxiety, depression?	5	4	3	2	1

Appendix G

世界衛生組織生存品質測定簡表

（**WHOQOL-BREF-Hong Kong Chinese version**）

以下問題涉及您對生活品質、健康、或生活其他方面的看法。在我讀出每一個問題的同時，請您做出選擇。**請選擇最適當的答案**。如果您暫時不能確定，則頭腦中的第一反應往往是最正確的。
所有問題都請您按照自己的標準、願望或自己的感覺來回答。注意所有問題都是您最近 **4 周內**的情況。

		很差	差	一般	好	很好
1.	您如何評價您的生活品質？	**1**	**2**	**3**	**4**	**5**

		非常不滿意	不滿意	一般	滿意	很滿意
2.	您對自己健康狀況滿意嗎？	**1**	**2**	**3**	**4**	**5**

下列問題是有關您在過去 4 周中經歷某些事情的感覺

		根本沒有	有點	中等	很大	極其
3.	您因軀體疼痛而妨礙您去做需要做的事感到有多煩惱？	**5**	**4**	**3**	**2**	**1**
4.	您對保持日常生活的醫學治療的需求程度有多大？	**5**	**4**	**3**	**2**	**1**
5.	您覺得生活有樂趣嗎？	**1**	**2**	**3**	**4**	**5**
6.	您覺得自己的生活有意義嗎？	**1**	**2**	**3**	**4**	**5**

		根本不	有點	中等	很大	極其
7.	您能集中注意力嗎?	**1**	**2**	**3**	**4**	**5**
8.	日常生活中您感覺安全嗎？	**1**	**2**	**3**	**4**	**5**
9.	您的生活環境對健康好嗎？	**1**	**2**	**3**	**4**	**5**

下列問題有關您在過去 4 周中做某些事情的能力。

		根本沒有	有點	中等	多數有（能）	完全有（能）
10.	您有充沛的精力去應付日常生活嗎？	**1**	**2**	**3**	**4**	**5**
11.	您認爲自己的外形過得去嗎？	**1**	**2**	**3**	**4**	**5**
12.	您有足夠的錢來滿足您的需要嗎?	**1**	**2**	**3**	**4**	**5**
13.	在日常生活中，您需要的資訊都能得到嗎？	**1**	**2**	**3**	**4**	**5**
14.	您有機會進行休閒活動嗎？	**1**	**2**	**3**	**4**	**5**

		很差	差	一般	好	很好
15.	您行動的能力如何?	**1**	**2**	**3**	**4**	**5**

		非常不滿意	不滿意	一般	滿意	很滿意
16.	您對自己的睡眠情況滿意嗎?	**1**	**2**	**3**	**4**	**5**
17.	您對自己做日常生活事情的能力滿意嗎？	**1**	**2**	**3**	**4**	**5**
18.	您對自己的工作能力滿意嗎?	**1**	**2**	**3**	**4**	**5**
19.	您對自己滿意嗎?	**1**	**2**	**3**	**4**	**5**
20.	您對自己的人際關係滿意嗎?	**1**	**2**	**3**	**4**	**5**
21.	您對自己的性生活滿意嗎？	**1**	**2**	**3**	**4**	**5**
22.	您對自己從朋友那裡得到的支持滿意嗎?	**1**	**2**	**3**	**4**	**5**
23.	您對自己居住地的條件滿意嗎?	**1**	**2**	**3**	**4**	**5**

24.	您對您能享受到的衛生保健服務滿意嗎?	**1**	**2**	**3**	**4**	**5**
25.	您對自己的交通情況滿意嗎?	**1**	**2**	**3**	**4**	**5**

下列問題是關於您在過去 4 周中經歷某些事情的頻繁程度。

		從不	很少	有時	經常	總是
26.	您有消極感受嗎？如情緒低 落、絕望、焦慮、憂鬱。	**5**	**4**	**3**	**2**	**1**

Appendix H

Set-up of the purpose-built force platform

The setup consisted of a tailor-made wooden force platform (90 cm x 76 cm) and an adjustable-height screen placed 1.5 m in front of the participants on which the COP was continuously displayed (Figure 2.2). Subjects' COP was measured by 4 load cells (SBDEG, Measurement Specialties Inc., Schaevitz) mounted in the 4 corners of the platform in the metal frame (Figure H.1). The measurement range of the load cells was 40-400 pounds force. All movement data from the force platform was sampled and digitized via a Multifunction Data Acquisition USB (National Instrument NI USB-6009, USA) with an 8-channel analog-to-digital converter at a sample rate of 1000 Hz. It was connected to a computer that was programmed using tailored LabView (version 8.6, National Instruments, USA) software to display and store in real time motion of the COP during the sitting balance tests.

Figure H.1 The load cells are mounted on the metal frame

1. Loading test

Test a. A total of 100 lb deadweight and a 2 kg as spacer were used for the loading test (Figure H.2). Nine positions were loaded which included 4 corners (Figure H.3), 4 edges and the center positions.

Figure H.2 Deadweight and 2 kg spacer in the center position

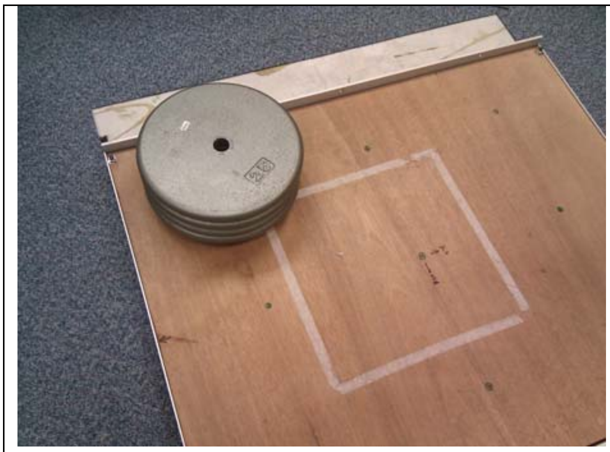


Figure H.3 Deadweight in a corner position

Findings: The total output of force platform was almost the same for all 9 positions. Forces were distributed to the 4 load-cells accordingly, structure affect was not observed (Table H.1).

Table H.1 Table shows the voltage outputs in different positions using 47.37 kg deadweight.

Vout1	**Vout2**	**Vout3**	**Vout4**	**Vout total**	**dead weight position (47.37kg)**
0.981199	1.01244	1.019943	0.982799	3.996381219	Centre
0.297781	0.336788	1.695127	1.655376	3.985072761	edge 23
1.665259	1.695459	0.338371	0.311759	4.010848881	edge 12
0.317901	1.688708	0.325734	1.652809	3.985152363	edge 24
0.296438	0.332629	1.696495	1.668919	3.994480721	edge 34
Vout1	**Vout2**	**Vout3**	**Vout4**	**Vout total**	**dead weight position (47.37kg)**
0.981829	1.01314	1.021489	0.979854	3.996312861	Centre
0.109063	0.538563	0.542604	2.786725	3.976954652	Corner 4
0.509536	0.128041	2.843803	0.505257	3.986636244	Corner 3
2.800053	0.539115	0.53334	0.111058	3.983566592	Corner 1
0.524779	2.820613	0.120335	0.532665	3.998392463	Corner 2

Test b. A total of 45lb x 3 deadweight and a 2 kg as spacer were used for 4 corners positions test.

Findings: The result was similar to the corner tests of Test a (Table H.2).

Table H.2 Table shows the voltage outputs in different positions using 63.25 kg deadweight.

Vout 1	Vout 2	Vout 3	Vout 4	Vout total	dead weight position (63.25kg)
1.334831	1.394669	1.383684	1.320937	5.434122152	Centre
0.143613	0.733933	0.745988	3.774808	5.398341057	Corner 4
0.705115	0.175311	3.802286	0.719221	5.401933097	Corner 3
0.722966	3.826605	0.169495	0.711723	5.430788818	Corner 1
3.769095	0.743107	0.740465	0.158768	5.411435585	Corner 2

2. Drift test

A drift test with 83.67 kg with 30 minutes of loading was performed (Figure H.4). Five second data were taken in every 5 minutes.

Figure H.4 shows the drift test in center position with 83.67 kg

Finding: No apparent drift was observed in the 30 minutes loading period (Figure H.5).

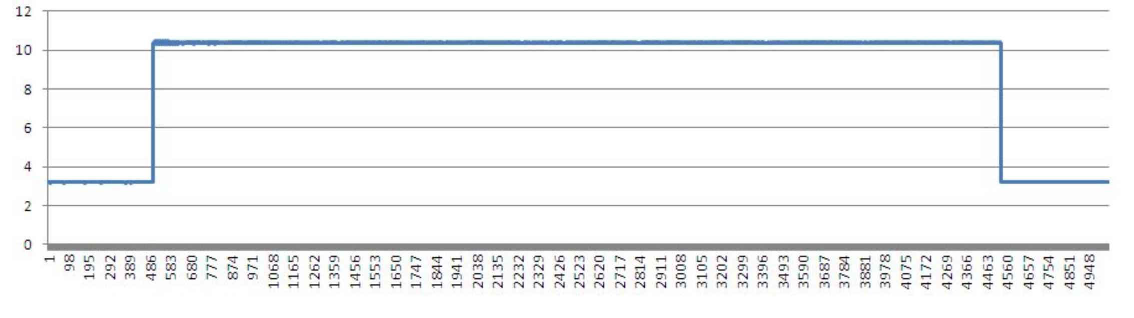


Figure H.5 Shows the voltage outputs during the 5 minutes drift test

3. Linearity step test (a step of 45 lb)

The linearity test was performed with a step of 45 lbs. The loadings were 0 lbs, 45 lbs, 90 lbs, 135 lbs and 180 lbs, respectively.

Findings: The result was shown in Figure H.6 and linearity was acceptable for the present project.

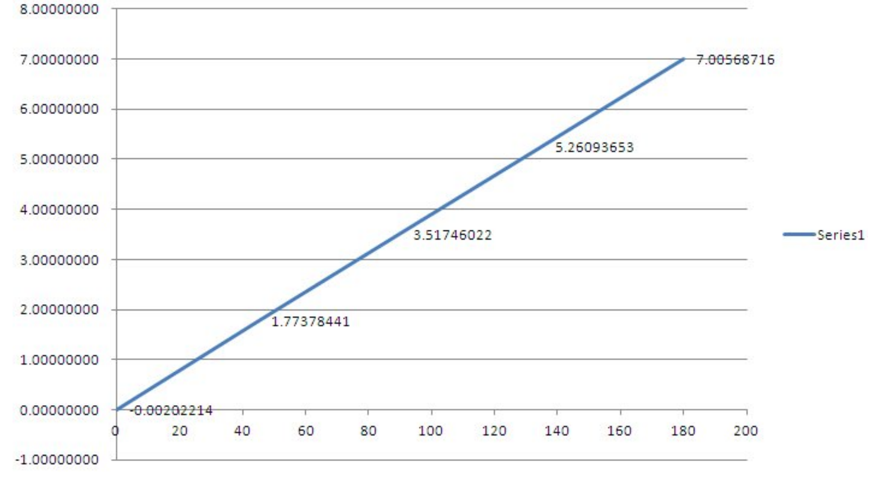


Figure H.6 Shows the linearity test result

4. Position cross check test

The 45 lb x 3 and 2 kg spacer was loaded to 9 positions with distance of 258 mm in x-axis and 305 mm in y-axis of the force platform. The measured distances by the load cells were then compared.

Findings: The result was found to be good and the error was within 1.x%.