INFLUENCE OF STRENGTH ON BALANCE IN OLDER ADULTS

A Thesis Presented for the Degree of Master of Applied Science

by

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September, 1994

DECLARATION

I hereby certify that the work embodied in this thesis is the result of original research and has not been submitted for a higher degree to any other University or Institution.

Shaohua Liu

[redacted]

September, 1994

To my parents.

ACKNOWLEDGMENTS

I would like to thank my supervisor Professor David Lawson for his encouragement and guidance throughout the period of my candidature.

I would like to extend my gratitude to Associate Professors Terry Seedsman and Terry Roberts for their advice and continual support.

The technical assistance and other advice of Tim Wrigley over the past two years have been greatly appreciated.

To the subjects who participated in the studies of this thesis I extend my sincere thanks and appreciation.

I would like to thank Ms. Patra Santry for her proof reading of this thesis. To Mr. Nigel Sherlock I wish to express my gratitude and appreciation for offering me some useful references.

Finally, I would like to thank my wife, Feng, for her love, support, encouragement and patience.

ABSTRACT

Many problems related to balance, strength and physical training for the elderly population remain unresolved. The purpose of this work was to investigate the influence of knee strength on static balance in the elderly and to determine specific physical training programs which could affect strength and balance. The correlation between balance and strength for the elderly population was studied and compared with that of the young population. The contribution of appropriately designed physical exercises to improve balance and strength for the elderly was also evaluated.

Not all the balance and strength testing apparatus which can be used for young persons are appropriate for the elderly population evaluated in this study. AMTI multi-component force platform and Biodex dynamometer systems were found to be good balance and strength testing apparatus for the elderly. The sensitivity and reliability of the force platform and Biodex dynamometer were evaluated with respect to body sway forces (F_x, F_y, F_z) and force moments (M_x, M_y) for balance and for knee extension-flexion at the angular velocities of $60°·s^{-1}$ and $180°·s^{-1}$ respectively. The intraclass correlation coefficient (ICC) for strength of r = 0.95 and for balance of r' = 0.63 indicated a high degree of reliability for these measurements.

In order to make a comparison between knee strength and static balance of the elderly population, a parallel investigation on knee strength and static balance for both an elderly and a young population was included. The elderly group (n = 25) was aged from 56 to 78 year while the young group (n = 25) was aged from 18 to 25 years. A one way ANOVA (at the level of α =.05) analysis of right knee extensions at angular velocities $60°·s^{-1}$ (RE 60), was

$F(1,48) = 85.6$, ($p < .001$). The ANOVA analysis of ML body sway force on the right legged stance (RF_X) was $F(1,48) = 54.6$, ($p < .001$), indicating that there were significant differences between the young and the aged in balance and strength.

The relationships between static balance and knee strength in the elderly and the young were investigated. Pearson product moment (PPM) coefficients were employed to determine correlations between strength and balance. The largest PPM coefficient were $r = -0.79$ and $r' = -0.29$ (right side, extensions at $60°\cdot s^{-1}$ vs SD of F_X) respectively for the aged and the young, indicating that there was a significant correlation between knee strength and static balance for the elderly whereas for the young group such a correlation was not significant.

Physical training or exercise improves physiological capacities. An appropriate ten week physical training program including Tai Chi and other exercises was designed for the elderly. An improvement on lower extremity strength and stability of single legged stance of the training elderly group (n=14) was measured after training. Comparisons were made between pre-training and post-training in the training group and between the training and the control groups (n=11) post-training. In the training group, the strength improvement at the high angular velocity was ~30% whereas at the low velocity it was ~20%. The body sway forces declined ~15-20% for the training group. No significant changes in strength and balance were found in the control group.

PUBLICATIONS RELATED TO THIS THESIS

1 S. H. Liu, D. Lawson, and T. Wrigley. (1993). Relationship Between Strength and Balance in the Young and the Elderly Populations. *National Annual Scientific Conference in Sports Medicine.* (Melbourne). October 26-31. (Abstract).

2 S. H. Liu, D. Lawson. (1995). Power Spectrum of the Fast Fourier Transform for Measurement of Standing Balance. *Australian Journal of Science and Medicine in Sport.* 27:3 62-67.

3 S. H. Liu and D. Lawson. (1994). Effect of Tai Chi Chuan to Balance and Strength in the Elderly. *The Asian Conference on Comparative Physical Education and Sport.* (Shanghai). December 1-5. (Abstract).

4 S. H. Liu and D. Lawson. (1994). Correlation Between Balance and Knee Strength in the Elderly. (in preparation).

5 S. H. Liu, and D. Lawson. (1994). Comparison of Balance and Strength in the Aged and the Young Populations. (in preparation).

6 S. H. Liu and D. Lawson. (1994). Effects of Tai Chi Exercise on Knee Strength and Static Balance in the Elderly. (in preparation).

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CHAPTER 1

INTRODUCTION

This thesis was concerned with studying aspects of the elderly population of the community; the relationship between their strength and their capacity to maintain balance; the potentials of appropriate physical training in improving their knee strength and postural control. It further considered the possibilities of transferring the existing measurement techniques, particularly those used for a young group, to an elderly population. In this Chapter, a historical overview on the study of the elderly is given. The problems of the elderly and the reasons and purposes of this project are presented. The definitions of some related terms involved in the investigation are also given.

1.1 HISTORICAL OVERVIEW

The world is ageing. There is little doubt that the elderly comprise the fastest growing age group in our society especially in the industrialised countries (American Medical Association Council on Scientific Affairs, 1984; Davis, Neuhuas, Moritz and Segal, 1992). As the percentage of the aged population grows in the world, the problems related with the aged become increasingly important in our society. Fundamental organic phenomena which occur in a living body gradually change during ageing inhibits physical functions and requires extensive investigations on health and its effect on a fulfilling life for the elderly.

The United Nations convened a World Assembly on Ageing which resulted in the adoption of the Vienna International Plan of Acting on Ageing in 1982. There has been a strong emphasis on the development aspects of ageing (Seedsman, 1993). As a result of the unprecedented success in health promotion and maintenance, more and more individuals are approaching the upper limits of the human life span. The age that individuals can be expected to reach is about 77 for females and 71 for males (Spirduso, 1988). In this era, individuals tend to spend more years in their aged life than have previous generations.

A dramatic way of describing the demographic age changes is to compare the number of individuals who were over 65 in 1900 with the number of those who will be over 65 in the year 2000. For example, in Australia from the information supplied by the Australian Bureau of Statistics (Christophidis, 1988), the aged population was 4% of the total population in 1900 but the percentage of the aged will be 12% in the year of 2000. In China (People's Daily, September 19, 1993), the population of the elderly (over 60 year of age) was only about 3% in 1900, but it is predicted to be 130 million in the year 2000 which will be about 10% of the population. In the United States (Spirduso, 1988), only 4% of the population was over 65 years of age in 1900, whereas in the year 2000 it is predicted that 32 million (15-20% of the population) people will be over 65 year of age. Figure 1.1 provides a description of the aged populations in Australia, China, and the United States in the years 1900 and 2000 respectively.

Over the last few decades, researchers have focused considerable attention on medical and health factors in attempting to improve the quality of the life of the community. Better housing and sanitation, less crowding, more clean air, greater food supply and improved nutrition have contributed to increased longevity. Antibiotics, vaccines and enhanced blood pressure control techniques have reduced the number of premature deaths. Improved surgical procedures have extended the lives of millions (Spirduso, 1988). Health education has been extremely effective in reducing smoking, improving dietary habits and controlling stress. Adult exercise programs have helped to make people more physically fit.

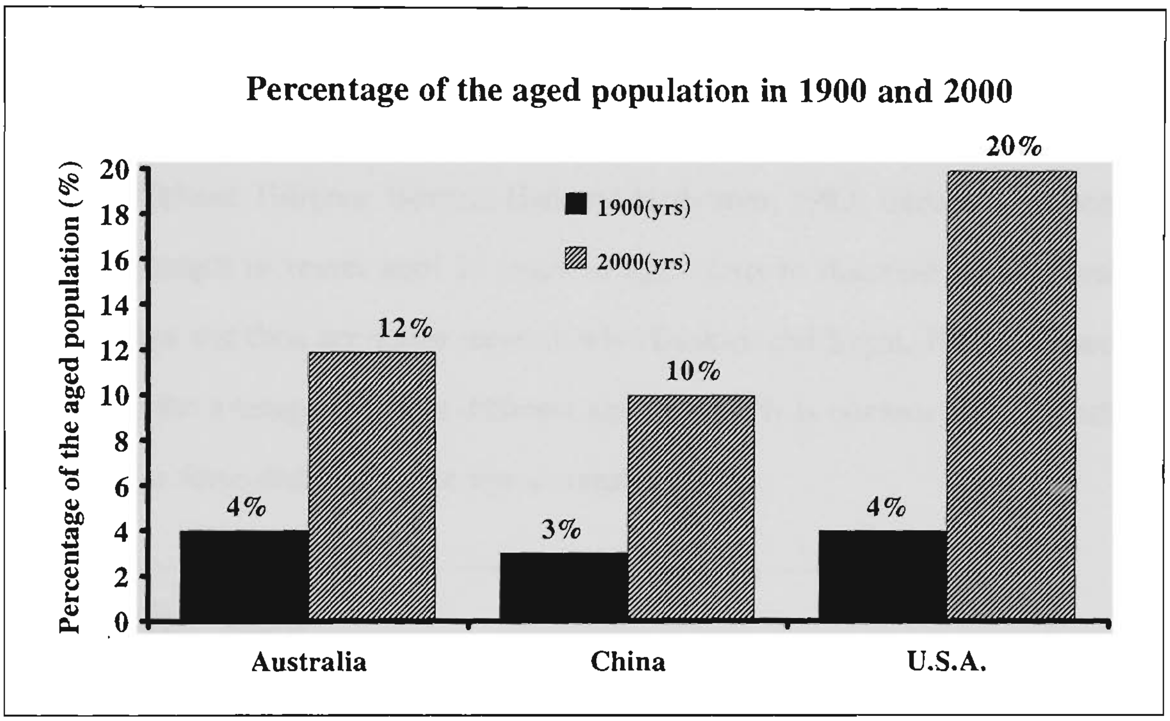


Figure 1.1 Percentage of the aged populations in Australia, China and the United States in the years of 1900 and 2000.

However, the quality of life is as important as longevity. Bonus years at the end of a well-planned and healthful life would provide an individual with an enriched additional period of time. People should be encouraged to achieve an average health expectancy rather than an average life expectancy.

Systematic and intelligent physical activity programs have great potential to enhance health in the aged (Spirduso, 1988). However, it is still not clear if there is a ceiling of benefit, or the rate at which it can be attained, or the cost of physical activity to the individual. Over the last decade, many investigations have indicated that the field of physical activity (Spirduso and Eckert, 1988) addresses the major issues associated with the contributions of health, fitness and motor skill to successful ageing.

Changes in muscle strength during growth and ageing have been a matter of sporadic scientific interest since Quetelet's (1836) pioneering study more than a century ago. Several investigators have established that there is a clear relationship between strength and age (Larsson, Grimby and Karlsson, 1979; Hamrin, Eklund, Hillgren, Borges, Hall and Hellstrom, 1982; Ekdahl and Broman, 1992). Strength increases until 25 years of age, starts to decrease rapidly until 55 years of age and then decreases more slowly (Buskirk and Segal, 1988). Figure 1.2 compares the average forces in different age groups. It is obvious that, for adults, the average force declines as the age increases.

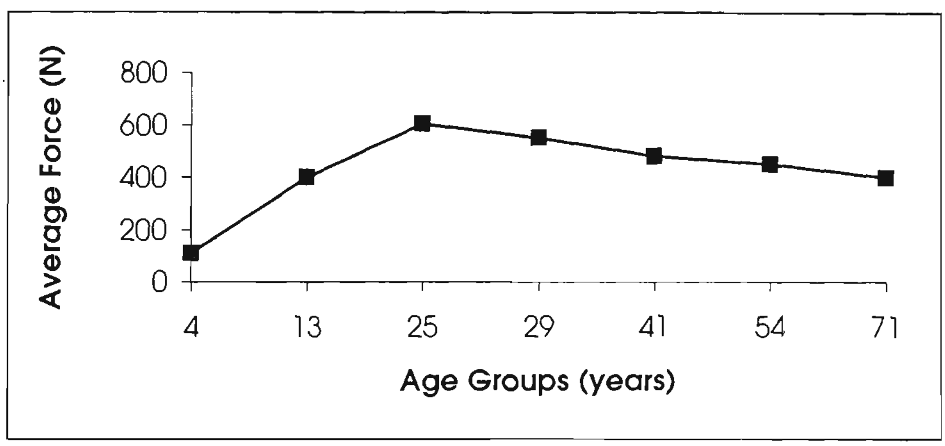


Figure 1.2 Comparisons of the average forces of skeletal muscle in different age groups.
The Data adopted from Table 4 of Buskirk and Segal (1988).

Age-related changes of the quadriceps femur muscle in healthy males were studied by Larsson et al. (1979). In their measurements, both isometric and isokinetic strengths increased up to 30 years of age, remained nearly unchanged until 50 years of age and then gradually decreased as the age increased. It has been postulated that a relationship exists between strength and balance. However, a review of the available literature, revealed limited direct research on the relationship between strength and balance.

On the other hand, investigations of postural balance and the ability to control the orientation of human body in space continues to challenge scientists (Lichtenstein, Burger, Shialds and Shiavi, 1990; Vandervoort, Kramer and Wharram, 1990; Williams and Isaac, 1991). The ability to maintain the body balance is of importance to the elderly since loss of balance is one of the important factors which cause falls in the elderly. Wild, Nayak and Isaacs (1981) have established that people who are prone to falling have a far higher risk of death than non-fallers (see Figure 1.3). Early in the 1960s, Sheldon (1960) studied the causes of falls in the elderly. Overstall, Exton-Smith, Imms and Johnson (1977) pointed out that many accidental falls were apparently caused by impaired balance.

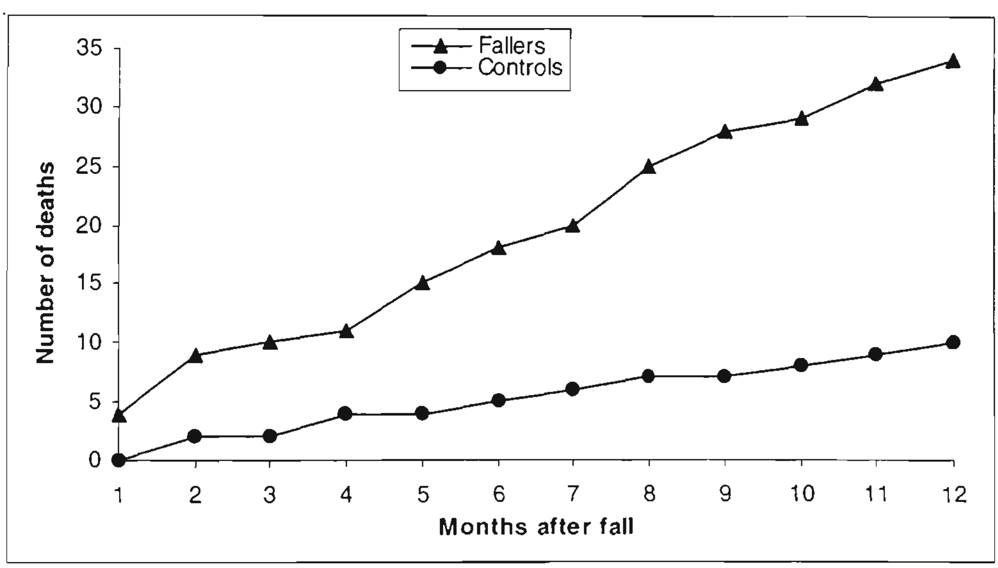


Figure 1.3 Cumulative mortality in 125 fallers and 125 controls in 12 months after index falls. The data were adopted from Wild et al. (1981).

Falls are a manifestation of a failing neuromuscular system in the elderly (Wolfson, Whipple, Amerman, Kaplan and Kleinberg, 1985). About one-third of older persons are at risk of falling and suffering serious injury. Falls in the elderly often have a more serious consequence than similar events in the young population. The ability of young people to regain balance rapidly and avoid an actual fall is in strong contrast to what happens to the elderly, although both young and old people may trip over a kerb stone or lose their balance while descending stairs. It is apparent that balance appears to be more easily threatened in elderly individuals than in young adults. As age increases, more and more balance problems occur, resulting in destructive falls, which are one of the major injury problems in the older population. It has been shown (Prudhjam and Evans, 1981) that the incidence of falls increases virtually exponentially with age so that falls frequently happen to the elderly.

Although the multiple reasons why older people fall are not yet well understood, it is clear that impairment in balance and gait are not normal aspects of ageing (Wolfson, Whipple, Amerman and Tobin, 1990). More quantitatively, a recent study of the value of systematic post-fall patient and environmental assessment in an institutional setting showed that a mean of 3.3 factors contributed to each fall: i.e., muscle weakness 62%, gait or balance 53%, postural hypotension 41%, and environmental hazards 33% (Rubenstein and Jones, 1992).

It has been suggested that central nervous system control of postural muscle tone and balance diminishes with ageing and postural responses become less effective, and this mechanism could be exacerbated by changes of the strength of muscle in the aged (Hasselkus and Shambes, 1975). Balance is contributed from external and internal forces which act on the body. The internal forces, are the strengths or tensions generated by muscle contractions that act to oppose external forces acting outside the body.

1.2 PRESENTATION OF THE PROBLEM WITH RESPECT TO THE ELDERLY

Recent research has pointed out that falls occur in about one-third of persons aged over sixty-five, and the risk of falling and suffering serious injury increases substantially with age (Vellas and Christen 1992). Though many factors could indicate falls there is always the one common element, loss of control of body balance.

Although more and more research attention has been devoted to the problems of the elderly, effective methodologies or techniques for delineation of the difficulties of the elderly have not been well developed. Previous investigations concerning the elderly have concentrated on the measurement and improvement of the body postural balance or body sway or on knee (or ankle) strength with certain physical exercises (or medical treatments). Not enough investigations for the elderly have focused on the correlations between postural balance and knee strength, and on the design of physical training programs which can improve muscle strength and hopefully the ability of controlling body balance. Additionally, most of the current available methods and/or techniques used for the examination of balance and strength in the elderly are those adopted from young people. Some of these techniques are not appropriate for older adults. Hence, there is a need to examine the techniques of measurement for the strength and balance in the elderly as well as to investigate the relationship between these factors.

1.3 PURPOSES OF THIS INVESTIGATION

The intent of this investigation was to determine the relationship between balance and strength in the aged and to develop a suitable program of physical exercises which improved lower leg strength and balance ability. The specific objectives of this study were to answer the following questions associated with aged people:

- What type of balance and strength parameters are the most appropriate to define these abilities of the elderly?
- Are specific measurements for static balance and knee strength reliable?
- What are the strength and balance differences between young and aged people?
- Are strength and balance correlated in the elderly?
- Can strength training programs begun late in life have beneficial effects?
- Can strength training programs improve balance?

In order to answer these questions the following research methodology was used.

- Measurements of strength and balance for both the young group and the aged group were determined.
- A ten-week training program aimed at increasing muscular strength and endurance for one of the two (control and training) aged groups was implemented.

- A retest for both strength and balance of the two aged groups (training and control) was undertaken after training.

1.4 LIMITATIONS AND DELIMITATIONS

A major limitation in this study was the nature of the balance test used in the elderly population. In order to prevent falls and to ensure a non threatening task for the elderly, a one-legged static stance with eyes open was used in the balance measurements.

Variation in the initial location of the subject on the force platform could cause errors and hence can be a limitation on the study of balance (see Chapter Three).

Because the subjects were aged, some performances on the force platform and the Biodex dynamometer could be inappropriate. Consequently, the parameters from one legged stance (single stance for both legs) with eyes open were employed as balance variables. For the knee strength, the Biodex dynamometer was used to measure the knee flexion and extension at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$, respectively.

Although every attempt was made to recruit and utilise subjects with no apparent balance disorders this could not be guaranteed.

1.5 DEFINITION OF TERMS

For the purpose of this thesis the following definitions were utilised.

The aged, elderly, older adults --- people aged over 55 years.

Balance --- the "body equilibrium or stability." (Webster's New World Dictionary, 1970). That is, balance is an ability of maintaining the centre of body gravity in the support area.

Equilibrium --- equilibrium is defined as equality between opposing forces. [Webster's New World Dictionary (1970)]. This means that a body is at its equilibrium if the sum of all forces on the body is zero.

Stability --- stability is "the state or quality of being fixed, the steadiness" [Webster's New World Dictionary (1970)]. Stability is the ability of maintaining equilibrium.

Static Balance --- Static balance tests require the maintenance of a single position of the body (Bass, 1939).

Dynamic Balance --- Dynamic balance is the maintenance of equilibrium while the body is in motion (Bass, 1939).

Strength --- Strength can be defined as the peak force or torque developed during a maximal voluntary contraction under a given set of conditions. It can also be defined as the maximum force that can be exerted against an immovable resistance by a single contraction (Müller, 1970).

Isokinetic Strength --- The term isokinetic means constant velocity during the strength test. Both concentric and eccentric contraction may be isokinetic.

Isometric Strength --- Isometric strength is measured as the peak force or torque produced by maximal voluntary isometric contraction, when the muscle remains at the same length.

Torque --- Torque indicates the force rotation about an axis. Because isokinetic devices have lever arms connected to strain gauges, torque is produced from the angular motion. Torque is the term used to indicate muscular strength (Caiozzo, Perrine, and Edgerton, 1981).

Muscle Training --- Muscle training is defined as any endeavour, deliberate or incidental, to improve or to maintain muscle function.

CHAPTER 2

LITERATURE SURVEY

Previous research on body balance, muscle strength, exercises (or physical training) and their relationships for the elderly is briefly reviewed in this Chapter. In particular, this Chapter focuses on the measurements of static balance and lower extremity strength, the effect of exercises on balance and strength, as well as the relationship between balance and strength in the elderly.

2.1. HUMAN BALANCE AND ITS MEASUREMENTS

As defined in section §1.5, balance is the "body equilibrium or stability." (Webster's New World Dictionary, 1970). Balance is a performance involving different components and mechanisms. It requires that the centre of body gravity never deviates beyond the support area (Hufschmidt, Dichgans, Mauritz and Hufschmidt, 1980). A complex array of factors will effect balance performance and abilities since modeling or measurement of human balance is not a simple task.

It has been suggested that balance can be modelled using combinations of different balance tasks with various characteristics of different difficulty. Of those balance measuring techniques developed, the force platform has been found to be a useful and reliable method.

2.1.1 Components and Mechanisms of Balance

The study of balance itself is not particularly new. An early study on balance (Bass, 1939) developed reliable parameters of balance measurements and indicated that there were two major types of balance tasks: static balance and dynamic balance. Some fifteen years later, Cumbee (1954) showed that the balancing of an object was unrelated to balancing the body. Studies of the structure of physical fitness by Fleishman (1962, 1963) identified two balance factors: a "gross body equilibrium" factor and a "balance with visual cues" factor. Meanwhile, Ismail and Cowell (1961) grouped two balance factors in their study of "motor aptitude" in young boys. A significant difference between the ability of balance on a one inch high beam and balance on a beam four feet above the floor indicated that balance might have both neuromuscular and psychological components (Wyrick, 1969).

Further evidence of the important nature of the tasks in defining balance ability were provided by Hesechen (1962), who administered two beam-walking tests, a stabilometer test and a measure of static balance (Bass stick test) to college age students and by Drowatzky and Zuccato (1967), who studied a variety of balance performances of junior high school girls. Tasks included stork stand, diver's stand, stick balance, balance beam walk, sidewards leap and Bass's stepping stone test. It was found that a relationship existed between measures of static and dynamic balance and both mental age and achievement scores of seventh-grade girls. These experiments inferred that development of balance ability and cognitive behaviours in young children were totally unrelated, and the tenuous relationship reported in some literature might, at best, represent their possible mutual dependence upon a common underlying set of central nervous system mechanisms. If this was the case, it was unlikely that, at a behavioural level, significant relationships between balance and cognitive development were ever likely to be forthcoming.

Katzan (1974) summarised the available behavioural research on balance. He also identified six major components involved in the performance of the majority of balance tasks.

1. Elevation: Is the performer asked to balance on the floor or on an object?
2. Vision: Is the performer asked to balance with eyes open or eyes closed?
3. Stability: Is the performer asked to balance on a stationary or moving object?
4. Number of Limbs: Is the performer asked to balance on one or two feet or multiple body parts?
5. Body Position: Is the performer asked to balance in an upright or a bent position?
6. Kind of Locomotion: Is the performer asked to maintain balance while walking, jumping or hopping?

According to Katzan (1974), evidence indicated that, rather than being a single, unitary ability, balance is better defined as a set of specific characteristics or components that describe the task to be performed.

Regardless of how balance ability is defined or described, it involves the successful integration of a number of anatomical and neurophysiological systems (Williams, Fischer and Tritschler, 1983). Behaviourally, balance is largely a matter of the proper relationship between the body's centre of body gravity and its supporting base. Neurophysiologically, it requires complex interactions among vestibular, proprioceptive, visual and motor systems. Biomechanically, balance is the ability to minimise the deviations of the body sway forces from the equilibrium.

Duncan, Chandler, Studenski, Hughers and Prescott (1993) summarised the physiological components of balance: sensory (vibration, proprioception, vision, vestibular), effector (ankle, knee, hip strength, range of motion) and central processing (response time to perturbations). Ensirnd, Nevitt, Yunis, Canley, Seeley, Fox and Cummings (1994) concluded that a combination of many factors, including medical conditions, health habits, physiological components, physical inactivity and direct measures of neuromuscular performance are associated with impaired balance in older women. The efficient functioning of all the mechanisms of the systems is a prerequisite to the individual's ability to judge when the body is balanced.

2.1.2 Possible Factors Affecting Balance

Since the mechanism of balance is complicated, the factors which could affect balance. Examples include personal difference intelligence, gender, age and physiological components. Among these factors, gender and age differences in balance performance have been investigated. At a behavioural level, balance seems to be improved from pre-school through adolescent years. Age differences are significant for some balance tasks but not for others. In general, balance performance was improved with increasing age from 3 to 19 years (DeOreo and Wade, 1971; DeOreo, 1975). Since age-related changes in balance performance are gradual, year to year performance differences were usually small and insignificant for adults (Bachman, 1961). However, there could be significant year to year changes in balance performance for young children (Seils, 1951; Figura, Cama, Capranica and Guidetti, 1991). There is an improvement in static balance in the 6-10 year range with a non-linear relationship between age and ability to balance (Figura et al, 1991). Postural performance improved significantly between the ages of 6 and 8, whereas between the ages of 8 and 10 the improvement was smaller. Winterhalter (1974) reported significant age differences on 16 different balance tasks performed by six, eight, and ten-year-old children respectively. Although the specific nature of age-related changes in balance performance is still not absolutely clear, there is evidence of improvement with increasing age of children (Bachman, 1961; Williams et al., 1983).

There is little or no obvious difference between gender (Figura et al., 1991). However, if the nature of the task is considered there is a tendency for girls to demonstrate better performance than boys on static balance tasks (Bachman, 1961; DeOreo, 1971; Winterhalter, 1974).

Very few balance investigations which appeared in the literature before 1980 concerned the older population. As the problems of the elderly have become more and more evident, scientists have started to investigate the health and physical fitness of older people. For example, the academic paper collections edited by Vellas, Toupet, Rubenstein, Albarede and Christen (1992) and by Spirduso and Eckert (1988) have investigated falls, balance and physical activity levels of the elderly. While these papers have focused their attention on the elderly, there has been little published work which attempts to explain the relationships between function (balance) and physiological or anatomical profile. However, Duncan et al. (1993), assessed the relationship between physiological components of balance and mobility in elderly men without significant disease. The assessment included mobility functions (6 minute walk, mobility skills, reach, 10 feet walking time) and physiological components of balance: sensory effects and central processing time.

It was suggested that the decline in physical function may be explained by the accumulation of deficits across multiple domains than by any single specific impairment.

2.1.3 Models and Measurements of Human Balance

How to model or quantify body balance is a difficult but important task. Perhaps the most meaningful way to describe the development of balance is to focus on the relationships among the balance tasks. Katzan (1974) suggested that balance tasks and the associated level of difficulty can be analysed by looking at the number and nature of task characteristics. Task characteristics might include such aspects as body movement, stability of the supporting base, use of vision, body position, body elevation, number of support limbs, and nature of the supporting surface. Some theoretical models of testing balance ability associated with the level of difficulty have been summarised in Table 2.1.

Existing balance measures have a variety of limitations, particularly for the elderly. Some of the balance models listed in Table 2.1, such as one-footed stance with eyes closed (the tasks beyond level II), are difficult to perform, even by healthy older individuals. Those models are sensitive but not very specific for clinical balance problems. In general, dynamic balance measures are superior to static tasks. Accepted dynamic balance tests include Wolfson's postural stress test (Wolfson, Whipple, Amerman and Kleinberg, 1986), the platform perturbation test (Nashner, Black and Wall, 1982), functional reach test (Duncan, Weiner, Chandler and Studenski, 1990) and centre of pressure excursion (COPE) (Dichgans, Mauritz, Allum and Brandt, 1976). However, dynamic balance tests are often too difficult and dangerous for the elderly, therefore static balance tests become more popular for the aged. On the static balance measurement, Winter, Patla, Frank and Walt (1990) highlighted the processing and interpretation of centre of pressure signal and the predictive abilities of static balance tests. A level II static balance task has been adopted for the balance test of the elderly (Patla, Frank and Winter, 1990) in the same project.

Table 2.1 Theoretical models of balance ability[a)]

Level of Difficulty	Examples	Characteristics
I	Sit, stance	Static position
		Stable base
		Vision used
II	Walk, run	Dynamic position
		Stable Base
		Vision used
	Two-foot stance:	Static position
	eyes open	Unstable base
		No vision
	One-foot stance:	Static position
	eyes open	Unstable base
		Vision used
III	Beam walk	Dynamic position
		Unstable base
		No vision
	One-foot stance:	Static position
	eyes closed	Unstable base
		No vision
IV	Beam walk:	Dynamic position
	eyes closed	Unstable base
		No vision

a) **Adopted from Williams et al. (1983).**

The question arises as to the parameters which could be used to describe static balance most appropriately? A popular and useful technique of balance measurement is to record the displacement (or deviations from the equilibrium) of body sway forces or the centre of the pressure (Hellebrandt, 1938; Bensel and Dzendolet, 1968; Kapteyn, 1972; Dichgans et al., 1976). Fernie, Gryfe, Holliday and Lewellyn (1982) measured the speed of postural sway and counted the number of falls listed in the nursing home records. Brocklehurst, Robertson and James-Groom (1982) measured vision, vestibular function, vibration and position sense in the lower extremities of independent, mobile, elderly individuals, which showed that sway was increased in fallers. Simple sway parameters were defined and measured by Kapteyn (1972), Hirashawa (1973), Njiokiktjien and van Parys (1976) and Taguchi, Jijiman and Suzuki (1978). Hufschmidt et al. (1980) quantitatively defined the body sway parameters including sway path, mean amplitudes of sway, mean sway frequency and sway area.

Balance or postural stability parameters can be measured by a variety of techniques. Another important task is how to record or to measure the balance parameters. Methods and techniques to evaluate balance have been developed for several decades, and efforts for further development are still being undertaken. The early mechanical devices of balance recording technique can be traced back to the work of Edwards (1941), who tested the static equilibrium of the human body. About three decades later, Montserrat (1969) detected the photographic registration of the sway path of a light attached to the head of the subject since sway indicates postural instability. Moreover, Uchytil (1962) and Lee and Lishman (1975) measured the distance-dependent capacity between a subject and an external metallic reference.

Research on the elderly on the description and comprehension of balance impairment has led to the development of several methods of assessing balance. For example, Brocklehurst et al. (1982) studied the clinical correlates of body sway of the aged and found that the amplitude of body sway increases with age. Cordo and Nashner (1982) and Inglin and Woollacott (1988) have investigated postural adjustments. The effects of stance have been studied in different ways by Nashner et al. (1982). Nayak, Gabel, Simons and Isaacs (1982) and Visser (1983) evaluated gait and balance in the elderly. Of these balance measurement techniques used, the force platform technique has been found to be one of the most useful and reliable balance measurement tools for the elderly.

Force platforms have been widely accepted in evaluating human standing postural control of balance since the 1970s (Stribley, Albers, Tourtellotte and Cockrell, 1974; Murray, Seireg and Sepic, 1975; Black, O'Leary, Wall and Furman, 1977; Clark and Zernicke 1981; Lucy and Hayes, 1985; Horak, 1987; Woollacott and Shumway-Cook, 1990). More recently, Van Emmerik, Spragve and Newell (1993) employed a force platform to quantify the postural sway patterns in tardive dyskinesia (TD). It was concluded from their work that assessments of postural centre of pressure profile orientation and variability may be useful indicators for investigating TD, especially in distinguishing between developmental disability and TD. On the other hand, because of their safety and reliability, force platforms have been employed in balance studies for the elderly. For example, based on the force platform, Lichtenstein, Shields, Shiari and Burger (1989) constructed a pilot controlled trial to demonstrate the feasibility of testing an exercise program as a means of improving balance in aged women. Judge, Lindsey, Underwood and Winsemius (1993) used a force platform to demonstrate the improvements in single stance postural sway in older women with exercise training. Whipple, Wolfson, Derby, Single and Tobin (1993) studied the effects of visual inputs while standing on an unstable surface.

The measurement of balance on the force platform is a continuing challenge since the physical variables which can model postural control are not unique. In 1983, Kaptey, Bles, Njiokiktjien, Koddle, Massen and Mol established the standardisation of the force platform. Goldie, Bach and Evans (1989) evaluated the reliability and validity of the force platform for the standard deviation (SD) of forces (F_x, F_y, F_z) and centre of pressure (A_x, A_y). The latter reported that test-retest correlation coefficients were significant ($r \geq 0.31$) especially for the forces. As Goldie et al. (1989) summarised, most previous work employed body sway force (F_x, F_y, F_z) and the centre of pressure (A_x, A_y) parameters to quantify body balance.

Methods and parameters used to evaluate human balance ability have never reached an optimal level. This becomes a driving force to seek good quantitative models for human stability. Hufschmidt et al. (1980) noticed that some parameters such as sway path (SP), mean amplitude of sway (MA) and mean sway frequency (MF) are also good parameters for quantifying balance. Lichtenstein et al. (1989) observed that fallers had a greater area of sway (AS) than none fallers. More recently, Hasan, Lichtenstein and Shiavi (1990) demonstrated a method for modifying area representation of the centre of pressure excursions of the effects of loss of balance. Motriuk and Nigg (1990) provided a useful technique to normalise and average the centre of pressure paths. These parameters can be employed to model balance since they address different aspects of postural control. It seems to be a tendency that an intensive analysis of balance may need a combination analysis using these parameters rather than just body sway forces and centre of pressure.

A major limitation in understanding human balance is the ability to accurately quantify the amount of physical activity or work performed by human subjects (Sun and Hill 1993). Some twenty-five years ago, people started to seek other methods and parameters rather than forces and centre of pressure to improve quantification of balance in order to understand in detail the motion of a human subject during the process of a test. Bensel and Dzendolet (1968) and Powell and Dzendolet (1984) introduced the idea of spectral analysis called "power spectral density" (PSD) technique to model balance. In this technique, a frequency range was introduced as a physical variable to quantify balance. Seidel and Brauer (1977) employed spectral analysis to model body balance and showed that the power density spectral analysis of a stabilogram is a suitable method for evaluating a biological effect of vibration. Two years later, Miyano and Sadoyama (1979) found that the shape of the spectral density, which was calculated using the fast Fourier transform (FFT) algorithm, does not change and its amplitude is directly proportional to the motor unit firing frequency and recruitment, if the contraction level is not too high.

The frequency and amplitude parameters obtained from a force platform were employed by Era and Heikkinen (1985) in both the lateral (ML) and antero-posterior (AP) directions to measure the balance differences among different age-groups. It showed a clear age-dependent increase in the extent of postural sway in their tests. In 1989, Pyykkö, Alto, Starck and Ishizaki studied postural stability using a force platform by introducing external vibrations with different frequencies. They found that the vibration-induced activation of the muscles was presumably derived by activation of stretch-sensitive secondary endings of muscle spindles that control postural ability. It was concluded in their later study (Pyykkö et al., 1993) that horizontal perturbations of the support surface lead to postural instability that is frequency-dependent. Geurts, Nienhuis and Mulder (1993) introduced some other parameters, such as the root mean square (RMS) amplitude, peak-to-peak amplitude and mean frequency to quantify postural control. In their recent work, Nakagawa, Ohashi, Watanab and Mizukoshi (1993) studied postural control via 100-Hz vibrator stimulation with respect to area, length and power spectra according to the method of FFT.

The previous work suggested that spectral or frequency analysis can be used as an alternative and complementary method to the force or centre of pressure parameters to model human balance. However, spectral or frequency analysis in previous studies either did not employ a force platform technique or the FFT method was used to analyse the spectrum of external vibrations which were introduced as perturbations but not the motion of human postural control. In order to understand the detailed instability (or movement) of a human subject in a given interval during the process of a test, Liu, Lawson and Wrigley (1994) investigated the fast Fourier transform (FFT) spectra from the force platform output.

Fourier transform has long been a principle analytical tool in science and technology and it is a frequency domain representation of a function via a transformation. Fast Fourier transform (FFT) is a computational algorithm and reduces the required computing time. Figure 2.1 gives a comparison of the FFT power spectrum of an object with the spectra of a human subject with one legged stance and two legged stance. (Liu et al., 1994).

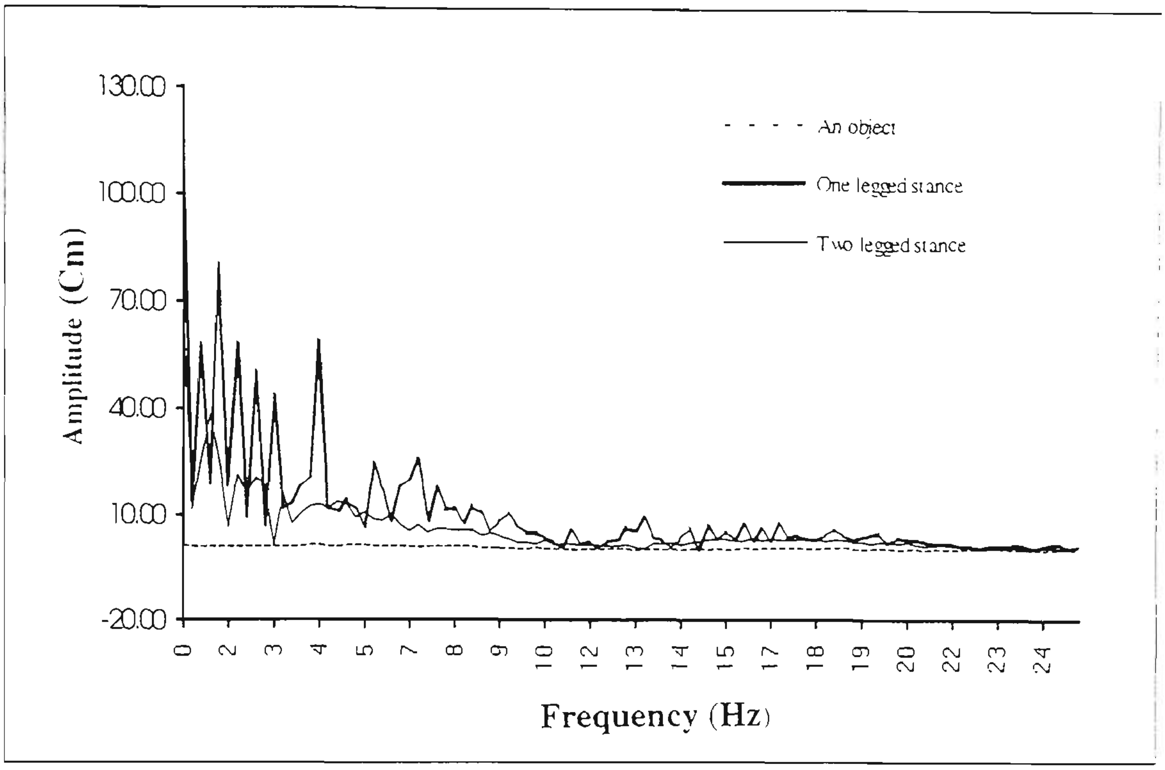


Figure 2.1 The FFT power spectrum of an object and a subject.

Compared with the existing parameters such as the SD of body sway forces and the centre of pressure, the FFT spectral analysis provides integral information over the period of the test. From the FFT spectrum, it is possible to detect when the most unstable perturbation occurs, how the subject oscillates during the test and how the amplitude of the oscillation decays as the frequency increases. The simply recorded SD of the forces provides information on general stability during the test but does not provide information on how the stability of a subject changes or when the most unstable movement appears in the test. That is, the SD of the forces does not provide details of the changes of stability during a test.

It is difficult to describe and to quantify balance in a repeatable and valid manner. Most of the balance measures have tended to be descriptive or are implemented as pass/fail indicators of this parameter. There does not appear to be a universally recognised gold standard for assessing postural steadiness nor are there any comprehensive norms for the comparative evaluation of this parameter. Even though the body sway forces and centre of pressure parameters are currently the most popular parameters used in evaluating balance, it can be predicted that an individual power spectrum derived from the FFT will provide a more intensive understanding of balance and also provide a means whereby standards can be developed to enable better interpretation of the resultant scores. However, the FFT balance analysis is still under development and more research effort is required before the FFT balance analysis becomes a widely accepted method. Hence, this thesis focuses on the body sway forces in analysing human balance.

2.2 LEG STRENGTH AND ITS MEASUREMENT

Muscle strength is an important factor affecting human balance. There exist a variety of methods and techniques of measuring muscle strength. The most popular muscle strength measuring technique is to use isometric and isokinetic dynamometers. In this section, various muscle strength measuring techniques are reviewed with an emphasis on the currently available dynamometers. Factors which influence strength measurements and the reliability of the dynamometers, especially the Biodex dynamometers, are discussed.

2.2.1 Muscle Strength and Its Classification

Muscle strength can be defined as the maximum force (torque) that can be exerted against an immovable resistance by a single contraction (Müller, 1970). In this study strength refers only to the rotational component, or torque produced by the muscle and not to the total tension generated by the muscle.

Muscles act in a complicated manner on the skeletal levers. The forces exerted by an extremity upon an external object is always the sum of component forces exerted by combinations of muscles (Müller, 1970). Therefore, muscle strength is usually not related to individual muscles but to groups of muscles which contract together to achieve extension, flexion or rotation of the part around the joint. What is generally measured is the torque at a certain position of a joint. Muscular concentration at a certain force and frequency is necessary to maintain the existing muscle strength (Müller, 1970). If this stimulus for maintenance of strength is surpassed, strength increases with an increase in the mass of the contractile fibres and also a change in efficiency of the innovation pattern of fibres.

Muscular work as one of the strength parameters is best defined and measured as the output of mechanical energy; or, externally applied force multiplied by the displacement of the force applied. Muscle power refers only to the rate of the muscular work output and should therefore always be expressed in units of work (energy) per unit of time (Sapega and Drillings, 1983). Muscular endurance is most commonly measured as one of the following:

1) the number of times that a repetitive submaximum contraction or task can be properly performed at a constant rate;

2) the ability of a muscle to delay the onset or to minimise the manifestations of fatigue (a decrease in force, work, and power output over time), or both, during repetitive maximum contractions.

Modes of muscle contraction are classified by the nature of the applied load or by the velocity and direction of change in the length of the muscle, or both (Sapega, 1990). Movements involve muscular contractions that can be classified as concentric, eccentric or isometric (Skinner, Tipton and Vailas, 1982). Isotonic strength occurs only in the physiology laboratory when an isolated muscle preparation moves a fixed load, thus maintaining a constant muscular tension regardless of the length of the muscle. Isokinetic strength is the ability to provide, at a constant velocity of angular movement, an accommodating resistance to meet the subject's changing capacity for maximum external-force output with changing positions of the joint. Isometric strength is the peak force or torque produced by maximal voluntary contraction. In isometric contraction, a muscle pulls against an immovable resistance and thus does not change in length. Concentric contractions, regardless of the specific loading characteristics, involve shortening of muscle. In eccentric contractions the force that is developed by a muscle is overcome by an opposing force such that the muscle merely provides active resistance as the opposing force stretches it to a more lengthened position (Sapega, 1990).

2.2.2 Measurement of Muscle Strength and Its Reliability

The terminology used to define modes of testing in the evaluation of muscular performance has often been ambiguous. In the first half of the twentieth century, the devastating muscular dysfunction produced by the poliomyelitis virus forced orthopaedic surgeons to develop better methods of testing muscular strength (Sapega, 1990). Semi-quantitative methods of grading manual tests and, ultimately, quantitative testing devices to assess variations in muscular strength over a specified time-frame were developed by pioneers such as Lovett and Martin (1916), Lowman (1927), Kendall and Kendall (1939), Schmier (1945) and Newman (1949). However, manual muscle-testing is largely a "lost art" (Sapega, 1990), the ability of today's computerised muscle-dynamometry systems to generate quantitative data has surpassed the average clinician's ability to interpret the results properly.

Testing strength by determining the ability to lift free weights against gravity has traditionally been referred to as isotonic testing, apparently in reference to the unchanging external load (Laird and Rozier, 1979). Others include cable or chain-and cam weight-lifting machines; hydraulic resistance devices; computerised robotics dynamometers that actively modulate changes in resistance or resistive movement velocity, or both; and passive isokinetic dynamometers that simply limit the speed of resistive movement. Any mode of dynamic testing that maintains or limits the velocity of body movement at a pre-selected, constant level should be referred to as evaluation of isokinetic muscular performance (Sapega, 1990).

There have been a number of methods available for the testing of strength. Manual muscle testing was initially considered to be useful in monitoring muscular function in patients who had paralytic involvement. However, the method failed to detect the weakness associated with femoral neuropathy caused by operative tourniquets when strength deficits were quantitatively determined to be less than 50% (Krebs, 1989). In an attempt to make manual muscle-testing more objective, Newman (1949) introduced the use of a small, portable, hand-held dynamometer. Since then several hand-held dynamometers have been introduced (Saraniti, Gleim, Melvin and Nicholas, 1980; Marino, Nicholas, Gleim, Rosenthal and Nicholas, 1982; Byl, Richards and Asturias, 1988) and have been demonstrated to have a satisfactory degree of accuracy (Bohannon, 1986); good intra-rater reliability (Bohannon, 1986; Byl et al., 1988; Stuberg and Metcai, 1988), and fair or good inter-rater reliability (Byl et al., 1988; Silverman, Rodriquez and Agre, 1989).

Dynamic variable-resistance weight-lifting, often inappropriately referred to as isotonic testing (Laird and Rozier, 1979), includes the lifting of free weights as well as weights that are coupled to elaborate weight-lifting machines. Correlations between values for repetition maximum strength and both isometric and isokinetic measures of strength are usually significant, but often not enough to be of practical use in predicting the latter values within an acceptable accuracy (Mendler, 1963; Hackney and Gilliam, 1984; Nunn and Mayhew, 1988). The method is time-consuming (Sapega, 1990) and the difficulty in controlling the forces of inertia that develop with subtle differences in techniques of lifting makes methods of weight-lifting inherently imprecise when applied to the study of muscular performance in humans (Knapik, Wright, Mawdsley and Braun 1983).

Most quantitative techniques for testing isometric muscular strength originally employed simply cable tensiometer systems (Schmier, 1945; Clarke, 1954; Beasley, 1956). Later studies (Scudder, 1980; Knapik and Romose, 1980; Knapik et al. 1983; Otis and Godbold, 1983) have yielded higher correlation coefficients between isometric and dynamic isokinetic strength than were previously observed (Osternig, Bates and James, 1977). Measurement of isometric strength bears a stronger predictive relationship with human functional capacity than has been previously believed (Sapega, 1990). However, it has the disadvantage of being limited to measurements of strength, and higher absolute muscle and joint forces are produced during testing than with dynamic tests of moderate or high speed. The isometric cable tensiometer is a useful, relatively inexpensive and accurate mode of testing muscular strength. Improved devices for isometric testing with the capability of automatic correlation for gravity and elaborate methods of stabilisation of the body have recently become available (Jone, Pollock, Graves, Fulton, Baldwin and Cirulli, 1988).

Dynamic isokinetic testing became available in the 1970's and dominated evaluation of muscular performance in the 1980's. Currently, a variety of isokinetic dynamometers are commercially available. Table 2.2 lists some currently available strength testing dynamometers. These devices generate the computerised measurements that combine parameters relating to force, work, power and endurance. A graphic display is often available. Studies of most major commercial dynamometer systems have shown that they are intrinsically accurate in their measurement of torque.

Table 2.2 Some currently available strength testing dynamometers[a].

Name	Isometric	Isotonic	Isokinetic Concentric	Isokinetic Eccentric	Velocity Range ($°s^{-1}$)	Torque Limit (N·m)
Ariel	Yes	Yes	Yes	-	0-900 / 1-1200	1350 / 2500
Biodex	Yes	-	Yes	Yes	0-450	880
Cybex	Yes	-	Yes	-	0-300	490
Dynatrac	-	Yes	-	-	-	-
Hydra-Fitness	-	-	Yes	-	-	-
Kin/Com	Yes	Yes	Yes	Yes	0-210	840
Lido Digital	Yes	-	Yes	-	0-400	540
Lido Active	Yes	Yes	Yes	Yes	0-400	540
Merac	Yes	Yes	Yes	-	0-500	678

a) Data are adopted from Sale (1991).

Dynamometer systems have good or excellent test and retest reliability, particularly after proper instruction and familiarisation of the subject with the testing procedures (Barbee and Landts, 1984; Moroz and Sale, 1985; Farrell and Richards, 1986; Aitkens, Lord, Bernauer and McCrory, 1987; Lord, Aitkens, McCrory and Bernauer, 1987; Bemben, Massey, Bemben, Misner and Boileau, 1990; Harding, Black, Bruulsema, Maxwell and Stratford, 1988; Reitz, Rowinski and Davies, 1988; Karnofel, Wilkinson and Lentil, 1989). Computerised dynamometer systems offer not only isokinetic testing but also additional modes that do not hold velocity of movements constant during dynamic testing (Sapega, 1990). However, little evidence supports the claim that dynamic isokinetic testing is superior to simple static testing of strength for the prediction of functional capacity in humans, and it is unlikely that any one variation of dynamic testing will be found to be superior to another. It is possible that the ideal clinical testing mode will prove to be the one that is simple, safe, accurate and reliable.

Several recent studies have assessed the test reliability of various protocols using a Biodex isokinetic dynamometer (Klopfer and Greij, 1988; Wilk Johnson and Levine, 1988; Montgomery, Douglass and Deuter, 1989; Feiring, Ellenbecker and Derscheid, 1990). However, two of the reliability indices (Klopfer and Greij, 1988; Wilk et al., 1988) were evaluated using the Pearson product moment (PPM) correlation, which is an inappropriate method of assessing test-retest reliability of motor skill or muscle performance measurements (Feldt and McKee, 1958; Kroll, 1967). Because the PPM correlation is an evaluation of association between two different measures, PPM is not an evaluation of agreement between repeated measures of the same variable (Kroll, 1967). Instead, the test-retest reliability estimates of knee strength using the Biodex dynamometer should be evaluated using the intraclass correlation coefficient (ICC).

In their evaluation of the reliability of the Biodex dynamometer, Montgomery et al. (1989) and Feiring et al. (1990) have reported estimates ranging from 0.83 to 0.97 for extension peak torque and from 0.58 to 0.98 for flexion peak torque respectively over a variety of angular velocities. A recent test-retest reliability using the Biodex dynamometer with knee isokinetic knee extension and flexion peak torque measurements has been published by McCleary and Anderson (1992).

Table 2.3 The ICC coefficients for six trials over 3 days of knee extension and flexion at velocity of 60°s^{-1}[a)]

Day	Condition	Trials					
		1	2	3	4	5	6
1	Extension	0.88	0.91	0.92	0.93	0.93	0.93
	Flexion	0.88	0.90	0.90	0.90	0.91	0.91
2	Extension	0.94	0.95	0.96	0.96	0.96	0.97
	Flexion	0.94	0.94	0.95	0.95	0.95	0.95
3	Extension	0.96	0.97	0.97	0.97	0.97	0.97
	Flexion	0.96	0.96	0.96	0.97	0.97	0.98

a) Data are from McCleary and Anderson (1992).

The ICC test-retest reliability estimates (McCleary and Anderson, 1992) have good agreement with the previous studies (Montgomery et al., 1989; Feiring et al., 1990) for peak torque over a range of angular velocities indicating that the tests on the Biodex dynamometer are highly reproducible.

2.2.3 Factors Influencing Muscle Strength

Muscle strength is a complex phenomenon to characterise due to its wide range of normal variability and the fact that strength is affected by many factors, such as sex, age, test position, type of contraction, as well as the test technique factors.

With any given method, say a dynamometer, attention to detail and standardisation of techniques of testing is the most effective means of ensuring test and retest reliability. The validity of a test, which is the ability of the test to assess the specific function, is also influenced by the techniques of testing. Standardisation and positioning of the body are critical factors affecting both reliability and the validating of tests of muscular performance. Schmier (1945) and Beasley (1956) recognised early that the true strength of a muscle cannot be assessed unless its origin is sufficiently stabilised to allow it to contract maximally against its insertion. Quantitative testing of muscular performance can also be affected by variations in velocity of test movements (Figoni, Christ and Massey, 1988; Prietto and Caiozzo, 1989), gravitational forces (Winter, Wells and Orr, 1981) instruction and familiarity of the subject with the testing procedures (Schenck and Forward, 1965), inertial forces during dynamic test movements (Sapega, Nicholas, Sokolow and Saraniti, 1982; Baltzopoulos and Brodie, 1989), calibration of the dynamometer (Rothstein, Lamb and Mayhew, 1987), damping of the signal from the transducer (Sapega et al., 1982; Sinacore, Rothstein and Delitto, 1983), adjustments of input lever-arm (Otis and Gould, 1986), special dynamometer accessories to minimise joint shear (Epler, Nawoczenski and Englehardt, 1988), time of day (McGarvey, Morrey, Askew and An, 1984), and even subject-induced or ambient noise (Ikai and Steinhaus, 1961).

The study of changes in muscle strength during growth and ageing started more than a century ago (Quetelet, 1836). Most studies on muscle strength have described a decline in isometric strength with age (Reijs, 1921; Ufland, 1933; Fisher and Birren, 1974). Some studies (Shephard, 1969) on muscle strength with age have shown a slow or imperceptible decrease from the twenties to the forties and then an accelerated decline. However, leg strength has been found to decline more rapidly with age than other muscle measures such as handgrip strength (Simonson, 1947). Asmussen and Heebøll-Nielsen (1961) investigated strength performance with age in different groups of muscles. The peak values of isometric strength in the knee extension muscles, calculated from the best-fitting smoothed curve was found at approximately 35 years of age. A more recent study (Larsson et al. 1979) where peak value from curvilinear regressions, of isometric and dynamic strengths were shifted to approximately 33 years of age is in good agreement with the previous study.

Leg strength is one of the important factors which affect body sway. Muscle strength around the knee declines more rapidly with increasing age than other groups of muscles (Simonson, 1947). Asmussen and Heebøll-Nielsen (1961) and Cuddigan (1973) studied the isometric knee muscle strength at a fixed knee joint position of 90 degrees of subjects up to 69 years of age. Murray, Baldwin and Gardner (1977) added to this information by evaluating maximum isometric torque of the knee flexor and extensor muscles in three other knee joint positions for men aged 20 to 65 years of age. In their investigation of the isometric and isokinetic contractions of knee strength, Murray, Gardner, Mollinger and Sepic (1980) found that the mean maximum isokinetic torque was significantly less than the mean maximum isometric torque for each joint position ($p < 0.01$). The magnitude of this difference varied with the joint position. Larger differences between maximum isometric and isokinetic torque values occurred at the more flexed angle (60 degree) for extensor muscle torque and at the more extended angle (30 degree) for flexor muscle torque. Moreover, the mean maximum torque values were highest for the youngest group and the lowest for the oldest group for both muscle groups and both types of muscle contraction.

Knowledge of the complex physiological processes that accompany ageing is still fragmentary. Some studies on knee muscle strength have shown the decline of the knee flexor and extensor muscles with advanced age and have emphasised the importance of using age-related standards of strength for evaluating the performance of the aged. Using different approaches and methodologies to investigate the deficits in motor performance associated with ageing requires intensive investigation.

Since ageing is characterised by a decreased adaptation to the repeated stimulation of acute exercise and so many other changes occur at the same time, it is usually impossible to isolate the effect of ageing on such a complex variable as muscular performance (Skinner et al., 1982). Numerous studies have demonstrated a reduction in muscle strength with age (Asmussen and Heebøll-Nielsen 1961; Åstrand and Rodahl, 1977; Howald, 1985). The atrophy and resulting loss of strength are not uniform throughout the body. Liemohn (1975) found a greater reduction in strength in muscles of the lower limbs, a finding corroborated by the account of atrophy present in the leg muscles of the elderly (Tomlinson, Walton and Reibseiz, 1969). Figure 2.2 reports the effect of age on strength performance.

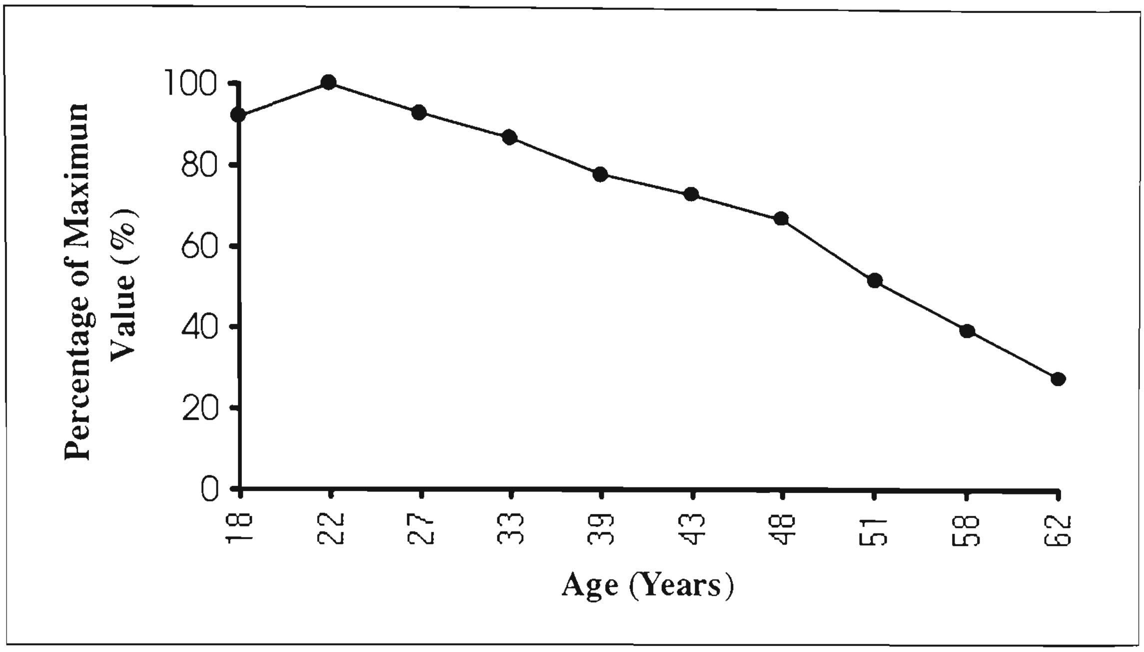


Figure 2.2 Muscle strength as a function of ageing. [Data adopted from Tomlinson et al., (1969).]

2.3 STRENGTH AND BALANCE ABILITY IMPROVEMENT OF THE ELDERLY BY TRAINING

Exercise is a form of physiological stimulation which requires the adaptation of many organ systems and complex regulatory procedures (Skinner et al. 1982). Örlander and Aniansson (1980) found that the ability to exercise can be increased by physical training at almost any age. The improvements can be markedly different if the degree of difficulty of the exercise performances are different (Johnson, 1972). The effects of exercise on strength and aerobic capacity are usually hypothesised as the most important contribution to disability and fall risk (Buchner, Cress, Wagner and Lateur, 1992).

2.3.1 Strength Improvement by Training

A Bureau of the Census publication in 1984, a special Supplement on Ageing (SOA), was designed to collect information about physical limitations as well as other health related and social information. This qualitative research indicated that the subjective difficulty of performance increased with age, as did the percent age of those unable to perform the respective task. People who were employed were less likely than retired people to have difficulty with any given task.

The functional capacity of muscle tissue, like that of other organs of the body, increases if used and decreases if unused (Müller, 1970). There is strong consensus that exercise can improve aerobic capacity and strength in the elderly. A recent review of the literature edited by Vellas et al. (1992) found over twenty studies showing that 3-12 months of aerobic exercise improve aerobic capacity in this group by 5-20% (Buchner et al., 1992). A few months of strengthening exercise has produced a wide range of improvement in strength (5-200%), probably mainly because exercise intensity and methods of measuring strength have varied among studies. Most of the studies of exercise have focused on strength improvement (e.g., Aniansson, Rundgren and Sperling, 1980; Danneskiold-Samoes, Kofod, Munter, Grimby, Schnohr and Jensen, 1984; Bassey, Bendall and Peason, 1988; Bendall, Bassey and Pearson, 1989; Verbrugge, Lepkowski and Imanaka, 1989; Fiatarone, Marks, Ryan, Meredith, Lipsitz and Evans, 1990; Lord, Aitkens, McCrory and Bernauer, 1992). Fewer studies have concentrated on the aerobic capacity and functional status (Cunningham, Rechnitzer, Pearce and Donner, 1982). In their recent review (Buchner et al., 1992) located about ten studies, utilising mostly non-randomised trials that provided evidence that exercise improves functional status.

Exercise-induced improvements in young people have been confirmed for many years (Leighton, 1964; Gardner, 1966 and Wickstrom, 1969). The elderly have been described as generally satisfied with their physical fitness, yet they underestimate their ability to exercise (Conrad, 1983). Similarly, McAvoy (1979) found that among those 65 and older, the barrier to regular recreational exercise was their perceived lack of physical ability. Sidney and Shephard (1977) observed that the physical fitness of elderly city dwellers was average or below average, but they perceived themselves as having adequate physical activity. It has been commonly reported that regular resistance exercises increased strength in the elderly (Chapman, Swezey and de Vries, 1970; Moritani, Nakamura and Kanetaka, 1989). Hettinger (1961) reviewed the studies on males and females aged from 6 to 65 years old with respect to their strength development with regular exercise. It was concluded that by the sixth decade men and women were roughly equal in ability and could gain strength at the rate of 30 to 40% of that demonstrated by 20-30 years old men. Barry, Steinmatz and Page (1966) reported that older men and women who engaged in a 3 month callisthenic and cycle ergometer program demonstrated significant increase in power as measured by a vertical jump. Moritani et al. (1989) suggested that older men gain strength largely through recruitment of more motor units, whereas younger men gain strength through muscle hypertrophy. In their research, Larsson (1982) and Aniansson and Gustavsson (1981) suggested that older men can achieve muscle hypertrophy with regular resistance exercises.

It is generally accepted that older individuals who exercise regularly have larger fibres which are important to strength performance than their untrained contemporaries (Hartley, Mason, Hogan, Jones, Kotchen, Mougey, Werry, Pennington and Richketts, 1972). However, training does not prevent the loss of fibres. This may partly explain why Hettinger (1961) found a decreased ability of older people to increase their strength with training.

Different exercises can contribute to different types of strength. For example, activities such as running, swimming, bicycling, rowing and free exercises are predominantly the result of concentric or eccentric contractions. Pushing, holding or "tension" activities are essentially isometric in character (Skinner et al., 1982). However, most movements are the combinations of isometric and isotonic contractions (Scheuer and Tipton, 1977; Tipton and Scheuer, 1977).

Exercise can be classified into two distinctive types: acute and chronic. In acute exercise, changes occur during the single work bout. It is best quantified by its energy requirement and the source of the energy. High-intensity, short-duration exercise is primarily covered by the anaerobic energy stores within the body, while prolonged, moderate exercise is associated with aerobic energy process mechanisms (Åstrand and Rodahl, 1977). In chronic exercise (training), there are adaptations occurring as a result of repeated bouts of acute exercises. As the result of chronic exercises, people tend to become more physically fit. Johnson (1972) investigated the concentric and eccentric muscle improvement after training. It was shown from their studies that training with either eccentric or concentric muscle contractions produced significant gains in strength over an eight-week training period (Johnson, Adamczyk, Tennøe and Strømme (1976). Neither training procedure was found to be superior to the other, nor were week-to-week changes in strength from concentric muscle training essentially different from those of eccentric muscle training. Figure 2.3 presents the improvement of concentric and eccentric strengths with training.

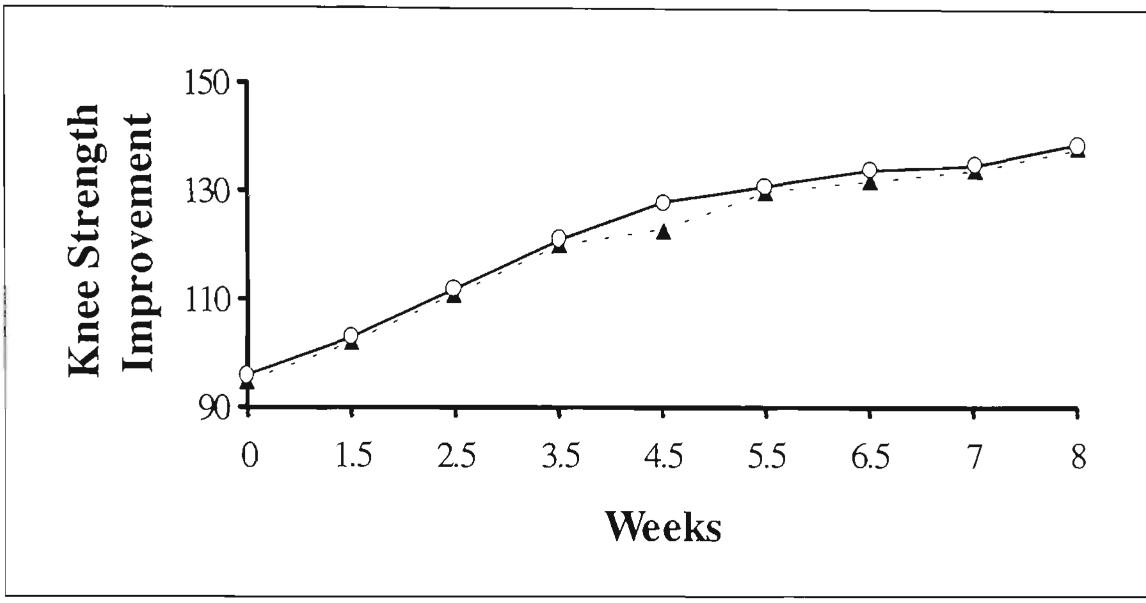


Figure 2.3 Comparison of the improvement of mean concentric strength (dash line) and eccentric strength (solid line) of knee extension-flexion by training (Johnson et al., 1976).

2.3.2 Balance Improvement by Training

Improvements in balance by training usually is not as apparent as that in strength. Conflicting results were presented by different researchers until late 1980s. It is however in general agreement that physical training does improve balance ability for the elderly. Changes with age involving higher levels of integration on such complex motor function as balance, reaction time and neuromuscular coordination are difficult to elucidate due to a lack of precise information (Skinner, Balnidi and Gardner, 1990). Table 2.4 summarises the effects of ageing and training on motor performances.

Table 2.4 The effects of ageing and training a).

Variable	Ageing	Training
Strength	-	+
Speed	-	+
Power	-	+
Muscular endurance:		
Light exercise (less than 20% maximal strength)	0	0
Moderate-heavy exercise	-	+
Flexibility	-	+
Balance	-	+
Reaction time	-	+ ?
Reflex time	-	+
Neuromuscular coordination:		
Fine motor skills	-?	+ 0
Gross motor skills	-	+
Mechanical efficiency	0 or -	0 or +

a) Motor performance, data adopted from Table II of Skinner et al. (1990). Where - = decrease or slower; + = increase or faster; ? = questionable or unknown effect and 0 = no effect.

The effect of exercise on balance for the elderly was unclear and results from different studies in the elderly were in conflict in the 1980s. For example, Aniansson and Gustavsson (1981) used a relatively short-term, low-intensity training program and found no changes. In a non controlled study of the effects of a ten week exercise program, Basset, McClamrock and Schmelzer (1982) found no significant changes in balance. Crilly, Willems, Trenholm, Hayes and Pelaquerriere-Richardson (1989) reported that at the end of a 12 week exercise program aimed at increasing postural stability for fifty elder female subjects (aged 72-92), there was no improvement in postural sway. These results conflicted with a number of other investigations with respect to improvement in strength and balance. Some of the results may be due to the limitations in the research design. For example, Denis, Chatard, Dormois, Linossier, Geyssant and Lacour (1986) measured capillary density for young and old subjects and found that there were no increases in muscle capillarization after endurance training. A potential shortcoming of the Denis et al. study was that many of the subjects had previously been training and therefore, the capacity for further skeletal muscle adoptions may have been limited (Rogers and Evans, 1993).

However, there is strong evidence that exercise improves balance (Lord et al., 1996). Exercise is a form of physiological stimulation which requires the adaptation of many organ systems and complex regulatory procedures (Skinner et al., 1982). Örlander and Aniansson (1980) found that the exercise ability can be increased by physical training at almost any age. Posner, Gorman, Windsor, Larsen, Bleiman, Shaw, Rosenberg and Knebl (1992) reported that upper-body strength of people in their 70s can be increased by about 20% after six months of training. It has been shown (Wolfson, Whipple, Judge, Amerman, Derby and King, 1993) that short term exposure to altered sensory input or destabilising platform movement results in significant improvement in sway control and inhibition of inappropriate motor responses, resulting in improved balance during repetitive testing. They reported (Wolfson et al., 1993) that balance training alone, or strength training alone will each be capable of significantly improving balance, gait, and functional mobility, and that a combined program of balance and strength training will be more effective than either approach alone. Brown and Holloszy

(1993) provided additional evidence that older adults are able to improve their functional capacity in response to exercise training.

The improvements can be markedly different if the degree of difficulty of the exercise performances are different (Johnson, 1972). For example, at the end of a six week wobble board exercise training program (Balogun, Olokungbemi and Kuforigi, 1992), the knee extensor and knee flexor muscle isometric force of young subjects had significantly increased ($p < 0.05$) by 56.3% and 58.6% respectively. Balance performance for the eyes open and eyes closed condition increased ($p < 0.05$) by 201.2% and 58.8% respectively. In the review of Buchner, Beresford, Larson, LaCroix and Wagner (1992) summarised from about 20 studies that a few months of strengthening exercise produces a wide range of improvement (5-200%) in strength. The variations of improvement are probably due to the differences in the training program designed, the exercise intensity and strength measurement methods used among the studies.

The sedentary nature of many elderly subjects has led to the speculation that this is a case of cause and effect, and activity would therefore be of benefit in balance and secondly in reducing falls (Overstall, 1980; Isaacs, 1985). Vanfraechem and Vanfraechem (1977) in a non controlled study found that a 10-week exercise program for sedentary institutionalised subjects did benefit their balance on one foot. Stones, Kozma and Stones (1987) claimed a significant improvement in balance (on one foot, eyes open) in a longitudinal study of subjects who enrolled in a formal exercise program. Myers and Hamilton (1985) evaluated the Canadian Red Cross Society's Fun and Fitness programs for the elderly and found the amount of home exercise a good predictor of balance. Winstein, Gardner, Mcneal, Barto and Nicholson (1989) designed a specific feedback device to train subjects in order to improve their standing balance. The device provided dynamic visual information about relative weight distribution over the paretic and non paretic limb. Subjects who trained with the feedback device showed significantly improved static standing symmetry than did subjects who did not receive augmented feedback.

Not all types of physical exercises are suitable to the elderly. Some, such as fast running and gymnastics, can be utilised only for young people or extremely physically fit older people. Participation in sports and organised group activities may motivate the elderly person to continue an exercise program on a life long basis. However, the exercise possibilities in such everyday activities as walking, climbing stairs, and gardening often do not provide sufficient physiological stress for the purpose of physical fitness. Moreover, the weakness or stiffness of key postural muscles can cause much of the disability observed in the elderly (Goertzen, Serfass, Sopko and Leon, 1984).

Training should be designed to start at each person's level of strength, balance and proceed gradually to strengthen weak muscles as well as balance disabilities. The type, intensity, duration and frequency of the exercise program will be based on such factors as the older person's health, estimated physical capability, physical activity interest and competence, and the exercise or recreational facilities available. To this end, Tai Chi should provide a good modality for the improvement of both strength and balance, because Tai Chi movement is directed by thought and by strength, and involves all the muscles and joints of the limbs and trunk. It was independently hypothesised in this research (research proposal, 1991) that a combined Tai Chi training program could improve the lower extremity strength and standing balance of the elderly population, although there was no enough scientific research to support such a hypotheses when this proposed project begun in 1991. Recently, Tai Chi has drawn research attention in the training program for the elderly in this field. Wolf, Kutner, Green and McNeely (1993) introduced Tai Chi as the exercise program to improve balance of the elderly. In their study, a condensation of 108 Tai Chi forms into 10 that emphasise movement components often restricted or absent with ageing was utilised. A home-base Tai Chi program was employed in the study of Wolfson, Whipple, Judge, Amerman, Derby and King (1993) to train both balance and strength in the elderly to improve their function. It was reported that, at the end of a combined training program including Tai Chi, the single stance postural sway in older women improved 17% (Judge et al., 1993).

CHAPTER 3

METHODOLOGY

3.1 RESEARCH DESIGN

The purpose of this research was to investigate the relationship between balance and strength performances in the elderly. In order to extend this research and achieve an indication of the sensitivity of the measures used, a group of young people, with the same number of subjects as the elderly group (n=25), were required to perform the balance and strength tests under the same conditions as the elderly. From this comparison, the differences in balance and strength of young and aged people were investigated. Additionally the capacity of the elderly group to increase their strength and balance was investigated by the use of a ten-week Tai Chi training study.

Unlike young people who are able to perform various and even difficult tasks, not all the available training techniques which could improve muscle strength and balance efficiently and rapidly are appropriate to the elderly. Hence, a suitable design of the training program has to consider this point for the aged relevant to the level of their muscle strength and balance development. Based on the original measurements on balance and strength, a ten-week Tai Chi training program with some other appropriate exercises was designed to improve muscle strength, (especially the knee strength) and static balance of the aged people. For comparison purposes, the elderly subjects were randomly divided into a training group (n=14) and a control group (n=11). All subjects (the elderly and the young) had the same balance and strength measurements in the pre-training tests.

The overall research design consisted of three steps, ie., pre-training, training and post-training. Such a procedure can be summarized in the following flow chart,

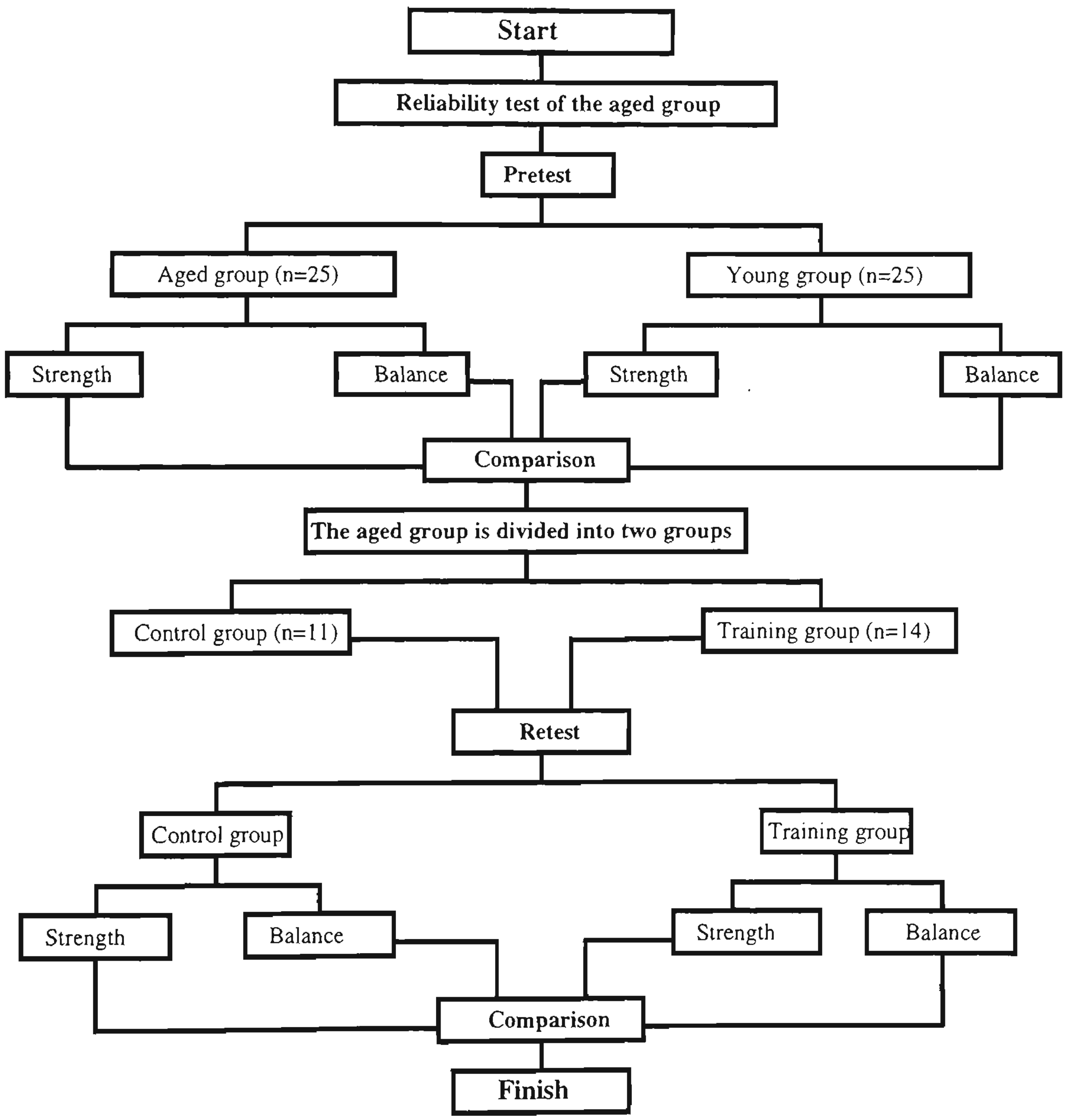


Figure 3.1 Research design.

Pre-training tests --- balance and strength tests for both the elderly group (n=25) and the young group (n=25) respectively;

Training period --- the elderly group was randomly divided into a control group (n=11) and a training group (n=14);

Post-training tests --- balance and strength tests for both control and training groups after training.

Phase (1) - Test-retest reliability of balance and strength for the elderly group.

Phase (2) - Pre-training tests of balance and strength for the elderly and the young groups.

Phase (3) - Training program (the aged training group).

Phase (4) - Post-training tests of balance and strength for the aged exercise and control groups.

3.2 DESCRIPTION OF THE SUBJECTS

Fifty healthy volunteers were recruited from three sources:

- Senior staff of Victoria University of Technology (Melbourne, Australia);
- Students of Victoria University of Technology (Melbourne, Australia);
- Members of the Community Centre of Maribynong (Melbourne, Australia).

The subjects were separated into two groups, an elderly group (n = 25) were aged from 56 to 78 years old and not currently engaged in regular physical exercise. This group was further divided into a training group (n=14) and a control group (n=11). The elderly subjects in this investigation were required to fill in a medical history form and have their participation approved by their doctor. They were also required to have their blood pressure taken before the strength test. The young group (n = 25) were aged from 18 to 25 years old. Table 3.1 gives a summary of the characteristics of the subjects. All subjects were required to give informed consent for their participation in the study (see appendix A). To be included, the subjects had to be without any injury, able to walk independently without limping, living independently in their own home (for the elderly) and not to have major disabilities which would seriously impair balance, eg. profound deafness.

Table 3.1 Characteristics of the Subjects.

Age Groups	Age (yrs)	Height (cm)	Weight (kg)
Elderly (n=25)	65±5	166±7	64±8
Young (n=25)	22±4	174±8	70±16

Elderly group: (males, n = 11 females, n = 14)
Young group: (males, n = 10; females, n = 15)

3.3 APPARATUS

3.3.1 Biodex Isokinetic Dynamometer System

A Biodex (2000 B) dynamometer was used to measure knee strength. Biodex is a hydraulically driven, computer-controlled dynamometer utilising isokinetic movements and measures the torque movement of muscle force at a constant angular velocity. The Biodex machine was linked with a PC computer loaded with Biodex advantage software (version 2.0). This system comprises the

Biodex clinical data station intended to facilitate the acquisition, analysis and output of isolated joint function data. Using this software it is possible to obtain related parameters such as peak torque, position, velocity, elapsed time, work and power during eccentric and concentric contractions. Curve analysis functions can be used to compare the results from different tests.

Using the Biodex dynamometer, knee strength was measured using the peak torques of knee extension and flexion at different angular velocities of knee joint rotation as the dependent variables. Two angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ were selected in the measurement of knee extension-flexion movements in this project. Four peak torques (extensions at $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$: E60 and E180; flexions at $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$: F60 and F180) were yielded on the performances of each leg. Hence, 2×4 peak torques of a subject (left knee and right knee) were detected from the knee strength measurement. Figure 3.2 gives an example of the diagram of knee extension-flexion at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively recorded by the Biodex dynamometer.

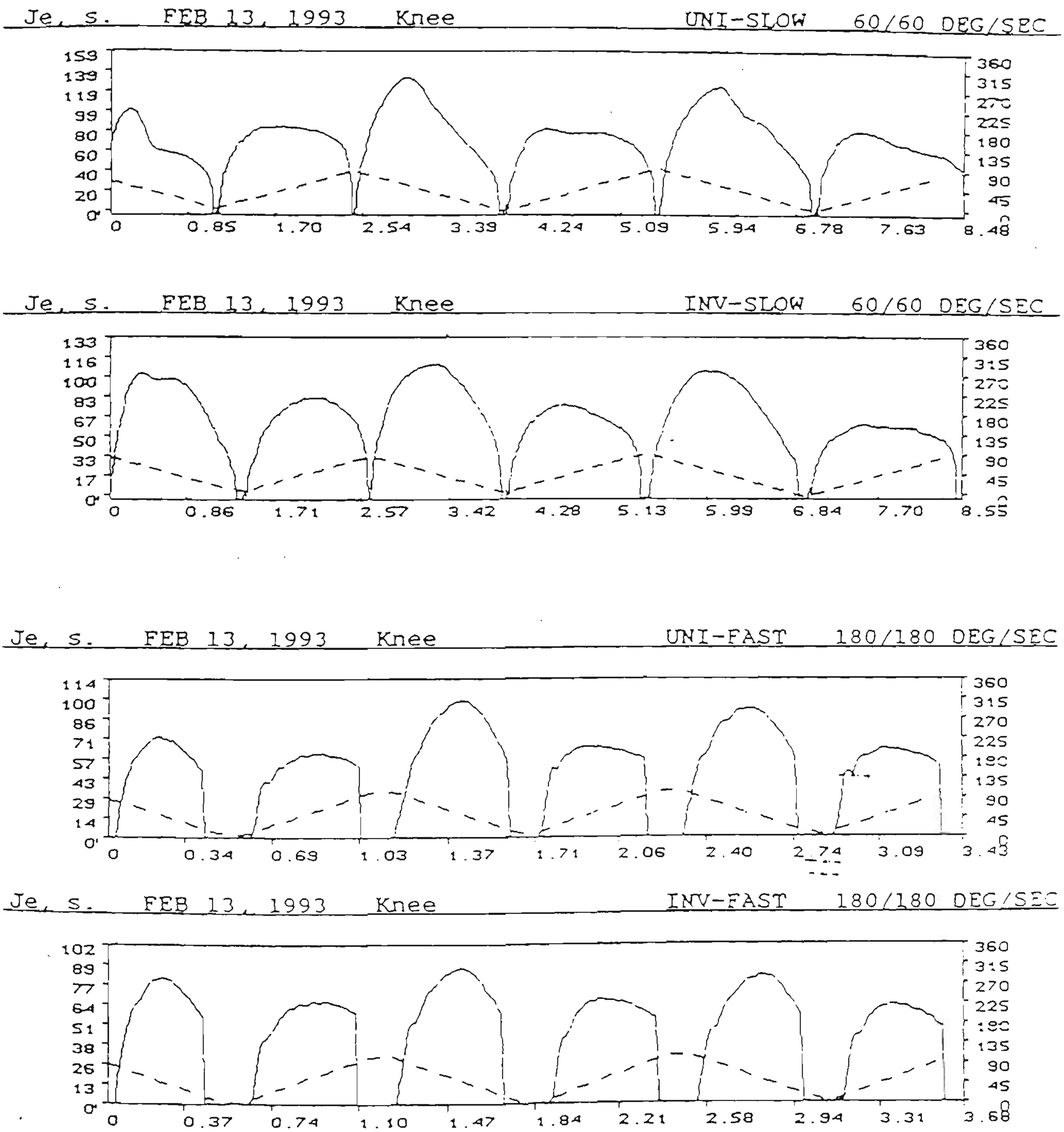


Figure 3.2 Knee strength recorded during extension and flexion movements.

3.3.2 AMTI Multi-Component Force Platform

A force platform was used to test the static balance. An IBM compatible IPX 286/10 computer installed BEDAS-2 (Biomechanics Data-Acquisition and Analysis Software) package is connected to an AMTI force platform system. BEDAS-2 comprises three programs, computer automated gait analysis (CAG), computer automated stability analysis (CAS), power analysis (PWR). Each program dedicates to a different type of data analysis. The programs in the BEDAS-2 package combine data-acquisition, analysis and graphics. They acquire data from the AMTI multi-component force platform through a Data-Translation DT2801A data-acquisition board. In this study the CAS program was used for static balance measurements. Like the other programs in the package, the stability analysis program CAS (Computer Automated Stability Analysis) also has channel analysis capabilities. There are different plots available in the CAS program, two stabilograms and one fast Fourier transform. A Hewlett-Packard 7475A six pen colour plotter, or an Epsom LX-800 dot-matrix printer can be used together with the force platform system. The force platform system is shown Figure 3.3.

In a test, the data from the output channels (F_x, F_y, F_z, M_x, M_y) were collected simultaneously in a 10 second period of time at an interval of 0.02 second. Therefore, 501 points (raw data) for each channel were obtained from a single balance test. In this study, the mean values and the standard deviation (SD) of the body sway forces (F_x, F_y, F_z) and the force moments (M_x, M_y) were used as the balance parameters. The body sway forces and force moments (F_x, F_y, F_z, M_x, M_y) were collected from the output channels with respect to each stance of a

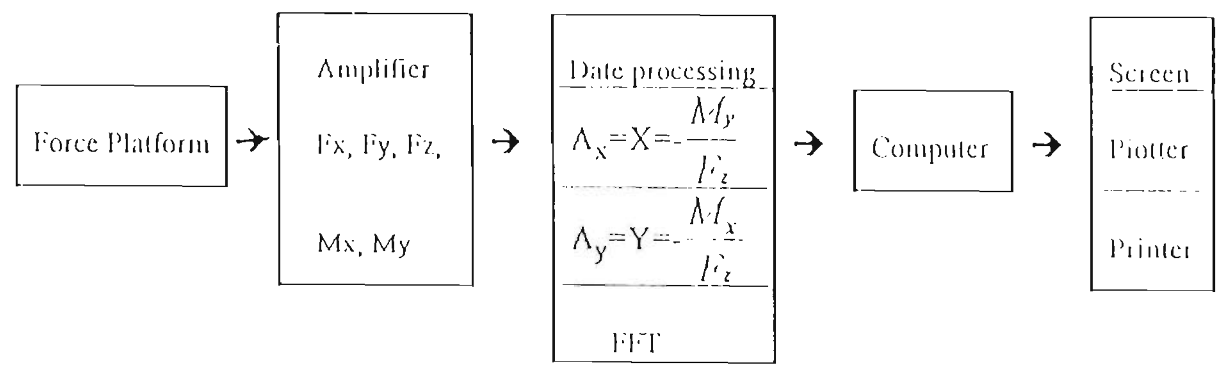


Figure 3.3 Configuration of the force platform. Here F_x, F_y and F_z are the body sway force components along x(ML), y(AP), and z(vertical) axes; whereas M_x and M_y represent the force moments in the x and y direction respectively. FFT stands for fast Fourier transform.

subject (left and right leg respectively) in a given time interval. Then the mean values and standard deviations (SD) with respect to each output were calculated for each test. Therefore, 10 values were obtained from the five output channels for one test (that is, 5 mean values and 5 standard deviations).

The stabilograms in Figure 3.4 show the path of the centre of pressure during the test. Here, Figure 3.4(a) refers to the average centre of pressure of a stance on the force platform, whereas in Figure 3.4(b) the origin is moved to the first datum of the path of the centre of pressure to minimise the errors introduced by the subjects' standing positions(on the platform).

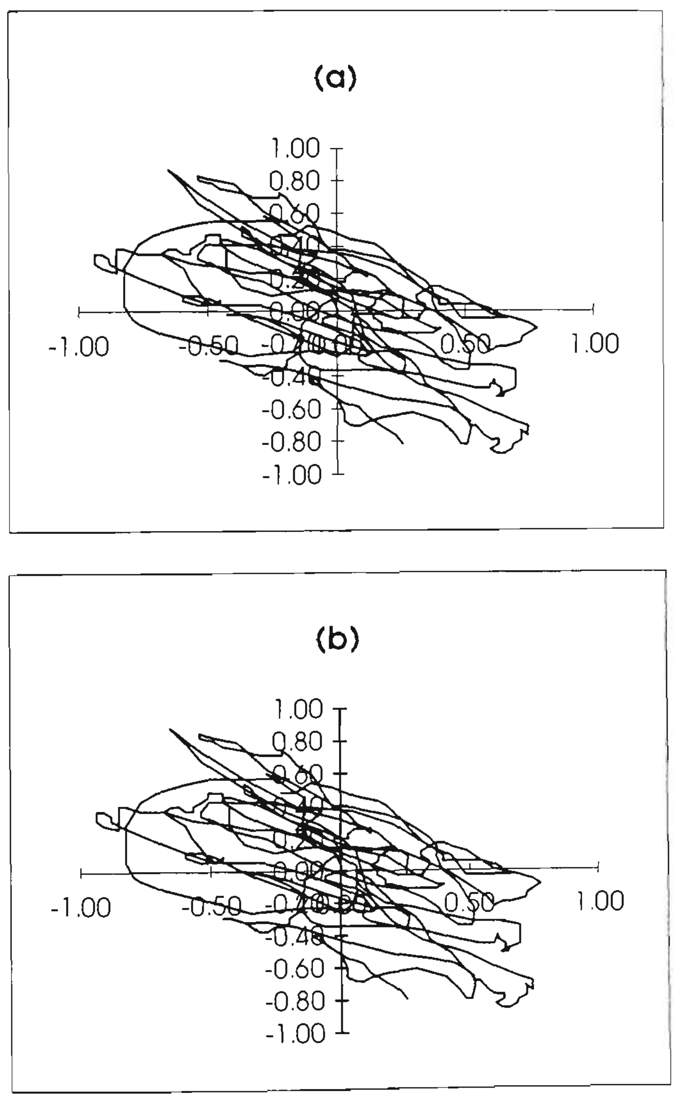
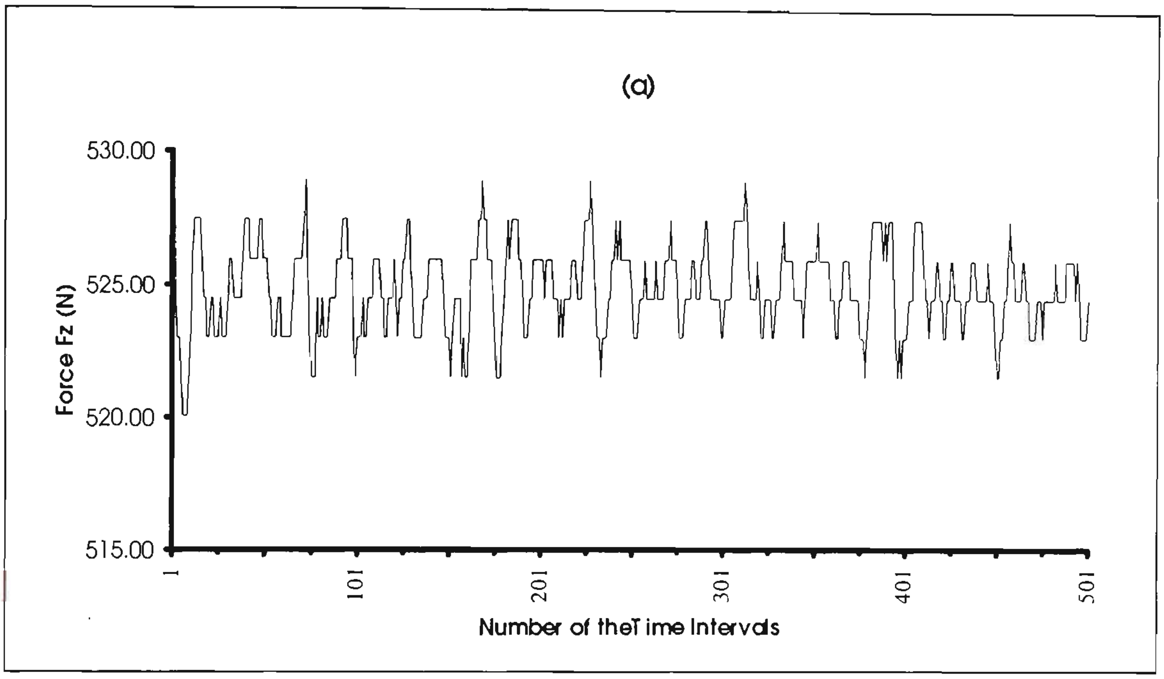
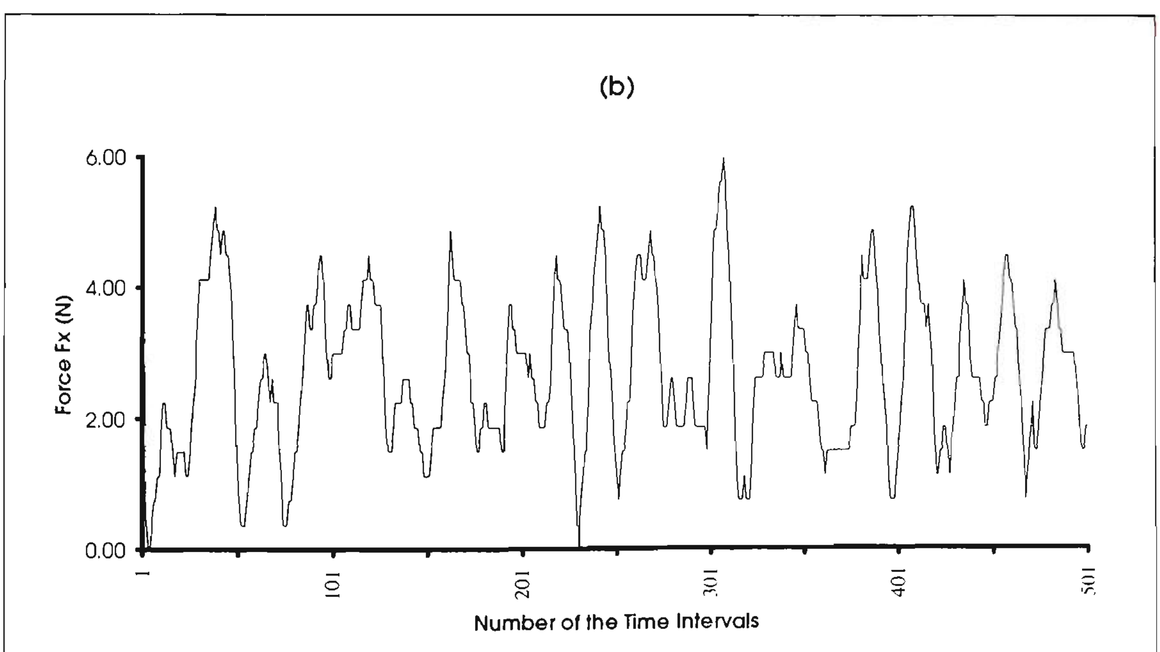


Figure 3.4 The path of the centre of pressure detected from the force platform.

Figure 3.5 gives the spectra of the force channels (F_x, F_y, F_z) as a function of the given time interval (0.02 second) collected in a 10 second period of time in a test (a sample of output data of the five channels from the force platform is given in the Appendix B).





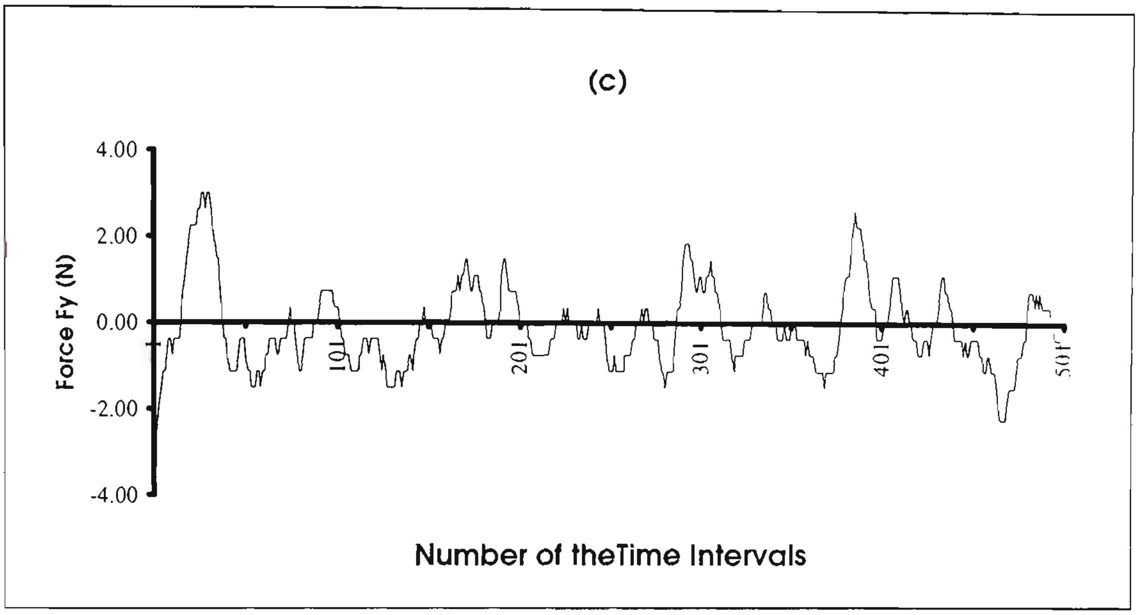


Figure 3.5 Variations of the body sway forces: (a) Vertical force (F_Z); (b) ML force (F_X); (c) AP force (F_Y).

3.4 THE GENERAL PROCEDURES FOR THE TESTS

The static balance and knee strength testing procedures had been approved by the ethics committee of Victoria University of Technology. Static balance was measured for left and right legged performances using the force platform; whereas knee strength was tested using the Biodex dynamometer after the balance tests. The strategy for the test procedures can be detailed in the following chart (Figure 3.6). Prior to the collection of data the subjects practised so that they become familiar with the laboratory environment and with the testing instruments. In this way, the possible errors which could have been introduced from the unfamiliarity of the subjects on the instruments were reduced.

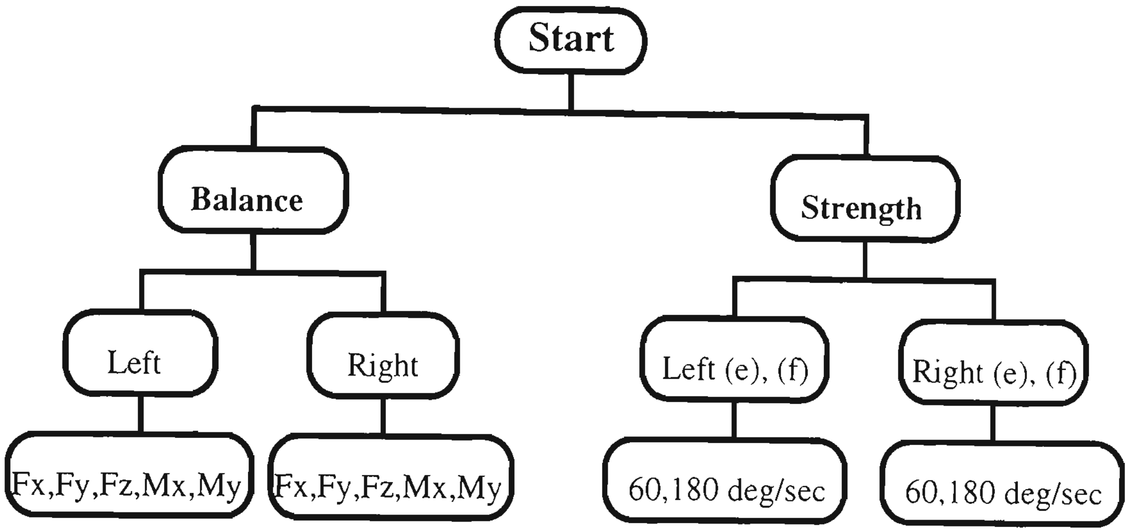


Figure 3.6 General procedure of the balance and strength tests.
where e = extension, f = flexion;
F_x, F_y, F_z = body sway forces in the X, Y, Z axis respectively;
M_x, M_y = force moments in the X and Y direction respectively;
60, 180 deg/sec = angular velocities at the $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively.

3.4.1 Static Balance Tests

A static balance procedure was used to establish a profile for the balance parameters. A single (one-legged) stance test for both legs was used for the measure of static balance. The subjects were asked to complete some simple exercises, such as ankle and knee press, one legged stance and fast walking (on the treadmill), for a total of five minutes as warm-up before they commenced the tests.

To perform a single legged stance, the subject stood on the force platform on one foot, shoes off, eyes open and the hands placed naturally on the hips. The subject was asked to look at a target at the eye level eight metres in front of the force platform. He/She was also instructed to direct maximum concentration and to correct the position as quickly as possible if a disturbance occurred during the test. The non-weight bearing leg was held in an optional position for balancing provided that this leg did not touch the supporting leg or the platform.

A slightly different technique from the balance measurements of one-legged stance described by Goldie, Bach and Evans (1992), was used in order to minimise instrumental errors. Prior to the balance tests in this study, the centre of the force platform was marked so that a subject could easily stand as close as possible to the centre of the force platform. Although the subjects' standing positions on the force platform should not affect the SD values of the balance variables, the displacements of the two positions (standing position and the center of the platform) affect the values of these balance parameters particularly on the force moments. Because by definition (Hutschmidt et al., 1980), the vertical force component (F_z) acting on the horizontal coordinates (x,y) creates the force moments (M_x, M_y),

$$M_x = y\,F_z \tag{1}$$

$$M_y = -x\,F_z \tag{2}$$

where F_z ≈body weight, the coordinates x and y are horizontal displacements of the subject's centre of body gravity from the centre of the force platform.

Supposed that (Δx, Δy) is the displacement between a subject's standing position and the centre of the force platform, whereas (x',y') is the derivation of the body gravity from the equilibrium (body sway), then,

$$x = x' + \Delta x \tag{3}$$

$$y = y' + \Delta y \tag{4}$$

What acts on the force platform are x and y. However, only x' and y' here report body sway of a subject rather than Δx and Δy which cause deficiencies such as test-retest deficiency. For example, if one subject has twice single stance tests under the same conditions except for the standing positions on the platform: the first time is on (Δx_1, Δy_1) and the second time is on (Δx_2, Δy_2). Where,

$$\Delta x_1 \neq \Delta x_2 \tag{5}$$

$$\Delta y_1 \neq \Delta y_2 \tag{6}$$

Assume that the subject has the exactly the same deviation (x',y') in the two tests, what is detected on the force platform will still be different:

$$x_1 = x' + \Delta x_1 \text{ and } y_1 = y' + \Delta y_1 \tag{7}$$

$$x_2 = x' + \Delta x_2 \text{ and } y_2 = y' + \Delta y_2 \tag{8}$$

so that,

$$x_1 \neq x_2 \tag{9}$$

$$y_1 \neq y_2 \tag{10}$$

Therefore, the first test gives

$$M_{x1} = y_1 F_z = y' F_z + \Delta y_1 F_z \tag{11}$$

$$M_{y1} = -x_1 F_z = -x' F_z - \Delta x_1 F_z \tag{12}$$

The second test gives,

$$M_{x2} = y_2 F_z = y' F_z + \Delta y_2 F_z \tag{13}$$

$$M_{y2} = -x_2 F_z = -x' F_z - \Delta x_2 F_z \tag{14}$$

Hence,

$$Mx_1 \neq Mx_2 \tag{15}$$

$$My_1 \neq My_2 \tag{16}$$

Equations (15) and (16) hold because of equations (5) and (6). In order to minimise such a test-retest deficiency,

$$\Delta x_1 = \Delta x_2 \ (=0) \tag{17}$$

$$\Delta y_1 = \Delta y_2 \ (=0) \tag{18}$$

Equations (17) and (18) can be ensured if the subject stands in the same position or as close as possible to the centre of the force platform.

A standard test for each subject was used to find out the centre of body gravity plotted on the screen of the connected PC computer for each subject. During the period of the ten second test, 501 data points were collected from the output channels at an interval of 0.02 second. Hence, 5×501 data points were simultaneously recorded for F_x, F_y, F_z, M_x and M_y on each test. The left leg was tested first then the right. The shift of the centre of body gravity were recorded automatically by the connected PC computer. The force platform outputs were sampled at 50 Hz for ten seconds and stored for subsequent analysis. All subjects performed the two stances (left and right) with eyes open. Criterion scores were used as described by Goldie et al. (1989), ie. the standard deviation of the five variables represented by centre of pressure excursion (ML axis, AP axis) and the three body sway force measures (ML axis, AP axis and Vertical axis).

3.4.2 Isokinetic Knee Strength Tests

Strength is the ability to exert force, and it may be measured with any force-recording instrument. Muscle contractions may be considered as isokinetic or isometric. In isokinetic tests, absolute strength is measured as the peak torque developed during a maximal voluntary contraction. Usually, for a subject, a more functional measure of strength is the peak torque corrected by body weight, ie. the ratio of torque and body weight. However, in this study peak torque was not considered with the body weight because, unlike the young, elderly people who have larger body weight do not necessarily have more muscle. As the age increases, the percentage of human body fat usually increases. Therefore, using peak torque to measure the strength of the elderly can be more meaningful than using the relative peak torque (ie. the ratio of peak torque and body weight).

All subjects were tested for isokinetic strength on the Biodex dynamometer. This device allows the evaluation of torque produced by concentric contraction of knee extensions and flexions. Before the strength tests, the Biodex dynamometer was turned on and warmed up for about 30 minutes so that the test mode, test protocol, joint, exercise pattern, and contraction options can be selected on the system and the electronics can be stabilised in order to ensure reliable operation.

Following the balance tests on the force platform, a subject was tested for knee strength by sitting in the appropriate position on the chair of the Biodex dynamometer. The subject was asked to bend and stretch the testing knee as much as possible in order to set up the Biodex machine. During the test, the subject performed three maximal contractions (extension-flexion). Subjects were verbally encouraged to perform to their maximum efforts (verbal instruction was given to the subjects). Each subject was measured for his/her left and right knees at the angular velocities of $60°\cdot s^{-1}$ and then $180°\cdot s^{-1}$ respectively. Therefore, a subject underwent four tests (left and right, $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$) for the knee strength test. A comprehensive report of the test was obtained from the computer for each performance of the subject.

3.5 TRAINING

The aged subjects were divided randomly into two groups (exercise and control group) with fourteen persons in the exercise group, and eleven in the control group. The exercise group underwent a ten-week training period with Tai Chi, which has been postulated as a good exercise for the elderly (Mackie, 1981). The Tai Chi regime was augmented with some simple exercises.

For the training group, the Cheng's style of twenty-four postures (see Appendix C) was employed. The routine was demonstrated and practised under supervision twice a week in the first five weeks, together with one hour individual practice everyday without supervision. Prior to the commencement of the training season the subjects walked for five minutes as a pre-exercise warm-up. In the second five weeks, the subjects could cope with the fundamental postures of Tai Chi performances. Instead of instructions when they practised, they followed Tai Chi music with eyes closed. In the ten week period, the training group practised together in a group for an hour every Monday and Wednesday.

The subjects in the training group were also asked to maintain an activity diary during the training period. The details of the training program is given in Table 3.2. The control group was asked to maintain a normal life and also requested to keep an activity diary. Both groups were requested not to change their normal routines during this period.

Table 3.2 The training program.

Contents	Monday and	Wednesday
	No. of Sets	Duration of Sets (Minutes)
Knee bending and stretching	3	2
Ankle dorsiflexion/plantar flexion	3	2
Left legged deep press	4	2
Right legged deep press	4	2
Tai Chi (Cheng 24 style) performance	3	10
Walking	1	5

Period of training: May 16. 1993-July 16. 1993.

3.6 RETEST

The same balance and strength parameters were tested and recorded again at the end of the ten week training period for the aged exercise and control groups respectively.

3.7 STATISTICS

In this study, the test-retest reliabilities of the force platform and the Biodex dynamometer system were evaluated using intraclass correlation coefficients (ICC). The correlations between the balance and strength parameters were evaluated and analysed using Pearson product moment (PPM). A one factor ANOVA was used at the level of α = .05 to determine if significant differences existed between the young and aged group for strength and balance measures. A paired student's t-test was employed to determine if significant improvements gained between pre-training and post-training of the training group and between the training and control groups.

CHAPTER 4

COMPARISON OF BALANCE AND STRENGTH IN AGED AND YOUNG POPULATIONS

4.1 INTRODUCTION

Muscle weakness is an extremely common finding among the elderly population (Rubenstein and Josephson, 1992). There is a reduction in muscle strength with age. It has been reported that the grossly detectable lower extremity weakness range from 48% among self caring aged people (Krebs, 1989; Campbell, Borrie and Spears, 1989) to 57% among residents in intermediate-care facilities (Tinetti, Williams and Mayewski, 1986) and to over 80% among nursing resident older adults (Robbins, Rubenstein, Josphson, Schulman, Osterweil and Fine, 1989). In a cross sectional study of 114 males from 11 to 70 years of age, Larsson et al. (1979) showed that age related loss in strength correlated significantly with a decrease in size of the fast muscle fibres.

Comparisons of strength between the young and elderly show that the isometric strength of a variety of limb muscles decreases in the elderly (Vandervoort and McComas, 1986). Larsson et al. (1979) reported that the knee extension, strength decrements during isokinetic (constant angular velocity) testing of elderly in comparison to young subjects were approximately 25% in aged 60-69, 45% in males aged from 70 to 86 (Murray et al., 1980), and 35% in women aged from 70 to 86 (Murray, Jacobs, Gore, Gardner and Mollinger, 1985). In a longitudinal investigation of 23 males ranging in age from 73 to 83 years, Aniansson et al. (1983) claimed that isometric and concentric knee strength decreased 10-22% over a seven-year period, depending on the test velocity. Also, some researchers (Davies, Thomas and White, 1986; Dedrick and Clarkson, 1990) reported that healthy individuals aged 70 to 80 score on average about 20% to 40% less during strength tests than young adults.

Age-related changes of the quadriceps femoris muscle in healthy males was studied by Larsson et al. (1979). In their measurement, both isometric and isokinetic strength increased up to the third decade, remained nearly unchanged until the age of 40-50, suffered approximately a 20% loss until the mid-60s, with a subsequent further decrease in the later years of age. There is an evidence that leg strength declines faster than other groups of muscles such as grip and arm strength (Grimby and Saltin, 1983; McDonagh, White and Davies, 1984). Hamrin et al. (1982) studied the muscle strength and balance in post-stroke patients. They reported that a high correlation existed between locomotion and the isokinetic torque of knee and between locomotion and balance. Recently, Ekdahl and Broman (1992) studied the relationship between postural control and muscle function in rheumatic diseases.

Balance appears to be more easily threatened in elderly individuals than in young adults. It has been suggested that the central nervous system control of postural muscle tone and balance diminishes with aging and postural responses become less efficient (Sheldon, 1960; Hasselkus and Shambes, 1974). Hellebrandt (1938) measured postural sway in a group of 109 subjects ranging in age from 3 to 86 years. The authors concluded that the mean location of the centre of gravity projection near the centre of the supportive base was consistent at all ages, but the magnitude of the sway around the centre of the base tended to be greater in the very old. However, the postural stability area is greatest in young and middle-aged adults. Other studies have shown differences in postural sway among persons of different ages (Brocklehurst et al., 1982). The study of human standing balance, on the other hand, has provided a basic comprehension in biomechanics in relation to health and disease. Because balance is the ability of maintaining the body equilibrium, it is important to detect and control static and/or dynamic balance of the human body.

However, the measurement of balance is a continuing challenge. For some time the force platform has been widely accepted in studies concerning the postural control of balance (Stribley et al., 1974; Murray et al., 1975; Black et al., 1977; Clark and Zernicke, 1981; Lucy and Hayes, 1985; Goldie et al., 1989). After Kapten (1972) created the standardisation of the platform, Goldie et al., (1989) evaluated the reliability and validity of the force platform by focusing on the body sway force and force moment output channels. The latter reported that the retest correlation coefficients are significant but reliable especially for the forces ($r \geq 0.31$).

Although several researchers have explored strength in both elderly and young groups, there is limited information describing the isokinetic strength characteristics of the elderly. Additionally the measure of balance utilised in this study appears to be novel to an aged population. It was decided to evaluate these parameters in both the young (who are expected to score relatively highly) and the aged population (who are expected to score relatively poorly) in order to obtain a measure of the sensitivity of these instruments.

This investigation compared the maximal voluntary concentric contraction force of knee extension and flexion at different angular velocities in the two populations. This study also compared postural sway during upright stance for a ten second single stance (one-legged) between young and elderly populations.

4.2 SUMMARY OF METHOD

4.2.1 Subjects

The fifty subjects involved in this study were divided into the young and the elderly groups. The group of young people had twenty-five healthy volunteers (male, n = 11 and female, n = 14) aged from 18 to 25 years ($\overline{X}$ = 22±4 yrs). They were all students of Victoria University of Technology (Melbourne, Australia). The subjects in the older group were mainly from the Maribynong Community Centre and some of them were staff members of Victoria University of Technology (Melbourne, Australia). These people were aged from 56 to 78 years ($\overline{X}$ = 65±5 yrs). The description of the characteristics of subjects in the two age groups is given in Table 3.1.

To be included, the subjects had to be without any injury and not have major disabilities which would seriously impair balance. They all had positive attitudes of cooperation.

4.2.2 Statistics and Analysis

For the balance measurements taken from the force platform, 501 sets of data from the five output channels (F_x, F_y, F_z, M_x, and M_y) were collected for a single stance in a duration of 10 seconds with an interval of 0.02 second. Each of the fifty subjects had 10 × 501 sets of raw data for both the left and right legs.

on the 10×501 sets of raw data which resulted in 10 mean ± SD data for each subject with the SD data being used as the postural control variables.

For the knee strength test, peak torques of the knee extension and flexion at the angular velocities of knee joint rotation of $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$ were obtained for both the left leg and right leg of each subject respectively. Therefore, 2×4 data points for each subject were collected in the strength test.

In this study, ten elderly subjects were requested to perform retests for both balance and knee strength parameters within a period of two weeks. The test-retest reliability of the force platform and the Biodex dynamometer system were evaluated using intraclass correlation coefficients (ICC). A one factor analysis of variance (ANOVA) was used to compare the strength and balance between the young and elderly group, for knee extension and flexion at low velocity ($60° \cdot s^{-1}$) and high velocity ($180° \cdot s^{-1}$) with body sway in x, y and z directions. Significant differences were evaluated at the level of $\alpha = .05$.

4.3 RESULTS

Table 4.1 gives the ICC of test-retest reliability scores for the one-legged stance on both (left and right) legs with eyes open on the force platform. The variations in the ICC values of the body sway forces (mean) for both right (F_x, $r = 0.44$; F_y, $r = 0.63$) and left (F_x, $r = 0.52$; F_y, $r = 0.56$) legs indicate a reasonable degree of reproducibility for these parameters. Moreover, different ICC coefficients of the channels also indicate that the precision of the parameters obtained from the five simultaneous output channels are not necessarily the same. Table 4.1 provides evidence that the force (F_x, F_y, F_z) output channels of the force platform are generally more reliable than the force moment (M_x, M_y) channels.

Table. 4.1 Test-retest reliability (ICC) values for the force platform (n=10)

	This work		Goldie et al. (1989)	
Channels	Left leg	Right leg	Preferred leg	Non-preferred leg
F_x [a)]	0.52	0.44	0.61	0.41
F_y	0.56	0.63	0.64	0.31
F_z	0.54	0.34	0.64	0.49
M_x [b)]	0.39	0.42	0.30	0.38
M_y	0.39	0.30	0.49	0.12

a) F_x, F_y, F_z are the body sway forces on the axis of X, Y, and Z respectively.
b) M_x, M_y are moments of body sway force on the axis of X and Y respectively.

It can be seen that there was a tendency for left-legged stances to show a better ability of reproducing the single stance balance performances (the subjects were predominantly right sided). Three out of five ICC coefficients of the standing balance parameters have larger values on the left leg than the corresponding parameters on the right. Table 4.1 also compares the ICC values with literature values. The ICC coefficients of test-retest reliability on the force platform from the present investigation are consistent with those given by Goldie et al., (1989), in particular the force variables. Though in this investigation, the procedure was designed to measure the left-legged and right-legged stance, Goldie et al. (1989) used preferred and non-preferred-legged stances. In comparing the ICC coefficients, it is seen that the ICC coefficients with respect to the left-legged stances are close to the preferred legged stances in Goldie et al. (1989) work.

It is possible that the relatively low value in ICC coefficients of the force moment (M_x, M_y) channels are partly from the methods employed on the force platform as the values obtained depend partly on the subject's standing position on the platform. During the pilot testing it was observed in this study that the validity of the tests on the platform appeared to be related to the subject's standing position with respect to the centre of the platform. Displacement of the two positions yielded poor (M_x, M_y) ICC values. Consequently, in the actual study care was taken to ensure that the two positions overlapped thus reducing deficiencies in the test-retest performances.

A comparison with literature values (McCleary and Anderson, 1990) of the calculated ICC coefficients for the knee extension-flexion at the angular velocities of 60 $°\cdot s^{-1}$ and 180 $°\cdot s^{-1}$ on the Biodex dynamometer are reported in Table 4.2. These coefficients indicate the high reproducibility of the knee extension-flexion tests on the Biodex dynamometer. The ICC for strength are both high and consistent (r = 0.90 to 0.95) indicating that the Biodex dynamometer is a highly reliable measure regardless of the velocities of joint rotation. The ICC values are in close agreement with the literature (McCleary and Anderson, 1992). Also, a tendency was observed in that the left knee had better ability of reproducing knee strength performances (the subjects are not left-sided) than the right knee for the normal elderly. This is consistent with the measurements on balance performance. Moreover, the flexion movements seem to be more reproducible than the extension movements.

Table 4.2 Test-retest reliability ICC for the Biodex dynamometer (n=10)

	This work		McCleary and Anderson (1990)[a)]
Conditions	Left leg	Right leg	
Ex 60$°\cdot s^{-1}$[b)]	0.92	0.90	0.94
Fl 60$°\cdot s^{-1}$[c)]	0.95	0.93	0.94
Ex 180$°\cdot s^{-1}$[b)]	0.93	0.91	-
Fl 180$°\cdot s^{-1}$[c)]	0.93	0.95	-

a) Day 2 at the trial 1 in McCleary and Anderson (1990).
b) Ex 60 $°\cdot s^{-1}$ and Ex 180 $°\cdot s^{-1}$ are knee extensions at the angular velocities of 60 $°\cdot s^{-1}$ and 180 $°\cdot s^{-1}$ respectively.
c) Fl 60$°\cdot s^{-1}$ and Fl 180$°\cdot s^{-1}$ are knee flexions at the angular velocities of 60 $°\cdot s^{-1}$ and 180 $°\cdot s^{-1}$ respectively.

The force platform and the dynamometer employed in the investigation are state-of-the-art instrumentation. With the help of computerisation, they are sound quantitative techniques for postural balance measurements and muscle strength determinations. They also have advantages in studies related to the elderly as performance on these machines is relatively easy, does not have unreasonable physiological concerns and is psychologically non-threatening.

Table 4.3 gives the Mean ± SD values of the knee strength and standing balance parameters for the elderly population. With respect to the knee strength parameters, it can be seen from the table that the left leg is slightly stronger than the right leg especially for the flexion movements; extensions display larger peak torques than the flexion at the same angular velocity; both extensions and flexions at lower angular velocity exhibit larger peak torque than their correspondents at higher angular velocity. The larger the angular velocity, the smaller the differences between left and right legs. For example, the differences between the extension and flexion at $60°\cdot s^{-1}$ are 0.7 N·m and 3.1 N·m respectively, while at $180°\cdot s^{-1}$ are 0.2 N·m and 2.9 N·m respectively. Moreover, the extension movements demonstrate torques nearly twice as great as the corresponding flexion movements at the same angular velocity. At the velocity of $60°\cdot s^{-1}$, the mean extension torque of the right leg yielded 85.5 N·m whereas the flexion was given by 42.7 N·m. Furthermore, mean torques with respect to the extensions and flexions at the lower angular velocity (say, $60°\cdot s^{-1}$, left leg) which are 86.2 N·m and 45.8 N·m respectively, are larger than those at the higher angular velocity (say, $180°\cdot s^{-1}$, left leg) which give 61.6 N·m and 35.4 N·m respectively.

On the other hand, for the balance variables, the ML force (F_x) and AP force (F_y) are closer in value than the vertical force (F_z). This is quite understandable since the vertical force F_z is related to the body weight of a subject, whereas the F_x and F_y forces are indications of body sway. Table 4.3 also demonstrates that both left and right legs exhibit a larger body sway in the ML direction than in the AP direction, ie., (F_x, F_y) are (2.8 ± 1.0 N) and (2.3 ± 0.7 N) for the left side; (2.7 ± 0.9 N) and (2.5 ± 0.7 N) for the right side. This occurs because for a single stance, the length (AP) of a foot (related to the supporting area) is larger than the width (ML) of the foot. Therefore, the centre of the body gravity is easier to shift out of the supporting area in the ML direction than the AP direction when a disturbance occurs.

Table 4.3. Mean ± SD values of the strength and balance parameters for the elderly group (n=25).

		Strength[a]		
	Ex 60°·s^{-1} (N·m)	Fl 60°·s^{-1} (N·m)	Ex 180°·s^{-1} (N·m)	Fl 180°·s^{-1} (N·m)
Left	86.2 ± 23.6	45.8 ± 18.6	61.6 ± 16.5	35.4 ± 12.8
Right	85.5 ± 23.7	42.7 ± 18.9	61.5 ± 15.8	32.5 ± 14.6
		Balance[b]		
		F_x(N)	F_y(N)	F_z(N)
Left		2.8 ± 1.0	2.3 ± 0.7	4.5 ± 2.1
Right		2.7 ± 0.9	2.5 ± 0.7	4.3 ± 2.1

a) Ex60°·s^{-1} and Fl60°·s^{-1} are knee extensions and flexions at the angular velocity of 60°·s^{-1} respectively.
Ex180°·s^{-1} and Fl180°·s^{-1} are knee extensions and flexions at the angular velocity of 180°·s^{-1} respectively.
b) F_x, F_y, F_z are the SD of forces of body sway in the x, y and z axes respectively.

Table 4.4 gives the Mean ± SD values of the knee strength and standing balance parameters for the young group. Similar to the elderly population, the mean torques of the extension movements are much larger than the corresponding flexion movements at the same angular velocity (but less than twice). For example, the mean peak torques of the right side of the young group demonstrate 168.9 N·m and 93.5 N·m at the angular velocity of $60° \cdot s^{-1}$ for extension and flexion respectively. Moreover, the extensions and flexions at the lower angular velocity (say, $60° \cdot s^{-1}$, left side) are 165.4 N·m and 88.6 N·m respectively, which are larger than those (117.5 N·m and 67.1 N·m) at the higher angular velocity ($180° \cdot s^{-1}$, left side).

On the balance measurements, similar to the older group, the ML (F_x) and AP (F_y) body sway forces are closer in value than the vertical force (F_z). However, different from the aged group, there are no apparent differences between the left side and the right side for the young group on their body sway. Also, the body sway seems independent of the directions (ML or AP) for young people.

Table 4.4 Mean ± SD values of strength and balance parameters for the young group (n=25).

		Strength[a]		
	Ex $60° \cdot s^{-1}$ (N·m)	Fl $60° \cdot s^{-1}$ (N·m)	Ex $180° \cdot s^{-1}$ (N·m)	Fl $180° \cdot s^{-1}$ (N·m)
Left	165.4 ± 40.7	88.6 ± 22.9	117.5 ± 29.4	67.1 ± 20.2
Right	168.9 ± 40.5	93.5 ± 23.6	117.4 ± 30.7	70.3 ± 24.0
		Balance[b]		
		F_x(N)	F_y(N)	F_z(N)
Left		1.3 ± 0.3	1.3 ± 0.3	2.1 ± 0.4
Right		1.3 ± 0.2	1.5 ± 0.3	2.1 ± 0.4

a) $Ex60° \cdot s^{-1}$ and $Fl60° \cdot s^{-1}$ are knee extensions and flexions at the angular velocity of $60° \cdot s^{-1}$ respectively.
$Ex180° \cdot s^{-1}$ and $Fl180° \cdot s^{-1}$ are knee extensions and flexions at the angular velocity of $180° \cdot s^{-1}$ respectively.
b) F_x, F_y, F_z are the SD of forces of body sway in the x, y and z axes respectively.

In the comparison of Table 4.3 (the elderly group) and Table 4.4 (the young group), it is apparent that the young group consistently exhibits stronger knee strength and better stability. The leg strength of the young group is nearly twice as strong as the elderly but their body sway forces are almost halved compared to the elderly group. On the knee strength, the peak torques of Ex60, Fl60, Ex180 and Fl180 in the aged group yielded 52.1%, 51.7%, 52.4% and 52.8% of those in the young group on the left side, whereas 50.6%, 45.7%, 52.4% and 46.2% on the right side. However, SD of body sway forces (F_x, F_y and F_z) of the young group were 46.4%, 56.5% and 46.7% on the left side but 48.2%, 60.0% and 48.8% on the right side of those in the elderly group. Moreover, the elderly group display a stronger left leg than the right leg. In contrast to the elderly, there is no such difference between left side and right side in the young group. At the angular velocity of $60°\cdot s^{-1}$, the differences of mean peak torque between right leg and left leg are 3.5 N·m and 4.9 N·m for the extension and flexion respectively in the young group, whereas -0.7 N·m and -3.1 N·m for the extension and flexions respectively in the elderly group.

Table 4.5 gives the ANOVA analysis of the balance tests (F_x, F_y, F_z) for the two age groups and for left and right legs of the two groups. As expected, the SD of forces of body sway for the young subjects are smaller than for the aged subjects (the forces indicate body sway in x, y and z directions). For the left side, the mean of the SD of body sway forces (F_x, F_y, and F_z) of the elderly are 2.8, 2.3, 4.5 (N) respectively, which are almost twice as much as the correspondent values of the young people [1.3, 1.3, 2.1 (N)]. A similar tendency was obtained in the right side. In the comparison of the young group and the elderly group, the ANOVA coefficients reported a large difference between the young and the elderly group in balance. On the left side, the ANOVA coefficients were: $F(1, 48) = 50.2$, 41.4, and 30.8 (*p< .001*) for SD of F_x, F_y and F_z, respectively. Similarly, for the right side, the corresponding ANOVA coefficients were given by F(1, 48)

= 54.6, 40.5, and 26.1, (*p< .001)*. The sequence of the ANOVA coefficients is given by $F_x > F_y > F_z$ for both left and right legs. This is also the sequence of the changes as the age grows.

Table 4.5 ANOVA of static balance for the young and the elderly groups

	Age Groups		
Variables	Y (N=25)$^{a)}$	E\` (N=25)$^{a)}$	*F*
LFx (N)	1.3 ± 0.3	2.8 ± 1.0	50.2***
LFy (N)	1.3 ± 0.3	2.3 ± 0.7	41.4***
LFz(N)	2.1 ± 0.4	4.5 ± 2.1	30.8***
RFx (N)	1.3 ± 0.2	2.7 ± 0.9	54.6***
RFy (N)	1.5 ± 0.3	2.5 ± 0.7	40.5***
RFz (N)	2.1 ± 0.4	4.3 ± 2.1	26.1***

	Legs		
Variables	L (N=25)	R (N=25)	*F*
YFx (N)	1.3 ± 0.3	1.3 ± 0.2	0.0$^{n.s}$
YFy (N)	1.3 ± 0.3	1.5 ± 0.3	2.8$^{n.s}$
YFz (N)	2.1 ± 0.4	2.1 ± 0.4	0.3$^{n.s}$
E\`Fx (N)	2.8 ± 1.0	2.7 ± 0.9	0.3$^{n.s}$
E\`Fy (N)	2.3 ± 0.7	2.5 ± 0.7	0.5$^{n.s}$
E\`Fz (N)	4.5 ± 2.1	4.3 ± 2.1	0.1$^{n.s}$

Y = the young group, E\` = the elderly group; L = Left leg, R = Right leg.
YFx, YFy, YFz are the forces of body sway on the x, y and z axes respectively of the young group.
E\`Fx, E\`Fy, E\`Fz are the forces of body sway on the x, y and z axes respectively of the elderly group.
*****p < .001, n.s = not statistically significant at α = 0.05 level.**

In the comparison of the leg differences in the two age groups, the mean ± SD values of the body sway forces (F_x, F_y and F_z) are 2.7, 2.5 and 4.3 N (right side) respectively for the aged; whereas 2.8, 2.3 and 4.5 N for their left side. There are no apparent differences between the left and the right legs for the aged group. On the other hand, the differences between the two legs in the young group are even smaller. The ANOVA coefficients (Table 4.5) confirm that no significant differences exist between two legs in both groups.

Table 4.6 gives ANOVA analyses of knee extensions and flexions for the two age groups. The results show significant differences in knee strength between the young and the elderly. The values for knee extensions and flexions for young people are nearly twice as large as those of the aged people. ANOVA analysis evidences significant differences of knee extensions and flexions between the aged group and the young group. The largest ANOVA coefficient is given by the right side extension at an angular velocity of $60°\cdot s^{-1}$ with the value of $F(1,48)=85.6$ ($p<0.001$). The smallest ANOVA coefficient in this comparison reported is the right side flexion at angular velocity of $180°\cdot s^{-1}$ with the value of $F(1,48)=44.3$ ($p<0.001$).

Furthermore, the mean ± SD values of the knee extensions are much larger than the corresponding flexions for both the young and aged groups, which is also reported by the ANOVA coefficients in Table 4.6. Extensions at different angular velocities yield consistently larger ANOVA coefficients than those at the corresponding flexions. It indicates that the extension torques decrease faster than the flexion torques as age increases. Also, the extensions and flexions at the lower angular velocity (say, $60°\cdot s^{-1}$) exhibit consistently larger ANOVA coefficients than higher velocity (say, $180°\cdot s^{-1}$). The ANOVA coefficients for the extensions at $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ angular velocities are $F(1,48) = 70.8$ and 70.2 ($p<0.001$) respectively for the left side, whereas $F(1,48) = 85.6$ and 65.6 ($p<0.001$) respectively for the right side. The knee strength declines at lower angular velocities more apparently than it declines at the higher angular velocities as age increases. However, the results of ANOVA in Table 4.6 exhibit that there are no significant differences in strength between left and right legs for both groups.

Table 4.6 ANOVA of peak torque (N·m) for knee extensions and flexions

	Age Groups		
Variables	Y (n=25)	E` (n=25)	*F*
LE 60°·s^{-1}	165.4 ± 40.7	86.2 ± 23.6	70.8***
RE 60°·s^{-1}	168.8 ± 40.0	85.5 ± 23.7	85.6***
LE180°·s^{-1}	117.5 ± 29.4	61.6 ± 16.5	70.2***
RE180°·s^{-1}	117.4 ± 30.7	61.5 ± 15.8	65.6***
LF 60°·s^{-1}	88.6 ± 22.9	45.8 ± 18.3	54.3***
RF 60°·s^{-1}	93.5 ± 23.6	42.7 ± 18.9	70.4***
LF180°·s^{-1}	67.1 ± 20.2	35.4 ± 12.8	45.5***
RF180°·s^{-1}	70.3 ± 24.0	32.5 ± 14.6	44.3***

	Legs		
Variable	L (n=25)	R (n=25)	*F*
YE 60°·s^{-1}	165.4 ± 40.7	168.8 ± 40.0	0.1$^{n.s}$
YE180°·s^{-1}	117.5 ± 29.4	117.4 ± 30.7	0.0$^{n.s}$
E`E 60°·s^{-1}	86.2 ± 23.6	85.5 ± 23.7	0.1$^{n.s}$
E`E180°·s^{-1}	61.6 ± 16.5	61.5 ± 15.8	0.0$^{n.s}$
YF 60°·s^{-1}	88.6 ± 22.9	93.5 ± 23.6	0.5$^{n.s}$
YF180°·s^{-1}	67.1 ± 20.2	70.3 ± 24.0	0.3$^{n.s}$
E`F 60°·s^{-1}	45.8 ± 18.3	42.7 ± 18.9	0.4$^{n.s}$
E`F180°·s^{-1}	35.4 ± 12.8	32.5 ± 14.6	0.5$^{n.s}$

Y: Young, E`: Elderly, L: Left, R: Right, E: Extensions, F: Flexions.
60°·s^{-1}, 180°·s^{-1} are the angular velocities of the joint rotations.
*****p < .001, n.s = not statistically significant at the α=0.05 level.**

In order to give a more comprehensive representation of the comparisons on strength and balance between the young and the elderly groups, Figure 4.1 presents a graphical comparison of the peak torques (left side) and Figure 4.2 presents the comparison of the static balance (left side) of the two age groups. It can be seen that the young group has consistently higher mean values of strength but lower mean values of body sway forces (better balance) than the elderly group. Furthermore, the SD values (SD bars) of the aged group (see Figure 4.2) of F_x, F_y and F_z body sway forces are large and varying, but the SD bars of the young group almost remain unchanged or are smaller than those of the elderly group. Therefore, it could be concluded that young people have a better physical fitness than the elderly, particularly in lower body strength so that they have a better ability to maintain body balance.

Figure 4.1 gives a comparison of the mean values of the peak torques between the young and the elderly groups on the left leg. Again, the young group have consistently higher mean values regardless of the angular velocities and the extension and flexion of the movements.

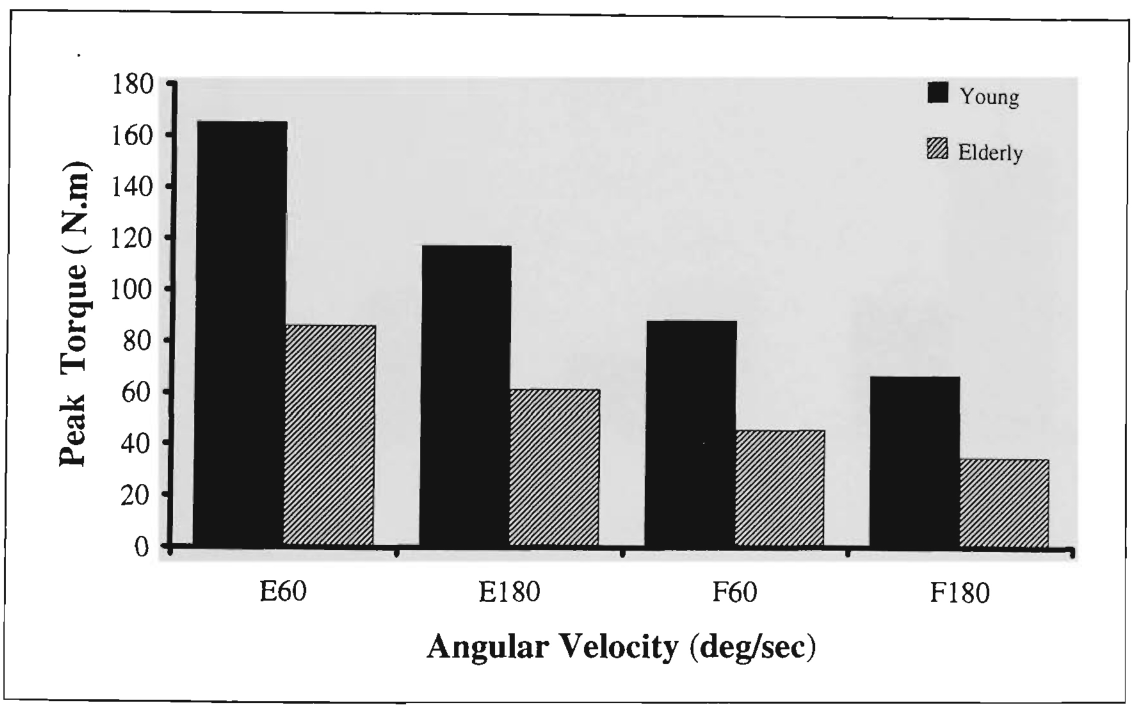


Figure 4.1 Comparisons of mean peak torques between the young and elderly groups (left leg).
E60 and E180 = knee extensions at angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.
Fl 60 and Fl 180 = knee flexions at angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.

At the angular velocity of extension $60°\cdot s^{-1}$ the peak torque for the young group is 165.4 (N·m) and the elderly group 86.2 (N·m), which gives the deficiency of the peak torque between two groups of 52.1%.

Figure 4.2 compares the body sway forces between the young and the elderly groups on the left leg stance on the force platform. The forces have lower mean values (better balance) in the young group than those of the elderly group. Moreover, the SD values (SD bars) of the aged group of F_x, F_y and F_z body sway forces are large and varying, but the SD bars of the young group are much smaller than those of the aged group.

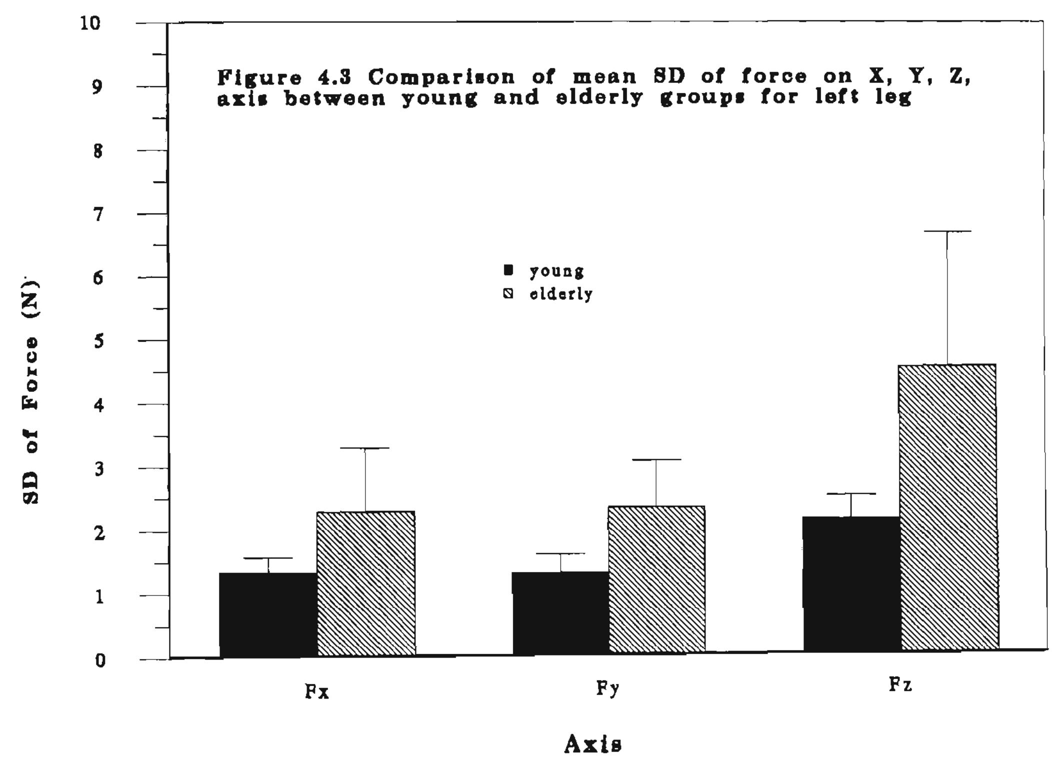


Figure 4.2 Comparison of mean ± SD values of the body sway forces in x, y and z directions for the young and the elderly groups (left leg).

4.4 DISCUSSION

4.4.1 Comparison of Strength

In this study the significant differences of both left and right knee torques of the mean extensions at the angular velocity of $60° \cdot s^{-1}$ for the elderly were reduced by 47.9%(L) and 49.4% (R) compared to the same strength parameters of the young group. Similarly, at the angular velocity of $180° \cdot s^{-1}$, the knee flexion strength of the elderly group was reduced by 47.2% (L) and by 53.8% (R) of the young people. The results from present study are consistent with a study of Murray et al. (1985) on a young and an elderly population, in which the corresponding percentages of reduction are given by 47.8% (left, extensions) and 54.0% (right, extensions); 47.9% (left, flexions) and 64.3% (right, flexions) at the respective angular velocities.

With respect to the peak torques, the strength of the elderly in the right side decreased more quickly than the left side. The reductions of the extensions (left) were 47.9% and 47.6% at the velocities of $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$ respectively; while the right side were reduced by 49.4% and 47.6% respectively at the same conditions. The strength reductions of the elderly group in this study are consistent with other studies of isokinetic muscle strength in the elderly population such as Larsson et al. (1979) and Borges (1989).

The age related difference in strength may be attributable to the failure of descending drive from the motor cortex during volitional efforts of the elderly group or the results of the contraction of smaller (atrophied) muscles. Decrease of strength in the elderly population has been attributed to a decreased excitable muscle mass (Vandervoort et al., 1990) although well-motivated elderly subjects can achieve a high level of voluntary muscle excitability (Jones and Rutherford, 1987). The decline in muscle strength associated with advancing adult age could result from a quantitative loss of contractile protein (loss of muscle fibres due to muscular and/or neural alterations). This is a decrease in the ability of skeletal muscle to generate tension due to localised changes (eg. a change in fibre length or angle), a reduction in the capacity of the central nervous system to activate otherwise normal motor units, or any combination of these mechanisms.

A major reason for the marked loss of strength in the elderly population is a quantitative and not qualitative change resulting from the loss of muscle fibres (Grimby and Saltin, 1983). This hypothesis was confirmed by Lexell, Taylor and Sjostrom (1988) who counted the number of fibres in autopsy in the vastus laterals muscle and reported an average reduction in muscle area of 40% and a total number reduction of fibres to 39% from ages 20 to 80. Also, it can be affected by the electromyography characteristics of contracting muscles in the elderly (Mitolo, 1967). The most consistent finding of those electromyography studies was an increased number of polyphonic action potentials in the elderly persons, as compared to young persons. Gutmann and Hanzlikova (1972) suggested that an increase in the frequency of polyphonic action potentials with increased age, might be related to morphological changes in the aging motor unit. Murray et al. (1980) showed that the very old age group generated their maximum muscle torque later during the five second isometric contractions than did the subjects in the two younger age groups.

4.4.2 Comparison of Static Balance

It has been established in this study that there is a significant static balance difference between the young and the elderly populations. The mean ± SD values of the body sway forces in the young group were almost a half of those in the elderly population. In particular, the body sway forces in the x and z directions were considerably reduced in the elderly group. Specifically, the ratios on F_x, F_y and F_z of the young and the elderly groups in the left side are 46.4%, 56.5% and 46.7% respectively; whereas 48.1%, 60.0% and 48.8% (see Table 4.5) respectively for right side. Nevertheless, Figure 4.2 implies that the young group have a better capacity to maintain body balance since the standard deviations (SD) of this group are much smaller (less than a half) than the SD values yielded by the aged group.

The age related difference in static balance may be attributable to degenerative changes with age in the vestibular system (Rosenhall, 1973). Postural control in the normal human body is maintained by three main mechanisms: the vestibular labyrinth in the inner ear, vision and proprioceptive information. Studies have shown degenerative change in vision with age in the vestibular system, though no one has shown the importance of degenerative change in vision and proprioception for postural disturbance in the elderly population (Rosenhall and Rubin, 1975). Pyykkö, Aalto, Starck and Ishizaki (1989) indicated that the stimulation activates the muscle spindles and Golgi tendon organs and causes increased vibration-induced body sway, and reflects the function of stretch reflexes in postural stabilisation. During vibration, the increase in body sway was relatively small when compared with the younger control subjects and in a sample of patients with vestibular deficits (Pyykkö et al., 1989). This result indicated that proprioceptive sensitivity of the calf muscle is poorer in the elderly population than in the young group. Also, Hasselkus and Shambes (1975) illustrated that the postural sway area of the elderly adults in their study was significantly larger than that of the young adults in both stance positions. This lends support to the theory that the postural control of the human neuromuscular system declines with aging.

Stretching a muscle activates the primary ending of muscle spindles and releases a stretch reflex which monosynaptically facilitates the same muscles and inhibits the activity of the antagonistic. The stretch reflex is involved in the acute control of a sudden fall. Malfunctioning of stretch reflexes, as appears to be the case in the present study and in that of Woollacott, Shumway-Cook and Nashner (1986) indicated a lack of this segmental corrective mechanism in elderly subjects. The secondary endings, besides activating agonistic muscles, mediate information on the length and extension of the muscles to the central postural mechanisms that execute control of the movement pattern concerned.

The elderly group in this study had a higher variation of Fx,y,z of body sway in the single legged stances of both legs (left and right) without any external stimulation. The results confirmed that the coactivation of limb muscles and sensorimotor function is poorer in the elderly population (Stelmach and Worringham, 1985).

CHAPTER 5

THE RELATIONSHIP BETWEEN STATIC BALANCE AND KNEE STRENGTH IN YOUNG AND ELDERLY POPULATIONS

5.1 INTRODUCTION

The results of Chapter Four indicate that there are significant differences in both strength and balance measures between the young and elderly populations. However, Chapter Four focused on the differences between the elderly and the young groups in strength and balance separately. We extended the study to investigate the relationship between strength and balance in the young group and the elderly group, respectively. Discriminations of the strength-balance relationship in the young and aged people were also examined.

The question of how lower extremity strength correlates with static balance for the elderly remains a challenge. Age-related changes of the quadriceps femoris muscle in healthy males were studied by Larsson et al. (1979). In their measurements, both isometric and isokinetic strength increased up to the age of 30 years, remained nearly unchanged until the age of 50 and then gradually decreased as the age increased. Hamrin et al. (1982) studied muscle strength and balance in post-stroke patients. They showed that there was a strong correlation between locomotion and the isokinetic torque of the paretic knee, locomotion and balance.

The relationship between postural control and muscle function for patients with rheumatic diseases was investigated by Ekdahl and Broman (1992).

In strength studies, it has been shown by some researchers (Davies et al., 1986; Clarkson and Dedrick, 1988) that healthy elderly populations aged 70 to 80 scored on average about 20% to 40% less during strength tests than a young population. Concentric strength tests have shown the age differences similar to those in isometric contractions. Vandervoort et al. (1990) compared the knee extension and flexion voluntary strength during eccentric versus concentric exercise in groups of young and elderly women. Elderly women had 25% to 45% ($p < .01$) lower peak torque and average torque values in all comparisons with the young women. In this study, Chapter Four confirmed the previous studies on the strength reductions (~45%) of the elderly.

Since the 1970s, force platforms have been widely accepted in evaluating human standing postural control of balance (Stribley et al., 1974; Murray et al., 1975; Black et al., 1977; Clark and Zernicke, 1981; Kaptey et al., 1983; Lucy and Hayes, 1985; Horak, 1987; Goldie et al., 1989; Woollacott and Shumway-Cook ,1990). In 1983, Kaptey et al. established the standardisation of the force platform. Goldie et al. (1989) evaluated the reliability and validity of the force platform for the standard deviation (SD) of forces (F_x, F_y, F_z), and centre of pressure (A_x, A_y). This thesis confirmed that the SD of body sway forces of the elderly group were 150-200% of those of the young group.

Previous studies focused on the determination and improvement of strength and balance, as well as the factors and potential influences which affect strength and balance. Little has been done on how strength and balance correlate in different age groups. The purpose of this study was to investigate the possible correlations between knee strength and static balance for aged and young populations and to understand how the lower extremity strength effects static balance factors. In this study, knee extension and flexion at low ($60°\cdot s^{-1}$) and high ($180°\cdot s^{-1}$) angular velocities were evaluated as the strength measurements. The body sway forces and force moments of a static stance were measured as the balance parameters.

5.2 METHOD

5.2.1 Subjects

The fifty subjects involved in this study were the same as those mentioned in Chapter Three (§3.2). They consisted of two age dependent groups, the young and the old. The young group had twenty-five healthy volunteers (male n = 10 and female n = 15) aged from 18 to 25 ($\overline{X}$ = 22 ± 4) years, who were students of Victoria University of Technology (Footscray campus, Victoria, Australia). The older group who were from Maribyrnong Community Centre and Victoria University of Technology (Footscray campus, Victoria, Australia), had twenty-five healthy volunteers (male n = 11 and female n = 14) aged from 56 to 78 ($\overline{X}$= 65 ± 5) years.

To be included, the subjects had to be without any injury and not to have major disabilities which would seriously impair balance. Moreover, they had positive attitudes of cooperation.

5.2.2 Procedure

The procedures, approved by the ethics committee of Victoria University Technology were described by the researcher and each participant consented to their participation in the study.

The basic data utilised in this Chapter were gathered from the initial project on strength and balance on the young and elderly groups. All subjects completed five minutes of warm-up exercises before the tests. The one-legged (with eyes open) standing balance parameters (F_x, F_y, F_z, M_x, M_y) of the individuals were measured on the force platform for both legs. Afterwards, knee strength tests were carried out to give the strength parameters (Ex, Fl) at the angular velocities of 60 $°\cdot s^{-1}$ and 180 $°\cdot s^{-1}$ for both knees.

As mentioned in Chapters Three and Four, the centre of the force platform was marked before the balance tests. Therefore, the standing positions of the subjects were very close to the centre of the force platform so that the instrumental errors could be minimised. During a 10 second test, each subject stood on one foot with shoes off with hands placed naturally on their hips. The data generated in the 10 second period were collected at intervals of 0.02 second, so that 501 data points were recorded for each output channel of the force platform. Therefore, 5×501 data points were simultaneously recorded from the five output channels (F_x, F_y, F_z, M_x, M_y) for each stance. Every subject was tested with single stance (one-legged) twice (left leg and right leg).

Following the balance tests on the force platform, the subjects performed the knee strength tests on the computerised Biodex dynamometer system. Each knee performed three times extension-flexion performance of concentric exercise at the angular velocities $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$, respectively. The

2×4 sets of strength parameters [(Ex, Fl) at the angular velocity of 60 $^{\circ}\cdot s^{-1}$; (Ex, Fl) at the velocity of 180 $^{\circ}\cdot s^{-1}$] were recorded for every subject with respect to left and right knee strength.

The procedure followed in this Chapter was that given in Chapter Four and detailed in Chapter Three.

5.2.3 Statistics and Analysis

Correlations between the balance and the strength measurements were analysed using the Pearson product moment (PPM).

For the balance parameters obtained from the force platform, five sets of 501 data points from the output channels (F_x, F_y, F_z, M_x, M_y) were collected with respect to each subject standing on his/her left and right leg respectively. The mean values and standard deviations (SD) with respect to each output channel under 501 data points were calculated for each test. Therefore, five pairs of the mean and SD values were obtained from the five output channels for each test (ie., 5 mean values and 5 standard deviations). The SDs of the balance variables were used as the dependent variables in this study as suggested by Goldie et al. (1989).

Using the Biodex dynamometer, knee strength was measured as the peak torques of knee extensions and flexions at the angular velocities of $60^{\circ}\cdot s^{-1}$ and $180^{\circ}\cdot s^{-1}$, respectively. Therefore, four peak torques were yielded for each performance. Hence, 2x4 peak torques of each subject (left knee and right knee) were detected in the knee strength test.

5.3 RESULTS

The relationships between strength and balance in the two groups (the young group and the aged group) were determined by the Pearson product moment (PPM) correlation coefficients. Since a more stable static balance should yield lower values of body sway forces, the relationships between knee strength and body sway forces can be presented as the negative correlations. Table 5.1 gives the PPM coefficients for the young and elderly population.

Table 5.1 PPM coefficients ($p<0.01$) of balance and strength for the young and elderly groups ($n=25$)

	Left				Right			
	E60°.s^{-1}	F60°.s^{-1}	E180°.s^{-1}	F180°.s^{-1}	E60°.s^{-1}	F60°.s^{-1}	E180°.s^{-1}	F180°.s^{-1}
				Elderly	Group			
Fx	-0.72	-0.65	-0.73	-0.69	-0.79*	-0.66	-0.58	-0.46
Fy	-0.69	-0.60	-0.71	-0.64	-0.64	-0.53	-0.41	-0.42
Fz	-0.54	-0.42	-0.61	-0.51	-0.39	-0.50	-0.34	-0.49
Mx	-0.40	-0.21	-0.34	-0.35	-0.28	-0.28	0.03	-0.12
My	-0.42	-0.22	-0.36	-0.37	-0.28	-0.22	0.04	-0.07
				Young	Group			
Fx	-0.29	-0.15	-0.17	-0.10	-0.30	-0.29	-0.20	-0.18
Fy	-0.20	-0.19	-0.26	-0.09	-0.23	-0.13	-0.13	-0.06
Fz	-0.03	-0.20	-0.08	-0.13	-0.17	-0.22	-0.12	-0.16
Mx	-0.28	-0.21	-0.11	-0.18	-0.21	-0.11	-0.04	-0.18
My	-0.11	-0.07	-0.08	0.05	-0.06	-0.02	-0.12	0.15

E60°·s^{-1}, E180°·s^{-1} = knee extensions at the angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.
F60°·s^{-1}, F180°·s^{-1} = knee flexions at the angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.
Fx, Fy, Fz = SD of body sway forces on the X, Y and Z axes respectively.
Mx, My = body sway force moments on the X and Y axes respectively.

The correlations between strength and balance can be mainly exhibited by the body sway forces (Goldie et al. 1989). There are a number of significant correlations ($|r| \geq 0.31$) between knee strength and standing balance for the elderly group, with the largest PPM coefficient given by Ex(r) $60°\cdot s^{-1}$ vs F_x, $|r| = 0.79$. In the elderly group, the PPM coefficients for the left side do not differ very much from those for the right side. On the other hand, the strength measurements with lower angular velocity ($60°\cdot s^{-1}$) and higher angular velocity ($180°\cdot s^{-1}$) do not have obvious differences in the correlation with balance either. Moreover, the correlations between body sway forces and extensions are generally stronger than those between the forces and flexions with regardless of angular velocities. These features can be better illustrated in Figure 5.1. However, the PPM coefficients (for the elderly group) with respect to the force moment measurements (M_x and M_y) presented oscillations for the criterion at the significance level ($|r| \geq 0.31$) and no apparent correlations existed between strength and body sway force moments, in particular on the right side.

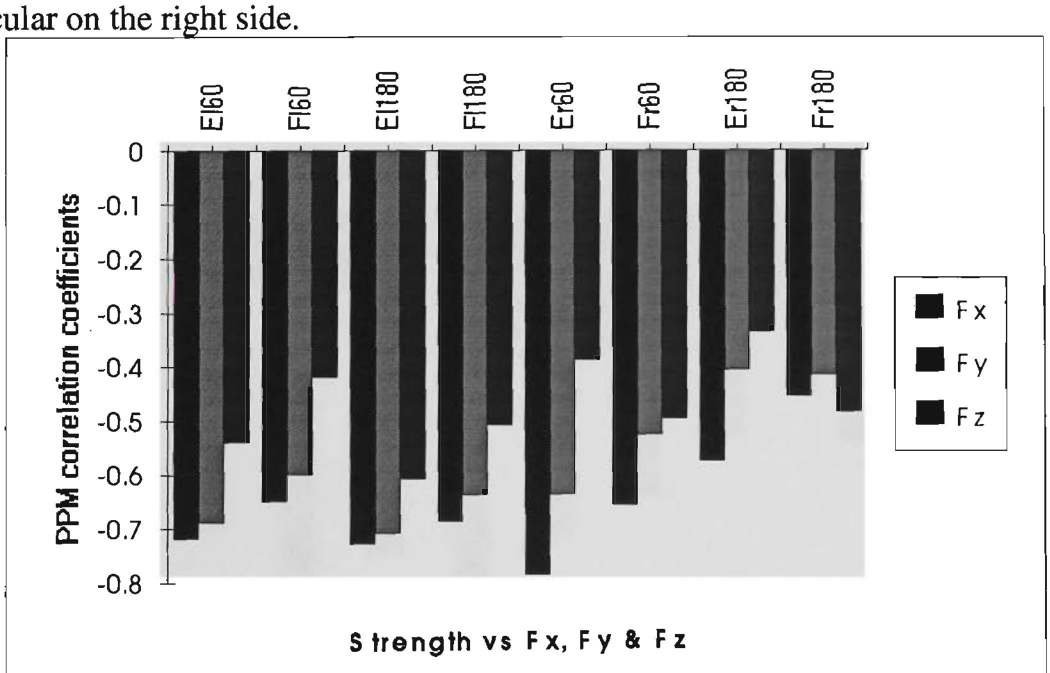


Figure 5.1 The PPM coefficients between strength and body sway forces of the elderly.

Moreover, it can be seen from Figure 5.1 that knee strength seems to represent stronger correlations in F_x and F_y components than with F_z [with the exception of Fl (r) 180°·s^{-1} vs F_z]. Furthermore, ML body sway forces (F_x) give larger PPM coefficients with strength than the AP forces (F_y) in this group, that is, the PPM correlation coefficients in absolute values have a general tendency of $F_x > F_y > F_z$.

Contrary to the elderly, there are no significant correlations between knee strength and standing balance in the young group. The PPM coefficients vary from -0.03 to -0.30 on strength and body sway force measurements. Therefore, knee strength did not correlate significantly with the standing balance for the young people. Figure 5.2 gives a comparison of the PPM correlation coefficients in knee extensions and flexions at the angular velocities of 60°·s^{-1} and 180°·s^{-1} with ML force F_x between the elderly group and the young group. As seen in Figure 5.2, none of the PPM coefficients in the young group is larger in magnitude than 0.31 (the criterion for significance). But the correlation of strength and balance is apparent in the elderly group.

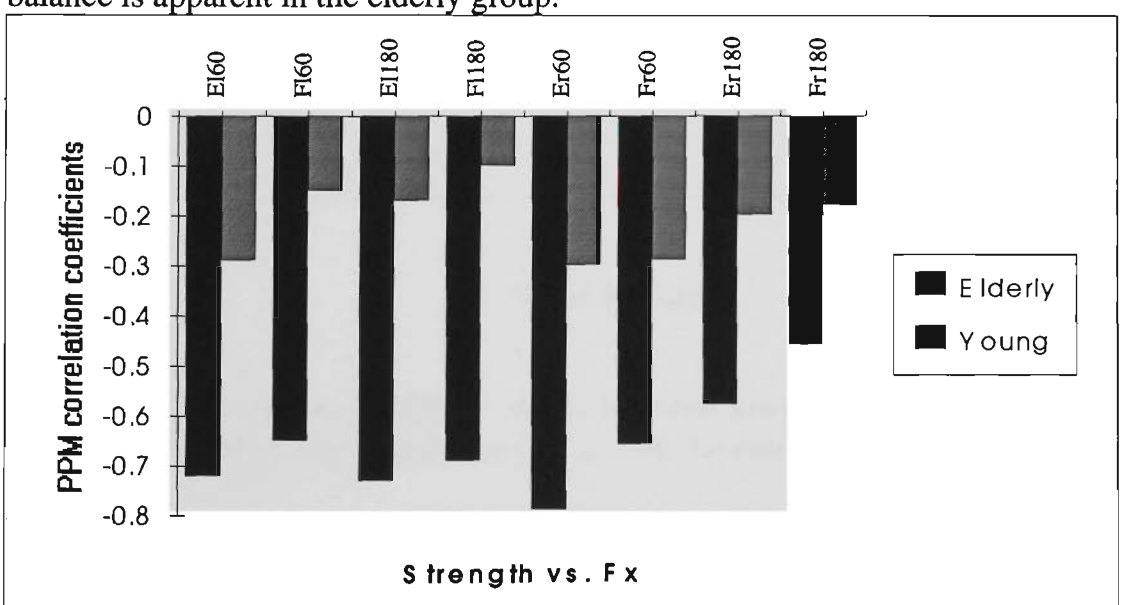


Figure 5.2 A comparison of the PPM coefficients between the elderly and the young groups.

Figure 5.3 and Figure 5.4 give details of the correlation between knee extensions at the angular velocity of $60°\cdot s^{-1}$ (left side) and the ML body sway force F_x with respect to the twenty-five subjects in the elderly and the young groups respectively. Using linear regression analysis, these data in the two groups can be fitted into two different straight lines respectively (as shown in Figure 5.3 and Figure 5.4). The slopes of the straight lines yield the PPM correlation coefficients. In the elderly group, the slope of the straight line (-0.72) in Figure 5.3 indicates a very clear negative correlation between strength and body sway forces [E(l) $60°\cdot s^{-1}$ vs F_x (l)]: the stronger is knee strength, the smaller are the body sway forces (ie better balance).

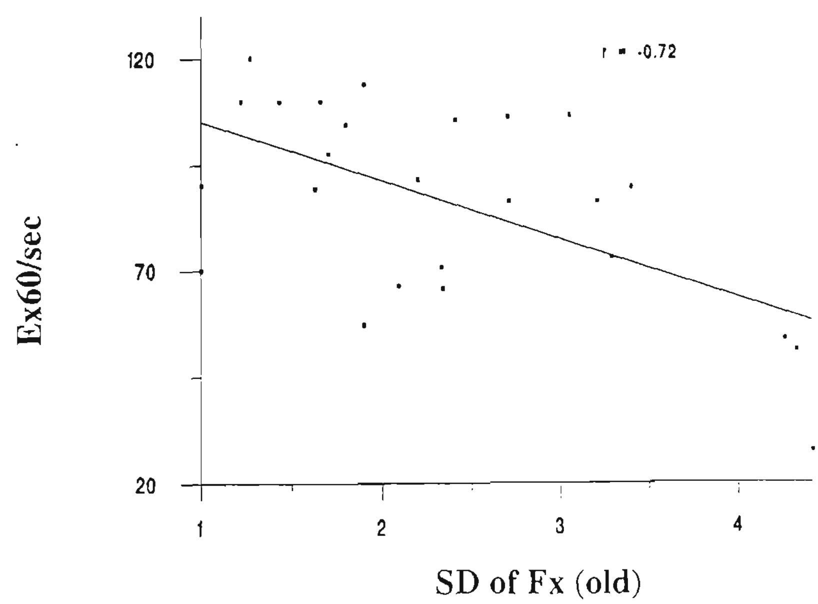


Figure 5.3 Correlation (PPM, r= -0.72) between knee strength [Ex(l), $60°\cdot s^{-1}$] and standing balance [F_x (l)] for the elderly group.

For the young group, however, the slope of the straight line in Figure 5.4 is -0.29 [E(l) $60°\cdot s^{-1}$ vs F_x] which is below the criterion of the significance

(0.31). Most of the data points in this group (Figure 5.4) are located between the area of two straight lines, that is, Ex = 100 and Ex = 200 N·m.

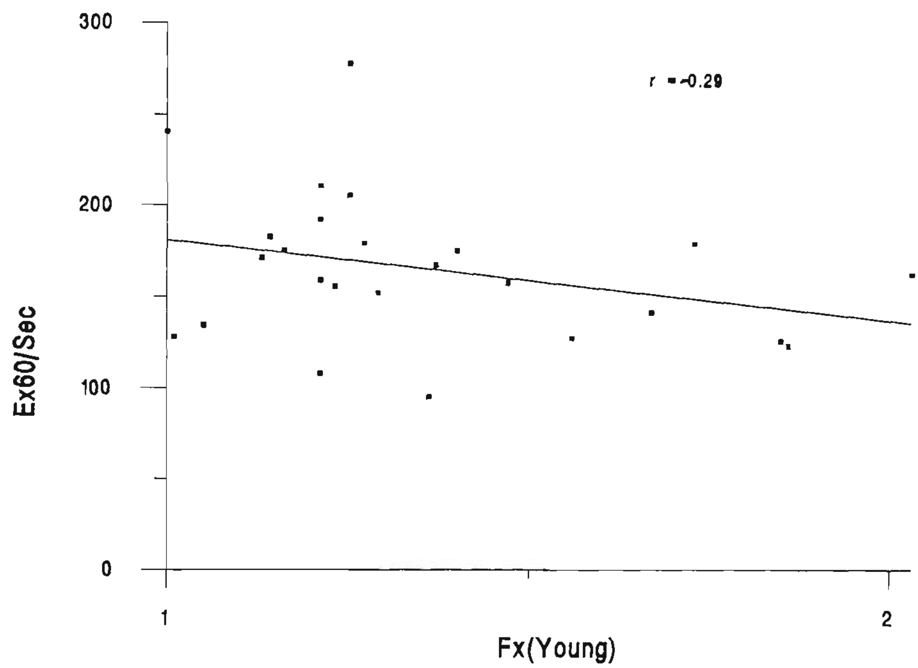


Figure 5.4 Relationship (PPM, r = -0.29) between knee strength [Ex(l), 60° ·s^{-1}] and standing balance [F_x (l)] for the young group.

5.4 DISCUSSION

The evaluated PPM correlation coefficients have demonstrated that lower extremity strength correlates significantly with balance in the elderly group but not for the young group. Such a result is consistent with the study of Rosenhall and Rubin (1975). The significant differences of the PPM coefficients between the elderly and the young imply a dramatic change as age progresses.

The results of PPM analysis indicate a significant relationship between strength and balance in the elderly group. Such a significant correlation between knee strength and balance of the elderly provides some validity to the hypotheses in this study. Postural control in the human is maintained by three main mechanisms

(Rosenhall and Rubin, 1975): the vestibular labyrinth in inner ear, vision and proprioception information. For an ordinary young person the functions of the three mechanisms operate under normal conditions, hence strength would not affect postural control or body balance significantly. However, as age increases, especially after 50s for an ordinary person, muscular strength of the lower extremity decreases rapidly (Johnson, 1972). With the degenerative changes in the vestibular system and vision of elderly people, lower extremity strength becomes a more important factor in maintaining static balance. As a result, elderly people could have difficulties in supporting their own body weight and balancing their posture. Therefore, better knee strength might enhance ability to maintain body balance.

The gradual quantitative changes of physical fitness and function of organs with ageing could lead to dramatic qualitative changes in strength and balance, as well as their relationships. Hence, for elderly people, the methods used and the study emphasis should not be the same as for young people. The qualitative model of Buchner et al. (1992) can be extended to explain the relationship between physical fitness (eg strength) and functional status (eg., balance). The relationship between balance (denoted as y) and strength (denoted as x) can be modelled generally using an exponential function with the form:

$$y = \beta - e^{\alpha x^2}$$

where α is a personal constant which decides the threshold H, $\beta > 1$, is also a personal constant. (see Figure 5.5). Since the older age is not uniformly associated with declines (Seeman, Charpentier, Berkman, Tinetti, Guralnik, Albert, Blazer and Rowe, 1994), the exponential constant α and therefore, threshold H is person dependent.

Figure 5.5 demonstrates the balance-strength relationship of the exponential function for a given α. There is a threshold H on the strength (x) axis. The balance and strength measures reach the optimum or best status at the threshold H. The strength axis can be therefore divided into two parts: the left side (strength $x < H$) and the right side (strength $x \geq H$) of the threshold H. If a person is not strong enough (the elderly people usually belong to this category), i.e., strength is in the left side of the threshold H, his or her balance ability will strongly correlate with strength. In this case, the greater the strength, the better the balance. The curve increases in the domain of $x \in (0, H)$. However, if the person is very strong, i.e., strength is on the right side of the threshold H, his or her balance ability would not have apparent changes as the strength varies. The curve in Figure 5.5 gives a straight line in the domain of $x \in [H, \infty)$.

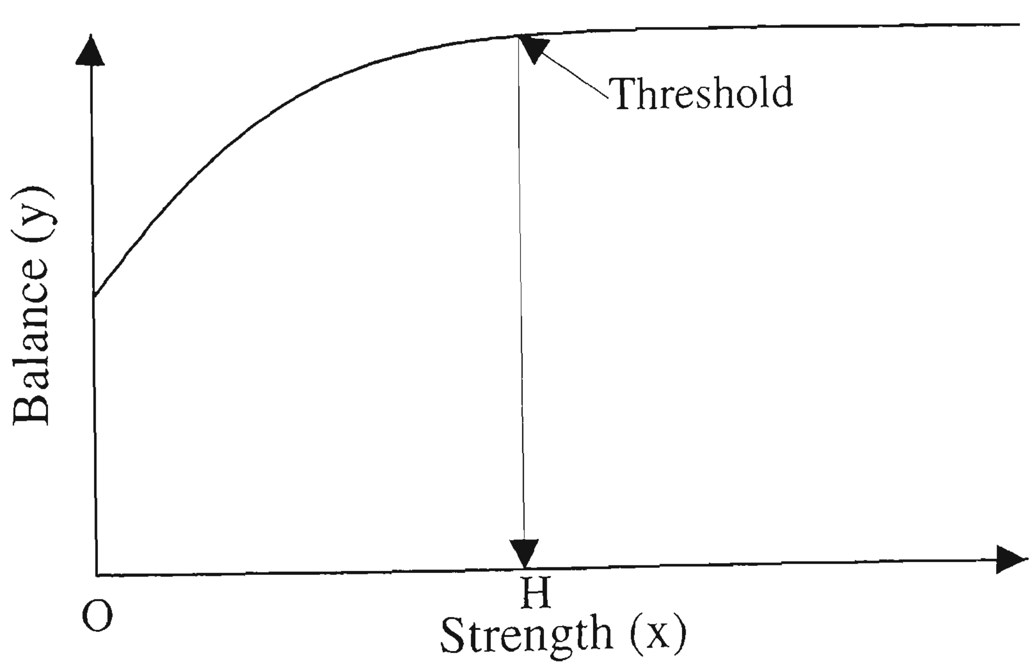


Figure 5.5 The general relationship between balance and strength.

While this research indicates that there exists a certain relationship between strength and static balance, it does not mean that this is a causal effect. It is possible that strength is related to a third (or multiple) factors which in turn has a direct influence upon balance. Strength as measured in this study could be an indicator of such factors as the sensitivity of the proprioception organs, the speed and coordination of motor nerve impulses, the speed of excitation of muscle cells or the extent of the electromechanical delay within the muscle. All of these factors, either singly or in combination, could have an effect upon balance and possibly, could be related to muscle strength.

In conclusion, the significant correlation between knee strength and static balance in the elderly indicates that knee strength either in its own right or as an indicator is an important element in maintaining body balance. However, as no causal relationship has been established it is not possible to quantitatively postulate that increases in strength in aged people will lead to protection against loss of balance and subsequent falls.

CHAPTER 6

EFFECT OF EXERCISES ON STRENGTH AND BALANCE IN THE ELDERLY POPULATION

6.1 INTRODUCTION

One of the objectives of this project was to investigate knee strength and postural sway in an elderly population. In Chapter Four it was established that the strength of the elderly population evaluated was ~45% of the young population, whereas the postural sway of the young population was only ~40% of the elderly. Chapter Five further analysed the information and indicated a strong correlation between lower extremity strength and static balance in the elderly population. However, a corresponding relationship was not found between strength and balance in the young population. The results from Chapter Four and Chapter Five have indicated that strength either directly or indirectly is an important element in affecting balance for the elderly population, but did not demonstrate if physical activity or exercises could affect strength and balance of the elderly.

Although there is no doubt that exercise induces improvements in function in young people (Leighton, 1964; Gardner, 1966; Wickstrom, 1969), the effect of exercise on balance and strength for the elderly is still equivocal with conflicting results from different studies. Some studies (Barry et al., 1966; Bassett et al., 1982; Crilly et al., 1989) argued that there were no improvements in balance ability for the elderly, especially for the very old. Crilly et al. (1989) reported that, at the end of a 12 week exercise program aimed at increasing postural stability for fifty elder female subjects (aged 72-92), there was no improvement in postural sway. Similarly, in a non-controlled study of the effects of a 10 week exercise program, Basset et al. (1982) found no significant changes in balance. Moreover, in spite of training directed specifically at the modification of balance and flexibility, it was found by Barry et al. (1966) that these abilities did not change at the end of a three month controlled study of 13 old subjects (mean age 72).

There is solid evidence that exercise enhances measures of fitness in older adults, particularly strength and aerobic capacity (Buchner et al., 1992). Exercise is a form of physiological stimulation which requires the adaptation of many organ systems and complex regulatory procedures (Skinner et al., 1990). Örlander and Aniansson (1980) and Bortz (1982) claimed that the ability to exercise could be increased by physical training at almost any age. Posner et al. (1992) reported that upper-body strength of people in their 70s can be increased by about 20% after six months of training. Buchner et al. (1992) summarised about 20 studies and concluded that a few months of strengthening exercise produces a wide range of improvement (5-200%) in strength. The evidence that exercise improves functional status is promising but inconclusive. Problems with existing studies include a lack of randomised controlled trials, a lack of evidence that effects of exercise can be sustained over a long period of time, inadequate statistical power, and failure to target physically unfit individuals (Buchner et al.,1992).

However, some existing studies have suggested that exercise may produce improvements in gait and balance. It has been shown (Wolfson et al., 1993) that short term exposure to altered sensory input or destabilising platform movement results in significant improvement in sway control and inhibition of inappropriate motor responses. This resulted in improved balance during repetitive testing. Wolfson et al. (1993) reported that balance training alone, or strength training alone will each be capable of significantly improving balance, gait and functional mobility, and that a combined program of balance and strength training will be more effective than either approach alone. Brown and Holloszy (1993) provided additional evidence that older adults are able to improve their functional capacity in response to exercise training.

Exercise usually is used as an alternative term for physical training or training. Strictly, exercise requires an immediate, short-term adaptation to increased energy demands, while physical training is a form of chronic or long-term adaptation to the repeated stimuli of exercise (Skinner et al., 1982). Several studies reported that the elderly population required a longer time to improve and that the improvements which they obtained with training were less than those found from younger people (Hettinger, 1961; Chapman et al., 1970). The principles of training for the elderly differ little from those used for young people, except they should be restricted to ensure that physiological stress is kept to a minimum (Rogers and Evans, 1993). It is apparent that the applications of some physical training programs which can be utilised to improve the strength or balance ability for young people, such as the wobble board (Balogun et al. 1992), are not effective or are not suitable in the elderly. The most suitable training programs to improve strength and balance in the elderly are not clear. The search for new, efficient and appropriate training programs for the elderly continues.

Certain basic guidelines need to be followed in the development of training programs for the elderly. In general, training programs should begin at low intensities to allow the older adults to gradually become more active. Usually, 25-35% $\dot{V}_{O_2}$ maximum would be a desirable starting level and this intensity should gradually be raised to about 50-60% V_{O_2} maximum. Sudden changes in intensity should be avoided as the elderly need more time to adapt to increasing demands of activity (Badenhop, Cleary, Schaal, Fox and Bartels, 1983). Also, the pattern of exercise should be modified on days when there are marked changes in the environment since these stresses add to those imposed by the exercise. Finally, since the elderly are generally less trainable, more time is required at each level of exercise to allow for a more complete adaptation before increasing the frequency, intensity or duration of the training program (Skinner et al., 1982). Moreover, further research should go beyond correcting methodological deficiencies in existing studies. Systematic studies are required on the functional effects of type, intensity and duration of exercise (Buchner et al., 1992).

It was hypothesised in this research that a combination of a Tai Chi training with other exercises aimed to increase knee strength and static balance would improve the lower extremity strength and standing balance of an elderly population. Tai Chi has been used for centuries in China and has been introduced to western countries. It is suitable for the middle-aged and the elderly (Mackie, 1981) as it complies with the existing guidelines on training programs for the elderly. Furthermore, the performance of Tai Chi involves all muscles and joints of the limbs and trunk. The intensity of the Tai Chi performance is relatively low and suitable to the elderly compared to many other activities. Tai Chi is a breathing exercise and its movements are directed by thought rather than by strength (Pang and Hock, 1984).

Wolf et al. (1993) introduced Tai Chi as the exercise program for one of three elderly groups in order to improve balance performance. Participants met twice weekly for 15 weeks to learn a condensation of 108 Tai Chi forms into 10 that emphasised movement components which were often restricted or absent with ageing. A home-based Tai Chi program was employed by Wolfson et al. (1993) in order to improve their function. It was reported that at the end of a combined training program including Tai Chi, the single stance postural sway in older women improved 17% (Judge et al., 1993).

These results support the hypothesis of this study. In this research, an intensive ten week training regime of the simplified 24-posture Tai Chi Chuan (Cheng style) and some simple exercises aiming to increase balance ability and lower extremity strength were investigated.

6.2 METHOD

6.2.1 Subjects

The same aged subjects (n = 25) as in Chapter Four and Chapter Five were involved in this training program. They were randomly divided into training and control groups, with fourteen subjects in the exercise (training) group, and eleven subjects in the control group. The characteristics of the subjects in the two groups are given in Table 6.1.

Table 6.1 Characteristics of the subjects in training and control groups

Variable	Training Group (N = 14)		Control Group (N = 11)		
	$\overline{X}$	SD	$\overline{X}$	SD	*p-value*
Age (yrs)	65.4	5.7	65.2	4.5	0.9
Weight (kg)	64.5	8.6	63.0	8.1	0.7
Height (cm)	165.9	7.2	165.2	7.4	0.8

6.2.2 Tai Chi Chuan

Tai Chi Chuan is an art and a science (Mackie, 1981). It was originally developed from martial arts and has existed for centuries in China. Tai Chi has become increasingly widely known and participated in by western communities. It is a science of control of physical and mental functions that improves the health and outlook of the performer. While undergoing Tai Chi, a performer's attention must be focused exclusively on what they are doing; the muscles must be relaxed; movements must be made slowly and smoothly; and consciousness---not effort---must guide all movements.

Tai Chi is very much an exercise designed to bring the body back into its natural balance (Mackie, 1981). Muscular cramps develop when the muscles do not have sufficient oxygen to enable them to contract smoothly. Tai Chi's gentle, unhurried movements and emphasis on deep breathing and relaxing the muscles give direct relief by helping untie cramps. Tai Chi is dynamic: once the movement has commenced, as at no time is the body motionless or static. Often, the greater part or all of the body weight is supported by only one leg. Transitions from one posture to the next are made very slowly and the knees are bent all the time. Moreover, the movements of Tai Chi are infused with both polarity and balance: concrete or hollow, open or closed, exhalation or inhalation, upper or lower, in front or behind, ascending or descending, tension or relaxation. Because of these characteristics, Tai Chi can be an ideal practice for the elderly to gain leg strength and body static balance.

Another advantage that Tai Chi has as an exercise is its convenience. Only ten minutes' exercise is all that is required for a practice session (Pang and Hock, 1984). It can be practised in a relatively small area and requires no special equipment or companion. Tai Chi is not only an exercise. Players can receive benefit not only physically, but also mentally and spiritually. Learning the movements and postures is just the beginning of the practice of Tai Chi.

The pictured simplified 24-posture Tai Chi Chuan (Cheng style) has been given in Appendix C.

6.2.3 Procedure

As mentioned in the previous Chapters, the procedures have been approved by the ethics committee of Victoria University Technology. Each participant signed the informed consent statement before the training program started. The procedures are detailed as follows.

1) Pre-Training Tests

The initial pre-training data were collected from those utilised for the elderly group in Chapters Four and Five (also see Figure 3.1 Research Design). That is, the one-legged (with eyes open) standing balance (F_X, F_y, F_Z, M_X, M_y) were measured on the force platform for both legs. Subsequently, knee strength with respect to extensions and flexions (Ex, Fl) was measured at the angular velocities of 60 $°\cdot s^{-1}$ and 180 $°\cdot s^{-1}$ respectively using the Biodex dynamometer system. The balance and strength parameters from the pre-training tests have been given in Table 4.3 for the elderly group.

2) Training

The 10 week training program for the exercise elderly group (n=14) has been outlined in Table 3.2 of Chapter Three. The training group exercised supervised twice a week for one hour with walking as the warm up activity and Tai Chi performances of three 10 minutes sessions each Tai Chi . During the breaks in the Tai Chi sessions, some simple combined exercises such as leg bending and stretching, ankle dorsiflexion and plantar flexion, leg pressing as well as postural control exercises were performed by the subjects in the training group. Moreover, in the period of the 10 week training program, daily individual Tai Chi home practice was requested.

The simplified 24-posture Tai Chi (Cheng's style, see Appendix C) was utilised in the training sessions. The movements of the simplified 24-posture Tai Chi program emphasise movement components restricted or absent with aging. In the first five weeks of the training period, the subjects were instructed to perform the basic Tai Chi movements and postures. The subjects followed the Tai Chi instructor and practised with eyes open. In the final five weeks, when the subjects were able to cope with the fundamental postures of Tai Chi, the training group practised independently (in a group) without instruction but under supervision. Meanwhile, the subjects in this group gradually played Tai Chi following the Tai Chi music with eyes closed. Both the training group and the control group were also requested to maintain an activity diary over the training period.

3) Post-Training Tests

The same balance and strength parameters were measured and recorded at the end of the ten week training period for both training and control elderly groups. The data were analysed with a paired student's t-test of the mean values of pre-training and post-training data, at the level of $\alpha = 0.05$.

6.3 RESULTS

The activity diaries for both the training and control groups underwent subjective analysis to determine if any extraneous, significant physical activity had occurred which might have influenced the results of the project. This review did not reveal any such physical activity and thus the results of the study could reasonably be interpreted as being caused by the training program.

6.3.1 Pre-Training Tests

The strength and balance measures of the pre-training tests for the training and control groups are given in Table 6.2. Since the training group and control group were randomly selected, there should not be any significant differences between the two groups. In order to confirm this hypotheses, the data given in Table 6.2 were analysed by a paired student's t-test. The calculated t-values are also given in Table 6.2 (last column). It is apparent from the t-values that there are no meaningful statistically significant pre-training differences between the training group and the control group for the measures of both strength and balance.

Table 6.2 Strength and balance parameters pre-training for the training and control groups.

	Training (n=14)	Control (n=11)	
Variable	$\overline{X} \pm SD$	$\overline{X} \pm SD$	t-value
	Strength		
E60°·s^{-1} (N·m)	73.7 ± 25.0	79.3 ± 14.4	$0.57^{n.s}$
E180°·s^{-1} (N·m)	48.9 ± 15.6	57.6 ± 14.7	$1.17^{n.s}$
F60°·s^{-1} (N·m)	42.5 ± 21.2	44.7 ± 15.0	$0.29^{n.s}$
F180°·s^{-1} (N·m)	28.6 ± 11.7	31.4 ± 9.8	$0.48^{n.s}$
	Balance		
F_x (N)	3.3 ± 1.1	2.6 ± 0.5	$-2.05^{n.s}$
F_y (N)	2.8 ± 0.7	2.1 ± 0.5	-2.48*
F_z (N)	4.6 ± 1.4	4.0 ± 1.9	$-0.81^{n.s}$

E60°·s^{-1}, E180°·s^{-1} = Knee extensions at the angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.
F60°·s^{-1}, F180°·s^{-1} = Knee flexions at the angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.
F_x, F_y, F_z = Body sway forces on the X, Y, Z axes of single stances.
*** = $p < 0.05$; $^{n.s}$ = not meaningful statistically significant at α=*0.05* level.**

6.3.2 Isokinetic Knee Strength

Table 6.3 gives the post-training results (mean and SD values) of the isokinetic knee strength for the training group and the control group. There are apparent differences in the training and the control groups with respect to the strength measurements. Compared to the corresponding strength parameters reported in the pre-training (see Table 6.2), the improvements ($\Delta\overline{X}$, Table 6.3) of the post-training strength parameters in the training group are significantly larger than those in the control group. Table 6.3 also gives the t-values of the t-test at α =0.5 level with respect to the pre-training and post-training within the training group and the control group, respectively. The results of the t-test indicate a statistical significance in the training group before and after the training, whereas significant differences between pre-training and post-training in the control group do not exist.

Table 6.3 Comparison of post training for leg strength in training and control groups

Variable	Training Group (n=14)			Control Group (n=11)		
	$\overline{X} \pm SD$	$\Delta\overline{X}$	t-value***	$\overline{X} \pm SD$	$\Delta\overline{X}$	t-value n.s
$E60°{\cdot}s^{-1}$(N·m)	87.5 ± 21.9	13.8	-5.58	82.2 ± 14.5	2.9	-1.50
$E180°{\cdot}s^{-1}$(N·m)	63.8 ± 15.9	14.9	-6.87	58.8 ± 13.0	1.2	-1.54
$F60°{\cdot}s^{-1}$(N·m)	51.6 ± 19.6	9.1	-6.22	45.0 ± 15.3	0.3	-0.30
$F180°{\cdot}s^{-1}$(N·m)	37.5 ± 10.2	8.9	-6.31	32.6 ± 9.3	1.4	-3.94

$\Delta\overline{X} = \overline{X}$ (post-training) - $\overline{X}$ (pre-training).
$E60°{\cdot}s^{-1}$, $E180°{\cdot}s^{-1}$ = Knee extensions at the angular velocities of $60°{\cdot}s^{-1}$ and $180°{\cdot}s^{-1}$ respectively.
$F60°{\cdot}s^{-1}$, $F180°{\cdot}s^{-1}$ = Knee flexions at the angular velocity of $60°{\cdot}s^{-1}$ and $180°{\cdot}s^{-1}$ respectively.
***** = $p < .001$; n.s.=not statistically significant at $\alpha = 0.05$ level.**

Figure 6.1 gives the comparison of knee strength measured pre-training and post-training of the training group. There is an apparent improvement in the strength from the post-training of the experimental group. The largest relative strength improvement in the training group is given by 31.1% ($F180°{\cdot}s^{-1}$) and the smallest is 18.7% ($E60°{\cdot}s^{-1}$). Moreover, the knee strength increase with respect to the higher angular velocity ($180°{\cdot}s^{-1}$) is more than that with the lower angular velocity ($60°{\cdot}s^{-1}$). The relative percentages of extension and flexion improvement at the velocity of $60°{\cdot}s^{-1}$ increased 18.7% and 21.4% respectively, while they were improved 30.5% and 31.1% at the velocity of $180°{\cdot}s^{-1}$. Moreover, the absolute extension strength increased more than the corresponding flexion strength. The absolute extensions have been improved 13.8 N·m and 14.9 N·m at the velocities of $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$ respectively; but they increased 9.1 N·m and 8.9 N·m at the two different angular velocities. In summary, the lower extremity strength of the training group has been improved 20%-30% at the end of the training program.

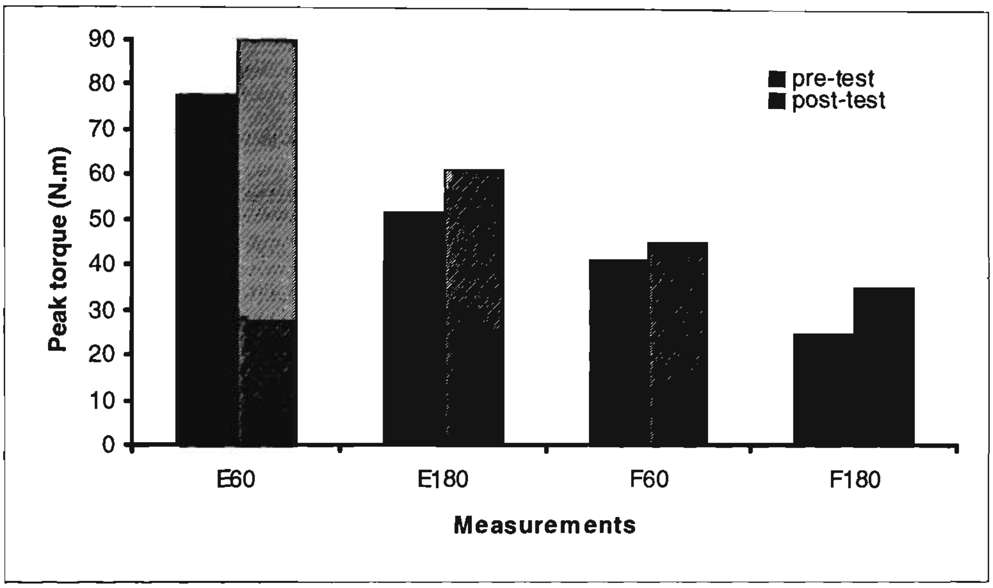


Figure 6.1 Comparison of the pre-training and post-training strength of the training group. E60, E180 = Knee extensions at the angular velocities of $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$ respectively. F60, F180 = Knee flexions at the angular velocities of $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$ respectively.

However, the results of the paired student's t-test demonstrate that there is no significant difference in strength between pre-training and post-training in the control group, which can be seen in Figure 6.2. There were slight increases of 3.7% and 2.1% for the extensions at the angular velocities of $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$, respectively; and 0.6% and 4.5% for the flexions at the two angular velocities. These changes in strength may arise from the daily activity during the training period or it may be that the subjects were more familiar with the Biodex system at the post-training measurements.

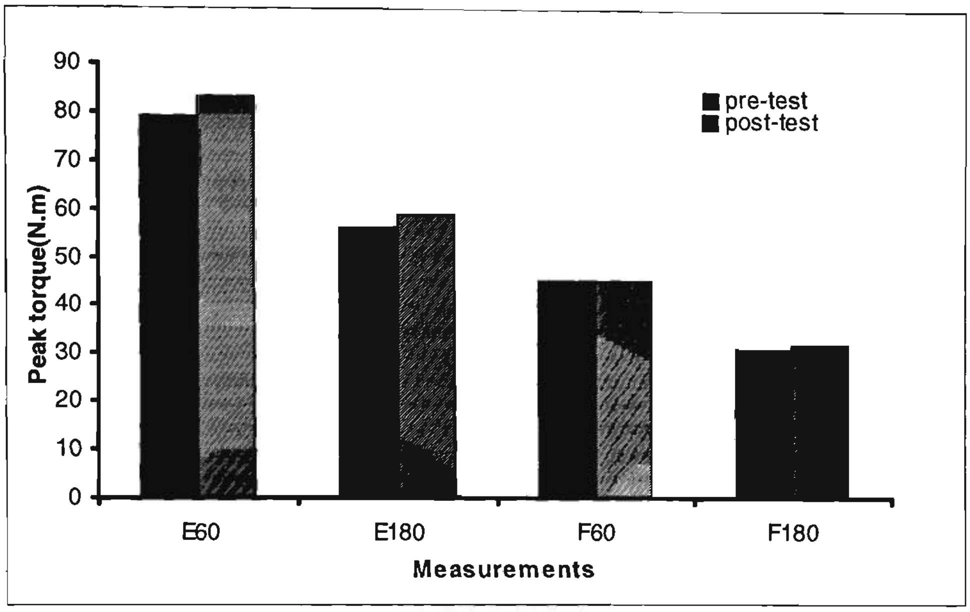


Figure 6.2 Comparison of the pre-training and post-training strength of the control group. E60, E180 = Knee extensions at the angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively. F60, F180 = Knee flexions at the angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.

Figure 6.3 gives the comparison of the improvements ($\Delta\overline{X}$ in Table 6.2) in lower extremity strength between pre-training and post-training measurements in the training group and the control group. It is obvious that the significant differences in the changes after training are in the training group and not the control group. Extension can be improved more efficiently than flexion. Figure 6.3 demonstrates that the Tai Chi training program utilised in this study improved the lower extremity strength of the elderly.

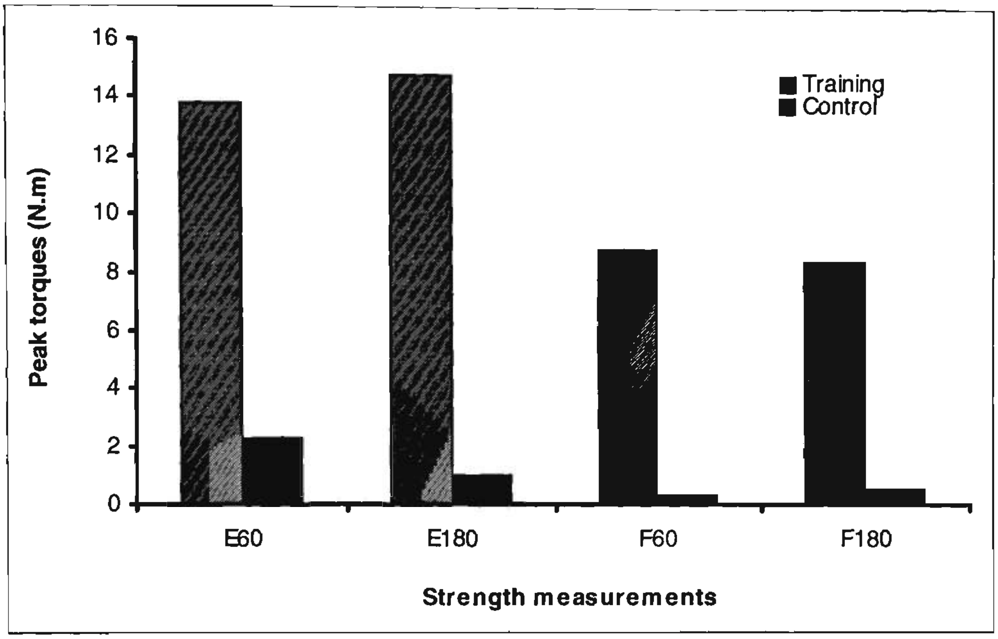


Figure 6.3 Comparison of the strength improvements by training between the training and control group.
E60, E180 = Knee extension at the angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.
F60, F180 = Knee flexion at the angular velocities of 60°·s^{-1} and 180°·s^{-1} respectively.

6.3.3 Static Balance

Post-training results (mean ± SD) of the static balance for the training group and the control group are given in Table 6.4. In the training group, the body sway forces declined 19.4%, 14.8% and 11.4% for F_x, F_y and F_z respectively. The values from paired student t-test analysis were of -3.80 for F_x ($p<0.01$) and -2.40 for F_y ($p<0.05$). However, F_z were not statistically significant difference between the pre-training and post-training of the training group. Because F_z is related to a subject's body weight which would not change much in a period of 10 weeks, such a result could be anticipated.

Table 6.4 Comparison of body sway forces of the post-training static balance in the training group and control group

	Training Group (n=14)			Control Group (n=11)		
Variable	$\bar{X} \pm SD$	*t-value*	*p*	$\bar{X} \pm SD$	*t-value*	*p*
F_x (N)	2.5 ± 0.9	-3.80	**	2.6 ± 0.5	-0.01	n.s.
F_y (N)	2.3 ± 0.6	-2.40	*	2.2 ± 0.5	0.62	n.s.
F_z (N)	3.9 ± 1.3	-1.68	n.s.	3.8 ± 1.3	-0.63	n.s.

F_x, F_y, F_z = body sway forces on the X, Y, Z axes of single stance.
***=*p<0.05*; **=*P<0.01*;**
n.s.= no statistically significant difference at α=*0.05* level.

The pre-training and post-training body sway forces (mean) for the training group are illustrated in Figure 6.4. The decrease of the body sway forces indicates better balance is gained after training.

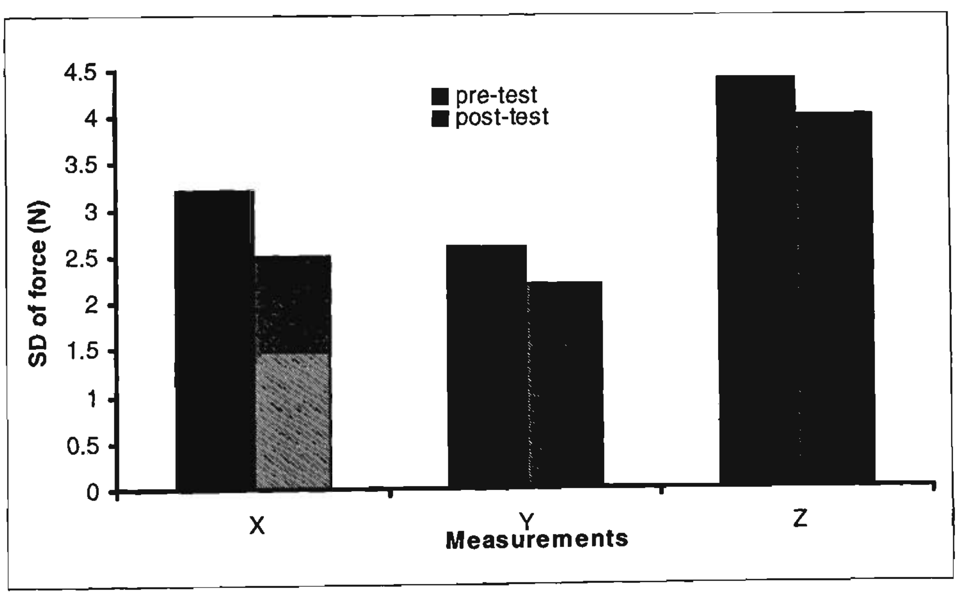


Figure 6.4 Comparison of body sway forces (static balance) in the pre-training and post-training of the training group, where X, Y, and Z are the body sway forces on X, Y, and Z axes, respectively.

On the other hand, the t-values in the control group (see Table 6.4) showed that there were no statistically significant changes in the body sway forces in the control group. The changes of the three body sway forces are inconsistent: the ML force (F_x) remained unchanged, while the AP sway force (F_y) increased up to 4.8%, but the vertical body sway force (F_z) a decrease. A comparison of pre-training and post-training measures of static balance for the control group is given in Figure 6.5.

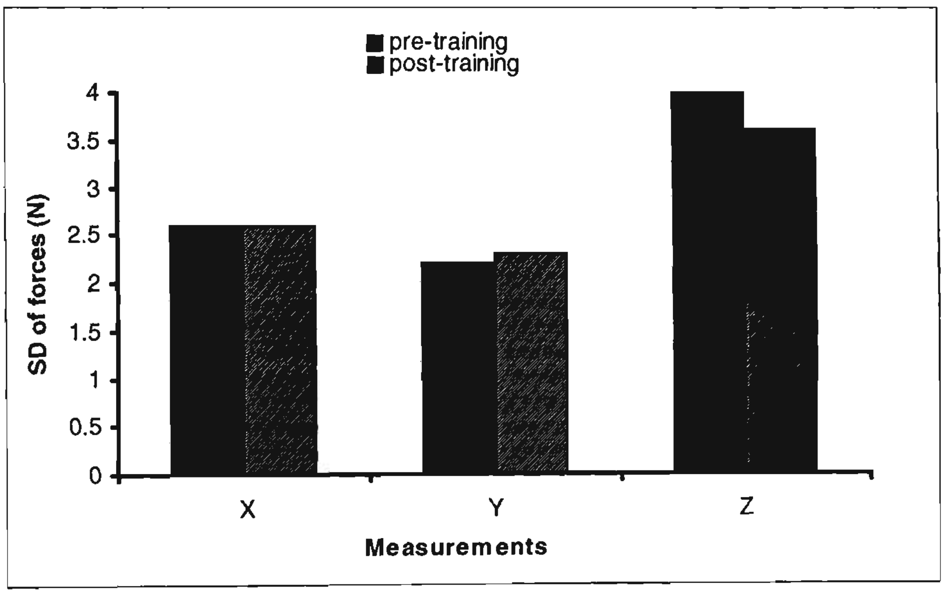


Figure 6.5 Comparison of body sway forces (static balance) in the pre-training and post-training of the control group.

Figure 6.6 compares the changes in body sway force between pre-training and post-training, in the training group and the control group. There are consistent declines in ML, AP and vertical body sway forces in the training group indicating that the static balance of the training group had improved at the end of the training period. However, the body sway forces in the control group changed randomly. The ML body sway force (F_x) gained no change, the AP force (F_y) increased by 0.5% and the vertical force (F_z) decreased by 5%.

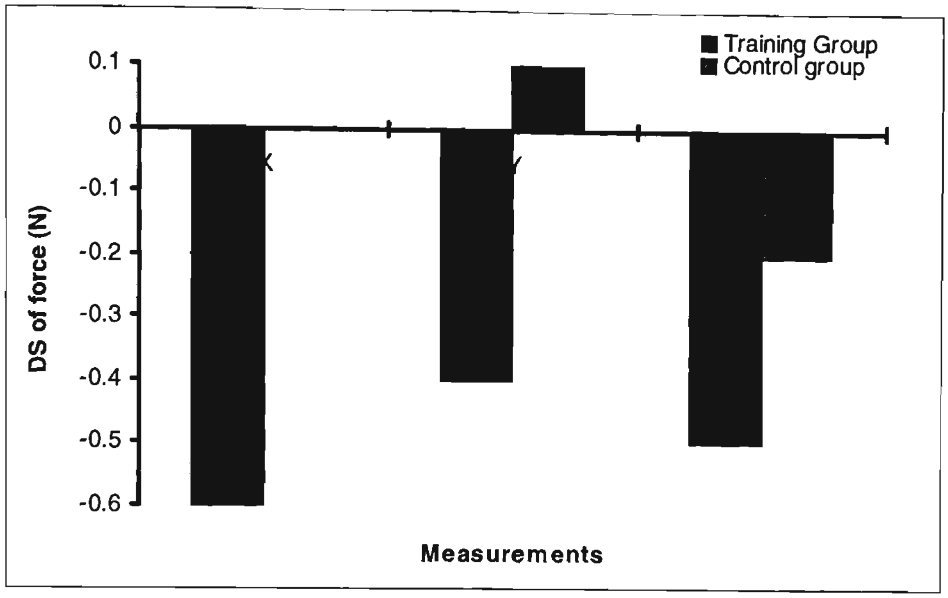


Figure 6.6 Comparison of the decreases in body sway forces (F_x, F_y and F_z) after training in the training group and control group.

6.4 DISCUSSION

The postulation of this study that the knee strength and static balance of the elderly can be improved with a specific training program has been confirmed. For the lower extremity strength, there was a ~20-30% increase in the training group but no significant changes found in the control group. The results were in the range of the improvement of strength of 5-200% summarised by Buchner et al. (1992). The strength improvement in this study also suggests that training program for the elderly can not be expected to be as efficient as the training programs for young people who can gain 5~200% increases in strength (Balogun et al., 1992).

The improvement of strength in the training group indicates that the training program designed in this project is appropriate for the elderly people. The fact that the knee strength at lower angular velocity ($60°\cdot s^{-1}$) increased less than at higher angular velocity ($180°\cdot s^{-1}$) and that the strength in extension improved more than that in flexion at the same angular velocity, indicated that the training program so designed was a suitable program especially for extension at the higher angular velocity. This could be the result of the Tai Chi performances which require tension at the knees, ie., the knees are bent to support the body weight. The knee bending postures can be considered as an effective way of strengthening knee and leg muscles.

The subjects in the training group decreased in their SD of body sway forces by 11-22% over the training period. The balance improvements in the training group validate the hypothesis of this study that exercise has beneficial effects on the elderly. It is possible that the balance improvement in this study could be the result of both better strength and balance ability gained from training. As such, this activity (Tai Chi) appears to be a useful technique for the maintenance or improvement of lower body strength. Most of the Tai Chi postures require a one-legged stance and maintenance of body balance. Tai Chi training programs are a useful addition to existing exercise programs on strength and balance of the elderly.

The results of this study have provided evidence of a correlation between the lower body strength and static balance in the elderly. While the improvements of both strength and balance infer a causal relationship, the results should be interpreted with some caution. As discussed above, some aspects of the training parallel the physical requirements of the measure of balance. It is possible that improvement in static balance is caused by a learning effect or by an improvement of a central factor influencing balance, ie. vestibular function rather than improvement in strength. It must also be recognised that the one-legged stance in Tai Chi resembled the task utilised to measure balance ability. Thus it is possible that there was a learning effect and part of the decrease in sway in the training group could be attributed to the subjects' ability to better perform the criterion test without any true increase in their ability to maintain balance.

As discussed in Chapter Five, it is also possible that there is a third (or indeed multiple factors) involved in these relationship changes. Such factors as response characteristics, nerve and muscle fibre conduction velocities, and/or electromechanical delay could influence the relationships described in this study.

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 SUMMARY

The relationship between static balance and lower extremity strength, as well as physical training in the aged were investigated in this thesis. Previous studies on static balance, muscle strength (especially for the lower leg extremity), physical training and their relationships were reviewed in Chapter One and Chapter Two. Chapter Three provides a detailed description of the methodology used in this project. For the static balance measurements, an AMTI multi-component force platform was determined as the most appropriate balance measuring apparatus for the elderly population. The balance parameters (body sway forces and force moments) were determined for 25 elderly subjects aged from 56 to 78 years on the force platform with the standard deviation of Fx, Fy, used as the criterion parameters. The test-retest reliability for these parameters yielded ICC coefficients up to 0.62. Knee strength was measured on a computerised Biodex dynamometer system for these subjects under the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$, respectively. Large ICC coefficients (with the highest of 0.95) indicated that the strength measurements using the Biodex dynamometer were highly reliable.

Based on these measurements, the relationship between balance and strength for the elderly was investigated in Chapter Four and Five. In order to understand the characteristics of the elderly population, a parallel balance and strength measurement profile was obtained for a group of young people (n=25). A distinct difference between the aged and the young was found. There was a significant correlation between balance ability and knee strength for the aged but not for the young. Pearson product moment (PPM) and a one factor ANOVA ($p<.05$) were used to analyse balance and strength relationship between different age groups.

There is general agreement that exercise can improve physical fitness for any age group (Örlander and Aniansson, 1980). Training programs for the elderly are more restricted than those used for young people. Such programs for the elderly should start at low intensities to allow the aged to gradually become more active. Due to its characteristics, Tai Chi Chuan is an appropriate exercise regime for the elderly population. A physical exercise program of Tai Chi combined with some simple exercises was developed to improve the lower leg extremity strength and balance ability for the older adults. Chapter Six provides a ten week Tai Chi training program, comparisons between the pre-training and post-training measurements for the elderly in the training group as well as post-training measurements between training and control groups. A paired student's t-test analysis was employed to analyse whether any significant changes existed in balance and strength between pre-training and post-training for the training group (n=14) and control group (n=11). The t-test analysis indicated that the training group significantly improved lower leg strength and body sway scores ($p<0.5$).

7.2 CONCLUSIONS

Within the limitations of this study the following conclusions have been reached.

There is a significant correlation between balance and lower extremity strength in the elderly. Such a correlation does not exist in young people, even though the latter have consistently better strength and balance than the elderly. For aged people, the stronger the knee strength, the better balance, ie., the smaller body sway.

Force platform and Biodex dynamometer systems are appropriate to measure balance and strength for the elderly. They are not only sensitive and reliable, but also safe and simple. Body sway forces are good parameters in quantifying balance ability; whereas absolute peak torques of knee extensions and flexions at certain angular velocities (say, $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$) are suitable parameters for the knee strength measurement of the elderly.

Tai Chi has beneficial effects on both strength and balance for the elderly. The improvements depend on the design of the training program, the intensity of the program as well as the training period. Although the changes gained from training vary from person to person, in this study generally strength increased more than balance at the end of the training regime.

Most exercise training programs improve strength more than balance for the elderly. Because balance is affected by multiple factors, its improvement is a more difficult task. Theoretically Tai Chi Chuan should be an appropriate exercise to increase both lower extremity strength and balance ability for all ages but particularly for the elderly. This study demonstrates that a Tai Chi training program combined with some simple exercises, can improve both knee strength and balance for the elderly.

7.3 RECOMMENDATIONS FOR THE LABORATORY ASSESSMENT OF ISOKINETIC STRENGTH AND STATIC BALANCE IN THE ELDERLY

7.3.1 Strength Measurements

There are some risks of both or either a cardiovascular episode or muscle strain in undertaking strength measurements in an elderly population. In order to avoid incidents of this nature, elderly subjects should be provided with considerable familiarisation of the testing protocol and instrumentation. A 5-10 minute warm-up should be given before any test performance. Suitable angular velocities for this group are $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ with a concentric contraction.

Measures of strength can be expressed as either absolute or relative measures. Relative measures take into account body size or an aspect of body composition, eg., lean body weight. It can be argued that relative measures are more closely related to ability to perform body movements (Kelley, Dainis and Wood, 1976). However, there is no standard measure of relative strength (Buchner et al. 1992). For example, Hopkins, Murrah, Hoeger and Rhodes (1990) divided strength by body height, whereas Buchner, de Lateur and Larson (1992) divided strength by both height and weight. In this thesis, the absolute value of the peak torque of isokinetic concentric contraction was used as the parameter of strength measurement for the aged as after fifty years of age, strength decreases although the body weight appears to increase in some elderly people. Body weight and/or height for the aged is not necessarily proportional to the mass of muscle but is often more related to fat content. Therefore the relative strength (ie., the ratio of the absolute peak torque and body weight or height), which can be a good parameter for the strength of young people, may not be a valid measurement for the aged.

7.3.2 Static Balance

The assessment of balance is a difficult task in the elderly population. Not all the existing measures of balance performance are practical for the aged. There are two commonly used methods for the elderly, centre of pressure excursion (COPE) with single and/or double legged stances, eyes open and/or closed; and body sway force measurements with single and/or double legged stances together with eyes open and/or closed combinations. The latter has been widely used as the balance measure for the aged. The eyes closed with single legged stance can be difficult for an elderly population. Consequently, one-legged and two-legged stances with eyes open are suggested as the flexible static balance measuring performances for the elderly.

Most research has concentrated on the body sway forces (F_x, F_y, F_z) and the centre of pressure (A_x and A_y) for balance measurements. Recently, frequency and amplitude (eg., Liu and Lawson, 1995) were introduced to measure balance. In order to detail a subject's behaviour during a balance measurement, a spectral description may be needed. The power spectrum of fast Fourier transform (FFT) is sensitive to the balance performance and should be a good description for the assessment of static balance. Therefore, FFT spectral analysis is highly recommended.

7.4 RECOMMENDATIONS FOR EXERCISE PROGRAMS OF THE ELDERLY

An obvious way that exercise could affect fall risk for the elderly is via its effects on physical fitness. Exercise may have other mechanisms for influencing functional status. For example, exercise has neurological effects, as illustrated by studies of exercise on cognitive function (Balogun et al. 1992). Research has indicated that a wobble board exercise program can significantly increase the strength of lower extremity muscles and improve balance performance for a young population (Joseph. et al. 1992). However, such a program could not be used for the elderly subjects because of the danger of falls.

Although exercise programs have been developed for rehabilitation and recreation in the elderly, exercise programs to improve strength and balance for the elderly are still under development. Tai Chi, in combination with simple muscle exercises, does appear to be effective in improving strength and balance in the elderly. Tai Chi Chuan involves a number of muscles and joints of the limbs and trunk, and its movements emphasis balance as well as muscular strength. It is recommended that a mixed exercise (Tai Chi combined with simple exercise) would be suitable for the improvement of lower leg extremity strength and stability in an elderly population.

7.5 RECOMMENDATIONS FOR FUTURE RESEARCH

There are multiple factors which affect balance and strength. The role played by each of the mechanisms associated with balance and strength remain unclear. The interplay of these factors may become more complicated as they are influenced by age.

Lower extremity strength is an important factor in maintaining body balance not only because leg strength is essential for the elderly to balance their body, but also because it appears to play a role in recovering from losses of stability. However, changes with age involving higher levels of integration (ie. the central nervous system) on such complex motor functions as balance, reaction time and neuromuscular coordination remain to be investigated. It is still an open question whether leg strength is the primary factor involved in balance or whether it is an indicator of the relative role of a third (or other) influence.

That exercise can improve leg strength and static balance has been confirmed by a ten week Tai Chi training. However, there is still a need to compare Tai Chi and other exercises to develop an optimal appropriate program for improving strength and balance of elderly people.

When it is possible to describe the mechanisms involved in the maintenance of balance it will then also be possible to better prepare self maintenance training programs to ensure the elderly are less likely to have injury causing falls. In a society where de-institutionalisation of the elderly is a social and economic priority such programs will have a beneficial effect upon both the resources required for our health system and for the quality of life of our elderly.

The relationships between exercise, the ageing process, strength and balance are complex and uncertain. More research in this challenging field is needed before such questions can be elucidated.

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APPENDIX A

1. Subject Information Sheet
2. Subject Informed Consent Form for the Young Group
3. Subject Informed Consent Form for the Elderly Group

SUBJECTS INFORMATION SHEET

Investigators:

Professor David Lawson
Mr. Shaohua Liu
Department of Physical Education and Recreation
Victoria University of Technology

Date:

Jan. 1993 to Aug. 1993

The object of this experiment is to determine the relationship between strength and balance in the old age group. Each subject in this experiment will be tested the muscle strength of the lower body by employing the Biodex system and balance which will be performed on the force platform. The subjects will be required to do three times of concentric contraction in each of isokinetic test of knee extension, flexion and one legged stance of each leg on the force platform for balance test. In general, the performances on both the Biodex system and the force platform system are quite safe for young subjects. However, it would have some potential risks for aged people.

Muscle strength test

Subjects will be arsed to bend and straighten their knee as strongly as they can - The Biodex machine will measure the maximum strength exerted. An appropriate light warm up will be provided prion to tis test. The subjects should not normally experience pain during this test . However , there is any discomfort , it should be reported to other test. It is possible trail slight muscle suffices may be experienced after the test. This is normal for this kind of exercise. During the test, your blood pressure will rise. This is normal, but if you feel that it may be a problem for you, inform the tester. We can check with your doctor if necessary.

Balance test

In this test, the subject will stand on a special measuring platform. The platform does not move. A completed will measure how well you keep your balance. If you feel anxious about losing your balance at any time, please inform the tester.

INFORMED CONSENT FOR YOUNG SUBJECTS IN EXPERIMENTS

Investigators: Professor David Lawson,
Mr. Shaohua Liu

Date: Jan. 1993 to Aug. 1993

I, ...
of ....
certify that I have the legal ability to give valid consent and that I am voluntarily giving my consent to participate in the experiment entitled:

"..
....
...."

being conducted at Victoria University of Technology by:

....

I certify that the objectives of the experiment, together with any risks to me associated with the procedures listed hereunder to be carried out in the experiment, have been fully explained to me by:

....

and that I freely consent to participation involving the use on me of these procedures.

Procedures

....
....
....
....
....

I certify that I have had the opportunity to have my questions answered and that I understand that I can withdraw from this experiment at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the confidentiality of the information I provide will be safeguarded.

Signed: ....)
)
Witness other than the experimenter:) Date: ....
)
....)

INFORMED CONSENT FOR ELDERLY SUBJECTS IN EXPERIMENTS

Investigators:

Professor David Lawson
Mr. Shaohua Liu
Department of Physical Education and Recreation
Victoria University of Technology

Date of Investigation:

Jan. 1993 to Aug. 1993

I, ______________________ hereby voluntarily consent to participate in the research entitled:

____

____

conducted by: ______________________________

I understand that the information obtained from this research may be used in future research, and may be published. However, my right to privacy will be retained, ie.: personal details will not be revealed.

The procedure as set out in the attached information sheet has been explained to me and I understand what is expected of me and the benefits and risks involved. My participation in the project is voluntary.

I acknowledge I have the right to question any part of the procedure and can withdraw at any time without this being held against me.

Signed by Subject: ______________________________

Date: ______________

Witness: ______________________ (Name)

______________________ (Signature)

______________________ (Date)

VICTORIA UNIVERSITY OF TECHNOLOGY

Study: ______________________________

Investigator: ______________________________

Subjects Name: ______________________________

Age: ____________________ Height: ____________________

Date: ____________________ Sex: ____________________

<u>MEDICAL HISTORY</u> (This will remain confidential)

Are you currently receiving medical treatment or advice?

1 [ ] Yes
2 [ ] No

Have you experienced over the past week: colds, influenza, fever, unusual fatigue or blood donation?

1 [ ] Yes
2 [ ] No

Do you know of any reason, health or otherwise, why you should not take part in these tests?

1 [ ] Yes
2 [ ] No

Family Medical History. Indicate if any of your immediate family (parents, brothers, sisters, grandparents) have experienced any of the following, the age at which diagnosis occurred and the person's relationship to you.

YES	Relationship and Age
High Blood Pressure	______________________________
High Cholesterol	______________________________
Heart Disease	______________________________
Stroke	______________________________
Diabetes	______________________________
Bleeding Disorders	______________________________

Fitting, Fainting, Blackouts, Muscle Weakness, Loss of Sensation

1 [ ] Yes
2 [ ] No

Details: ____________________

Headaches

1 [ ] Yes
2 [ ] No

Details: ____________________

Nervous Conditions

1 [ ] Yes
2 [ ] No

Details: ____________________

Bone or Joint Injury (Back/Knee/Ankle/Hip/Shoulders)

1 [ ] Yes
2 [ ] No

Details: ____________________

Other Joint Problem (Arthritis/Gout/Other)

1 [ ] Yes
2 [ ] No

Details: ____________________

How often do you take over the counter medications such as aspirin etc.

1 [ ] Daily
2 [ ] Weekly
3 [ ] Occasionally
4 [ ] Never

Gut Problems (Ulcer/Abdominal Pain/Diarrhoea/Constipation/Hernia)

1 [ ] Yes
2 [ ] No

Details: ______________________________

Unexplained Weight Loss

1 [ ] Yes
2 [ ] No

Details: ______________________________

Urinary Problems (Burning/Difficulty with control of urine)

1 [ ] Yes
2 [ ] No

Details: ______________________________

Blood Loss (In vomit/Sputum/Bowel Action/Urine)

1 [ ] Yes
2 [ ] No

Details: ______________________________

Easy Bruising

1 [ ] Yes
2 [ ] No

Details: ______________________________

Other Bleeding Disorders

1 [ ] Yes
2 [ ] No

Details: ______________________________

Endocrine Problems (Diabetes/Thyroid/Other)

1 [ ] Yes
2 [ ] No

Details: ______________________________

Personal Medical History. Check any symptoms that currently apply to you.

1 [ ] Pain or discomfort in the chest following exercise, eating or exposure to to cold.
2 [ ] Frequent heart palpitation or flutter
3 [ ] Pain in the lower legs when walking or climbing stairs.
4 [ ] Unusual shortness of breath
5 [ ] Very poor exercise tolerance
6 [ ] Frequent dizziness
7 [ ] Chronic cough
8 [ ] Frequent colds or flu
9 [ ] Frequent headaches
10 [ ] Frequent aches or pains in the joints
11 [ ] Frequent backache
12 [ ] Do you bleed easily e.g., after shaving; cuts and scratches
13 [ ] Do you bruise easily

Other current symptoms that exercise may affect (specify)

____

____

Are you presently experiencing, or have you ever been treated by a doctor for any of the following:

Lung problems (asthma/Emphysema/Bronchitis/Shortness of Breath)

1 [ ] Yes
2 [ ] No

Details: ____________________________________

Blood Pressure Problems

1 [ ] Yes
2 [ ] No

Details: ____________________________________

Cholesterol Problems

1 [ ] Yes
2 [ ] No

Details: ____________________________________

APPENDIX B

1. A Sample of Spreadsheet Calculations of Force Platform Data for Static Balance
2. A Sample of BIODEX Comprehensive Report

A sample of testing data sheet of static balance.							
				1 These data are in Metric Units (N, N-cm)			
				501 data sets			
				0.020 period (sec)			
				KEITH THORNTON			
				Age: 65yr			
				LEFT			
				1 1 Starting sets for platforms 1 and 2			
				501 1 Ending sets for platforms 1 and 2			
				1 number of platforms			
				0.00 0.00 X and Y distance between platforms			
				1 5 start channel and end channel			
				50.80 Lengths of platform 1 (cm)			
				46.35 Width of platform 1 (cm)			
				725.54 Subject's weight, if available, N			
Time (Sec)	Fx (N)	Fy (N)	Fz (N)	Mx (N.m)	My (N.m)	X (N.m)	Y (N.m)
0.00	2.25	-0.75	727.03	11.36	12.60	1.73	1.56
0.02	1.87	-0.37	727.03	11.36	13.16	1.81	1.56
0.04	1.12	-0.75	727.03	11.36	13.35	1.84	1.56
0.06	0.75	-1.12	725.54	11.17	13.54	1.87	1.54
0.08	1.12	-1.87	724.06	10.79	13.72	1.89	1.49
0.10	0.75	-2.25	722.58	10.79	13.72	1.90	1.49
0.12	0.75	-2.62	722.58	10.60	13.72	1.90	1.47
0.14	0.75	-2.62	722.58	10.60	13.54	1.87	1.47
0.16	1.50	-2.25	721.09	10.79	13.16	1.83	1.50
0.18	1.87	-1.87	719.61	10.79	12.78	1.78	1.50
0.20	2.62	-1.87	719.61	10.79	12.41	1.72	1.50
0.22	3.37	-1.87	721.09	10.79	12.03	1.67	1.50
0.24	4.12	-1.87	722.58	10.41	11.47	1.59	1.44
0.26	4.87	-2.25	724.06	10.22	10.90	1.51	1.41
0.28	5.62	-2.62	725.54	9.84	9.96	1.37	1.36
0.30	6.75	-3.37	725.54	9.27	8.65	1.19	1.28
0.32	7.50	-3.75	724.06	9.08	7.52	1.04	1.25
0.34	7.87	-4.12	722.58	9.08	6.58	0.91	1.26
0.36	8.25	-4.50	721.09	9.27	5.83	0.81	1.29
0.38	7.87	-3.75	718.13	9.84	5.45	0.76	1.37
0.40	7.12	-3.00	718.13	10.60	5.83	0.81	1.48
0.42	6.37	-1.50	719.61	11.54	6.58	0.91	1.60
0.44	5.25	-0.37	721.09	12.68	7.33	1.02	1.76
0.46	4.87	1.12	722.58	13.82	8.27	1.14	1.91
0.48	4.50	2.62	722.58	15.14	9.02	1.25	2.10
0.50	4.12	3.37	724.06	16.09	9.78	1.35	2.22
0.52	3.75	3.37	724.06	16.65	10.53	1.45	2.30
0.54	3.37	3.37	724.06	16.84	11.09	1.53	2.33
0.56	3.00	3.37	722.58	17.03	11.47	1.59	2.36
0.58	2.62	3.00	722.58	17.22	11.66	1.61	2.38
0.60	2.62	2.62	721.09	17.22	12.03	1.67	2.39
0.62	3.00	2.62	721.09	17.41	12.03	1.67	2.41
0.64	3.00	2.25	721.09	17.60	12.22	1.69	2.44
0.66	2.62	1.87	722.58	17.60	12.60	1.74	2.44
0.68	1.87	1.87	724.06	17.79	12.97	1.79	2.46
0.70	1.50	1.50	724.06	17.79	13.35	1.84	2.46
0.72	1.12	1.12	725.54	17.60	13.72	1.89	2.43
0.74	1.12	1.12	725.54	17.41	14.10	1.94	2.40

0.76	1.12	1.12	724.06	17.41	14.29	1.97	2.40
0.78	1.12	1.12	722.58	17.22	14.29	1.98	2.38
0.80	0.75	0.75	722.58	17.03	14.48	2.00	2.36
0.82	0.75	0.75	724.06	16.65	14.29	1.97	2.30
0.84	0.75	0.37	725.54	16.47	14.10	1.94	2.27
0.86	0.75	0.37	727.03	15.90	13.54	1.86	2.19
0.88	1.50	-1.12	728.51	14.95	12.41	1.70	2.05
0.90	3.37	-0.75	724.06	14.76	11.47	1.58	2.04
0.92	3.75	-0.37	719.61	14.95	11.28	1.57	2.08
0.94	3.37	-0.37	718.13	14.95	11.28	1.57	2.08
0.96	2.62	-0.37	716.64	14.76	11.47	1.60	2.06
0.98	1.87	-0.75	716.64	14.76	11.66	1.63	2.06
1.00	1.87	-0.75	719.61	14.57	11.66	1.62	2.02
1.02	1.87	-0.75	724.06	14.00	11.47	1.58	1.93
1.04	1.87	-1.87	725.54	13.44	10.90	1.50	1.85
1.06	2.25	-2.25	727.03	12.87	9.96	1.37	1.77
1.08	3.75	-3.00	728.51	12.30	8.65	1.19	1.69
1.10	5.25	-3.37	727.03	12.11	7.33	1.01	1.67
1.12	6.75	-3.37	722.58	12.30	6.20	0.86	1.70
1.14	7.87	-3.37	719.61	12.68	5.26	0.73	1.76
1.16	8.62	-3.37	716.64	12.87	4.51	0.63	1.80
1.18	8.62	-2.62	716.64	13.63	4.14	0.58	1.90
1.20	8.25	-1.50	715.16	14.57	4.70	0.66	2.04
1.22	6.75	-0.75	716.64	15.71	5.83	0.81	2.19
1.24	4.12	0.37	722.58	16.65	7.52	1.04	2.30
1.26	1.87	0.75	728.51	17.41	8.84	1.21	2.39
1.28	1.12	1.87	730.00	18.17	9.59	1.31	2.49
1.30	1.12	3.00	730.00	18.93	9.78	1.34	2.59
1.32	1.87	3.00	728.51	19.30	9.40	1.29	2.65
1.34	3.00	2.62	727.03	19.11	8.46	1.16	2.63
1.36	4.12	1.87	725.54	18.93	7.14	0.98	2.61
1.38	6.37	1.12	721.09	18.74	6.02	0.83	2.60
1.40	7.50	1.50	716.64	19.30	5.45	0.76	2.69
1.42	6.75	2.25	715.16	19.68	5.45	0.76	2.75
1.44	6.00	2.25	716.64	19.87	5.64	0.79	2.77
1.46	5.62	2.25	719.61	20.25	5.45	0.76	2.81
1.48	6.00	2.25	722.58	20.44	5.45	0.75	2.83
1.50	6.00	3.00	725.54	20.63	5.83	0.80	2.84
1.52	5.25	3.37	725.54	21.01	6.58	0.91	2.90
1.54	4.50	3.75	725.54	21.20	7.52	1.04	2.92
1.56	3.37	3.75	724.06	21.01	8.46	1.17	2.90
1.58	3.00	3.75	724.06	20.82	9.02	1.25	2.88
1.60	2.62	3.75	722.58	20.44	9.40	1.30	2.83
1.62	2.25	3.00	724.06	19.49	9.40	1.30	2.69
1.64	2.62	1.50	725.54	18.55	9.02	1.24	2.56
1.66	3.00	0.00	727.03	17.41	8.46	1.16	2.39
1.68	4.12	-1.50	727.03	16.28	7.52	1.03	2.24
1.70	5.25	-1.87	724.06	15.52	6.77	0.94	2.14
1.72	6.37	-1.87	721.09	15.14	6.02	0.83	2.10
1.74	6.75	-1.87	719.61	14.95	5.83	0.81	2.08
1.76	6.75	-2.25	719.61	14.95	5.83	0.81	2.08
1.78	6.75	-2.62	719.61	15.14	6.20	0.86	2.10
1.80	6.00	-1.87	719.61	15.52	6.96	0.97	2.16
1.82	4.87	-0.75	721.09	16.09	8.08	1.12	2.23
1.84	3.37	0.00	722.58	16.47	9.21	1.27	2.28

1.86	2.25	0.00	722.58	16.65	10.34	1.43	2.30
1.88	1.87	-0.37	724.06	16.65	11.47	1.58	2.30
1.90	0.75	-0.37	724.06	16.28	12.60	1.74	2.25
1.92	-0.37	0.00	725.54	16.09	13.35	1.84	2.22
1.94	-0.37	0.37	725.54	16.09	13.72	1.89	2.22
1.96	-0.37	0.00	725.54	15.90	13.72	1.89	2.19
1.98	0.00	-0.37	724.06	15.52	13.35	1.84	2.14
2.00	0.75	-0.75	721.09	15.52	12.78	1.77	2.15
2.02	1.50	-0.75	721.09	15.52	12.41	1.72	2.15
2.04	1.87	-0.75	721.09	15.52	12.22	1.69	2.15
2.06	1.87	-0.75	722.58	15.52	12.03	1.66	2.15
2.08	1.87	-0.75	722.58	15.33	11.84	1.64	2.12
2.10	2.25	-0.75	724.06	15.14	11.47	1.58	2.09
2.12	3.00	-0.75	722.58	15.52	10.90	1.51	2.15
2.14	3.00	-0.75	722.58	15.52	10.72	1.48	2.15
2.16	2.62	-1.12	721.09	15.52	10.72	1.49	2.15
2.18	2.25	-1.50	721.09	15.33	10.90	1.51	2.13
2.20	1.87	-1.87	721.09	15.14	10.90	1.51	2.10
2.22	1.87	-1.87	722.58	15.14	10.90	1.51	2.10
2.24	1.50	-1.87	724.06	15.33	10.90	1.51	2.12
2.26	1.87	-1.50	725.54	15.52	10.34	1.43	2.14
2.28	2.62	-1.87	725.54	15.52	9.78	1.35	2.14
2.30	3.37	-2.62	727.03	15.14	8.84	1.22	2.08
2.32	4.50	-3.00	727.03	14.57	7.71	1.06	2.00
2.34	5.62	-3.00	724.06	14.19	6.58	0.91	1.96
2.36	6.37	-3.00	722.58	14.38	5.83	0.81	1.99
2.38	7.12	-2.25	721.09	14.76	5.26	0.73	2.05
2.40	7.12	-1.87	718.13	15.14	4.89	0.68	2.11
2.42	7.12	-1.12	719.61	15.71	4.70	0.65	2.18
2.44	6.75	-0.75	721.09	16.09	4.70	0.65	2.23
2.46	6.37	-0.37	722.58	16.47	4.70	0.65	2.28
2.48	6.37	0.37	724.06	17.03	4.89	0.68	2.35
2.50	5.62	0.75	724.06	17.41	5.08	0.70	2.40
2.52	5.25	1.12	725.54	17.79	5.26	0.72	2.45
2.54	5.25	1.50	724.06	18.17	5.64	0.78	2.51
2.56	5.62	1.12	722.58	18.17	5.26	0.73	2.51
2.58	6.00	1.12	721.09	18.36	5.26	0.73	2.55
2.60	6.00	0.75	719.61	18.55	5.08	0.71	2.58
2.62	6.37	0.75	721.09	18.55	5.08	0.70	2.57
2.64	6.37	0.75	719.61	19.11	5.26	0.73	2.66
2.66	5.25	1.12	721.09	19.87	6.20	0.86	2.76
2.68	4.12	1.50	722.58	20.63	7.33	1.01	2.86
2.70	3.00	2.25	722.58	21.39	8.08	1.12	2.96
2.72	2.62	3.00	724.06	21.76	8.84	1.22	3.01
2.74	2.25	3.00	724.06	21.95	9.40	1.30	3.03
2.76	2.25	2.62	724.06	21.95	9.59	1.32	3.03
2.78	2.62	2.25	724.06	21.76	9.59	1.32	3.01
2.80	3.00	2.25	721.09	21.76	9.96	1.38	3.02
2.82	2.25	2.25	719.61	21.76	10.53	1.46	3.02
2.84	1.50	2.25	721.09	21.57	11.09	1.54	2.99
2.86	1.50	1.87	722.58	21.39	11.47	1.59	2.96
2.88	1.12	1.50	724.06	21.01	11.47	1.58	2.90
2.90	1.50	0.75	724.06	20.63	11.66	1.61	2.85
2.92	1.50	0.75	725.54	20.44	12.03	1.66	2.82
2.94	1.12	0.75	725.54	20.06	12.41	1.71	2.76

2.96	1.12	0.75	724.06	20.06	12.60	1.74	2.77
2.98	1.12	0.75	722.58	19.87	12.97	1.79	2.75
3.00	0.75	1.12	722.58	19.87	12.97	1.79	2.75
3.02	0.37	0.75	724.06	19.68	12.97	1.79	2.72
3.04	0.75	0.75	725.54	19.30	12.78	1.76	2.66
3.06	1.12	0.00	725.54	18.74	12.41	1.71	2.58
3.08	1.50	-0.75	725.54	17.98	11.84	1.63	2.48
3.10	1.87	-0.75	724.06	17.60	11.28	1.56	2.43
3.12	2.25	-1.12	721.09	17.22	11.09	1.54	2.39
3.14	2.25	-1.87	721.09	16.84	11.09	1.54	2.34
3.16	1.87	-1.87	721.09	16.84	11.09	1.54	2.34
3.18	1.50	-1.87	721.09	16.65	10.90	1.51	2.31
3.20	1.12	-2.62	724.06	16.28	10.72	1.48	2.25
3.22	1.50	-3.00	727.03	15.90	10.34	1.42	2.19
3.24	1.87	-3.00	730.00	15.71	9.40	1.29	2.15
3.26	3.00	-3.00	730.00	15.52	7.90	1.08	2.13
3.28	5.25	-3.00	727.03	15.71	6.39	0.88	2.16
3.30	7.12	-3.00	722.58	15.71	5.08	0.70	2.17
3.32	7.87	-2.62	718.13	16.09	4.14	0.58	2.24
3.34	7.50	-1.87	716.64	16.65	3.57	0.50	2.32
3.36	7.12	-1.50	716.64	17.03	3.01	0.42	2.38
3.38	6.75	-1.12	718.13	17.41	2.63	0.37	2.42
3.40	6.75	-1.12	721.09	17.79	2.26	0.31	2.47
3.42	6.75	-0.75	724.06	18.17	1.88	0.26	2.51
3.44	7.50	0.00	722.58	19.11	1.88	0.26	2.64
3.46	7.12	1.50	721.09	20.44	2.44	0.34	2.83
3.48	6.00	2.62	721.09	21.57	3.20	0.44	2.99
3.50	5.25	3.37	721.09	22.14	4.14	0.57	3.07
3.52	4.87	4.12	722.58	22.71	4.70	0.65	3.14
3.54	4.12	4.50	724.06	23.09	5.26	0.73	3.19
3.56	4.12	4.12	725.54	23.09	5.26	0.72	3.18
3.58	4.50	3.37	725.54	22.90	5.08	0.70	3.16
3.60	5.25	3.00	725.54	22.71	4.89	0.67	3.13
3.62	5.62	2.62	724.06	22.52	4.70	0.65	3.11
3.64	5.62	2.62	722.58	22.52	4.70	0.65	3.12
3.66	5.62	3.00	721.09	22.71	4.89	0.68	3.15
3.68	6.00	3.00	721.09	22.71	4.89	0.68	3.15
3.70	6.00	3.00	719.61	22.90	5.08	0.71	3.18
3.72	5.25	3.00	719.61	22.90	5.83	0.81	3.18
3.74	4.50	2.62	721.09	22.90	6.77	0.94	3.18
3.76	3.37	3.00	722.58	22.90	7.71	1.07	3.17
3.78	2.25	3.37	724.06	22.71	8.65	1.19	3.14
3.80	1.87	3.37	725.54	22.52	9.40	1.30	3.10
3.82	1.87	3.00	727.03	21.95	9.78	1.35	3.02
3.84	2.25	2.25	727.03	21.20	9.78	1.35	2.92
3.86	2.62	1.12	727.03	20.44	9.59	1.32	2.81
3.88	3.00	0.37	724.06	19.49	9.21	1.27	2.69
3.90	3.37	-0.37	722.58	18.74	9.02	1.25	2.59
3.92	3.75	-0.75	721.09	18.36	8.84	1.23	2.55
3.94	3.75	-0.75	719.61	18.17	8.84	1.23	2.52
3.96	3.37	-0.75	721.09	17.79	9.02	1.25	2.47
3.98	3.00	-1.12	722.58	17.41	9.21	1.27	2.41
4.00	3.00	-1.12	722.58	17.22	9.21	1.27	2.38
4.02	2.62	-0.75	724.06	17.22	9.40	1.30	2.38
4.04	2.62	0.00	724.06	17.03	9.78	1.35	2.35

4.06	2.62	0.00	722.58	16.65	9.96	1.38	2.30
4.08	2.25	0.00	722.58	16.28	10.15	1.40	2.25
4.10	2.25	-0.37	722.58	15.90	10.34	1.43	2.20
4.12	2.25	-0.37	722.58	15.52	10.53	1.46	2.15
4.14	2.25	-1.12	722.58	15.33	10.53	1.46	2.12
4.16	2.25	-1.12	722.58	14.95	10.53	1.46	2.07
4.18	2.25	-1.12	724.06	14.76	10.53	1.45	2.04
4.20	2.25	-1.50	725.54	14.57	10.53	1.45	2.01
4.22	2.62	-1.50	724.06	14.57	10.53	1.45	2.01
4.24	2.62	-1.12	724.06	14.57	10.53	1.45	2.01
4.26	2.62	-0.75	722.58	14.76	10.53	1.46	2.04
4.28	2.62	-0.75	722.58	14.76	10.34	1.43	2.04
4.30	2.62	-0.75	722.58	14.76	10.15	1.40	2.04
4.32	2.62	-0.75	724.06	14.57	9.78	1.35	2.01
4.34	3.00	-1.12	722.58	14.38	9.59	1.33	1.99
4.36	3.00	-1.50	721.09	14.38	9.59	1.33	1.99
4.38	3.00	-1.50	722.58	14.19	9.59	1.33	1.96
4.40	3.00	-1.50	722.58	14.00	9.78	1.35	1.94
4.42	3.37	-1.87	722.58	13.82	9.59	1.33	1.91
4.44	3.37	-2.25	722.58	13.25	9.40	1.30	1.83
4.46	3.75	-2.62	724.06	13.06	9.02	1.25	1.80
4.48	3.75	-2.62	725.54	12.87	8.46	1.17	1.77
4.50	4.12	-2.25	725.54	12.87	7.90	1.09	1.77
4.52	4.87	-2.25	724.06	12.49	7.14	0.99	1.72
4.54	5.25	-2.62	722.58	12.49	6.39	0.88	1.73
4.56	5.62	-2.25	719.61	12.68	5.83	0.81	1.76
4.58	6.00	-2.25	718.13	12.68	5.45	0.76	1.77
4.60	6.37	-2.25	719.61	12.68	5.26	0.73	1.76
4.62	6.37	-1.50	721.09	13.25	4.89	0.68	1.84
4.64	6.37	-0.75	724.06	13.82	4.70	0.65	1.91
4.66	6.75	0.00	725.54	14.57	4.51	0.62	2.01
4.68	6.75	1.12	722.58	15.33	4.89	0.68	2.12
4.70	6.37	2.25	721.09	16.47	5.64	0.78	2.28
4.72	4.87	3.00	721.09	17.41	6.77	0.94	2.41
4.74	3.75	3.75	721.09	18.17	7.71	1.07	2.52
4.76	2.62	3.75	719.61	18.55	8.65	1.20	2.58
4.78	1.87	3.75	722.58	18.74	9.21	1.27	2.59
4.80	1.87	3.37	724.06	18.74	9.59	1.32	2.59
4.82	2.25	3.00	725.54	18.55	9.21	1.27	2.56
4.84	3.00	2.25	727.03	18.17	8.84	1.22	2.50
4.86	3.75	1.87	727.03	17.79	8.46	1.16	2.45
4.88	4.50	1.50	725.54	17.41	7.71	1.06	2.40
4.90	5.25	1.12	722.58	17.03	7.14	0.99	2.36
4.92	5.62	0.37	721.09	16.65	6.77	0.94	2.31
4.94	6.00	0.00	719.61	16.28	6.58	0.91	2.26
4.96	6.37	-0.37	719.61	15.90	6.58	0.91	2.21
4.98	6.00	-0.75	718.13	15.71	6.77	0.94	2.19
5.00	5.62	-0.37	719.61	15.71	7.33	1.02	2.18
5.02	4.87	0.37	721.09	15.90	8.08	1.12	2.20
5.04	4.50	0.75	722.58	15.90	9.02	1.25	2.20
5.06	3.75	0.75	724.06	15.90	9.78	1.35	2.20
5.08	3.37	0.75	724.06	15.52	10.53	1.45	2.14
5.10	3.00	0.37	724.06	15.14	11.28	1.56	2.09
5.12	2.25	-0.37	725.54	14.38	12.03	1.66	1.98
5.14	1.87	-0.75	727.03	13.63	12.41	1.71	1.87

5.16	1.87	-1.12	725.54	13.06	12.60	1.74	1.80
5.18	1.87	-1.50	724.06	12.30	12.78	1.77	1.70
5.20	1.87	-2.62	724.06	11.54	12.78	1.77	1.59
5.22	1.50	-3.37	725.54	10.79	12.78	1.76	1.49
5.24	1.50	-3.75	724.06	10.22	12.78	1.77	1.41
5.26	1.87	-3.75	724.06	9.84	12.78	1.77	1.36
5.28	2.25	-3.75	724.06	10.03	12.60	1.74	1.39
5.30	2.25	-3.00	722.58	10.41	12.78	1.77	1.44
5.32	2.25	-2.62	724.06	10.79	12.60	1.74	1.49
5.34	2.25	-1.87	722.58	11.17	12.60	1.74	1.55
5.36	1.87	-1.87	722.58	11.54	12.60	1.74	1.60
5.38	1.87	-1.50	724.06	11.73	12.60	1.74	1.62
5.40	1.87	-1.50	725.54	11.92	12.41	1.71	1.64
5.42	2.62	-1.12	724.06	12.30	12.22	1.69	1.70
5.44	2.62	-0.75	722.58	12.87	12.22	1.69	1.78
5.46	2.25	-0.37	719.61	13.44	12.41	1.72	1.87
5.48	1.87	0.00	719.61	13.82	12.78	1.78	1.92
5.50	1.12	0.00	721.09	14.19	12.97	1.80	1.97
5.52	0.75	0.37	724.06	14.57	13.16	1.82	2.01
5.54	0.75	0.37	727.03	15.14	12.97	1.78	2.08
5.56	1.87	0.75	728.51	15.71	12.22	1.68	2.16
5.58	2.62	0.75	728.51	16.09	11.47	1.57	2.21
5.60	3.00	0.37	728.51	15.90	10.15	1.39	2.18
5.62	4.50	0.00	727.03	15.33	8.65	1.19	2.11
5.64	6.37	-1.12	722.58	14.76	7.14	0.99	2.04
5.66	7.50	-1.12	718.13	14.76	6.58	0.92	2.06
5.68	7.12	-1.12	716.64	14.76	6.39	0.89	2.06
5.70	6.37	-0.75	718.13	14.95	6.39	0.89	2.08
5.72	6.37	-0.37	719.61	15.33	6.39	0.89	2.13
5.74	6.00	0.37	722.58	15.71	6.58	0.91	2.17
5.76	5.25	0.75	724.06	16.09	6.96	0.96	2.22
5.78	5.25	1.87	724.06	16.65	7.52	1.04	2.30
5.80	4.50	2.25	724.06	17.03	8.27	1.14	2.35
5.82	3.75	2.62	724.06	17.22	9.02	1.25	2.38
5.84	3.37	3.00	722.58	17.22	9.40	1.30	2.38
5.86	3.37	2.62	724.06	16.84	9.40	1.30	2.33
5.88	3.37	2.25	724.06	16.65	9.40	1.30	2.30
5.90	3.75	1.50	725.54	16.28	9.02	1.24	2.24
5.92	4.50	1.12	724.06	15.90	8.65	1.19	2.20
5.94	5.25	0.37	724.06	15.90	8.46	1.17	2.20
5.96	5.25	0.37	722.58	15.71	8.27	1.14	2.17
5.98	5.62	0.37	722.58	15.52	8.08	1.12	2.15
6.00	5.62	0.00	721.09	15.33	7.90	1.10	2.13
6.02	6.00	-0.37	722.58	14.95	7.71	1.07	2.07
6.04	6.00	-0.75	722.58	14.76	7.71	1.07	2.04
6.06	6.00	-0.37	721.09	14.76	8.08	1.12	2.05
6.08	5.25	-0.37	721.09	15.14	8.84	1.23	2.10
6.10	4.12	0.37	721.09	15.14	9.59	1.33	2.10
6.12	3.37	0.75	722.58	15.33	10.53	1.46	2.12
6.14	2.62	0.75	721.09	15.14	11.09	1.54	2.10
6.16	2.25	0.37	722.58	14.76	11.66	1.61	2.04
6.18	1.50	-0.37	725.54	14.19	12.41	1.71	1.96
6.20	1.50	-0.75	727.03	13.82	12.60	1.73	1.90
6.22	1.50	-1.12	727.03	13.44	12.78	1.76	1.85
6.24	1.87	-1.50	725.54	13.25	12.97	1.79	1.83

6.26	1.87	-1.12	724.06	13.25	12.97	1.79	1.83
6.28	2.25	-1.12	724.06	13.25	12.78	1.77	1.83
6.30	2.25	-1.50	725.54	13.44	12.41	1.71	1.85
6.32	2.62	-1.50	727.03	13.25	11.84	1.63	1.82
6.34	3.00	-1.50	727.03	13.44	11.09	1.53	1.85
6.36	4.12	-1.12	724.06	13.63	10.53	1.45	1.88
6.38	4.12	-1.12	719.61	13.82	10.53	1.46	1.92
6.40	3.75	-1.12	716.64	13.82	10.72	1.50	1.93
6.42	3.00	-1.12	716.64	13.82	11.09	1.55	1.93
6.44	2.25	-1.12	718.13	13.82	11.47	1.60	1.92
6.46	1.50	-1.12	722.58	13.63	11.47	1.59	1.89
6.48	1.87	-1.12	727.03	13.63	11.47	1.58	1.87
6.50	2.25	-0.75	728.51	13.82	11.09	1.52	1.90
6.52	3.00	-0.37	730.00	14.00	10.53	1.44	1.92
6.54	4.12	-0.75	727.03	13.82	9.96	1.37	1.90
6.56	5.25	-1.12	722.58	13.63	9.21	1.27	1.89
6.58	5.62	-1.50	719.61	13.44	8.84	1.23	1.87
6.60	5.25	-1.87	719.61	13.06	8.65	1.20	1.81
6.62	4.87	-2.25	721.09	12.87	8.46	1.17	1.78
6.64	4.87	-2.62	722.58	12.87	8.08	1.12	1.78
6.66	5.25	-2.62	727.03	12.87	7.71	1.06	1.77
6.68	6.00	-2.25	727.03	13.25	7.33	1.01	1.82
6.70	6.75	-1.50	725.54	14.00	6.96	0.96	1.93
6.72	7.12	-0.75	722.58	14.57	6.77	0.94	2.02
6.74	7.12	-0.37	721.09	14.95	6.96	0.97	2.07
6.76	6.37	0.00	719.61	15.14	7.33	1.02	2.10
6.78	5.62	0.00	721.09	15.33	7.71	1.07	2.13
6.80	5.25	0.00	722.58	15.52	7.71	1.07	2.15
6.82	5.25	0.00	722.58	15.71	8.08	1.12	2.17
6.84	5.25	0.00	722.58	15.90	8.27	1.14	2.20
6.86	5.25	0.37	722.58	16.09	8.65	1.20	2.23
6.88	5.25	0.00	722.58	16.28	9.21	1.27	2.25
6.90	5.25	0.00	721.09	16.47	9.78	1.36	2.28
6.92	4.50	0.00	722.58	16.65	10.34	1.43	2.30
6.94	4.12	0.00	722.58	16.84	11.09	1.53	2.33
6.96	3.37	0.00	724.06	17.03	11.84	1.64	2.35
6.98	2.62	-0.37	725.54	17.03	12.41	1.71	2.35
7.00	2.62	-0.75	725.54	17.22	13.16	1.81	2.37
7.02	2.25	-0.75	725.54	17.22	13.72	1.89	2.37
7.04	1.87	-0.37	725.54	17.60	14.10	1.94	2.43
7.06	1.50	0.00	724.06	17.79	14.48	2.00	2.46
7.08	1.50	0.37	724.06	18.17	14.48	2.00	2.51
7.10	1.50	0.37	722.58	18.55	14.29	1.98	2.57
7.12	1.87	0.37	722.58	18.55	14.10	1.95	2.57
7.14	1.87	0.37	721.09	18.93	14.29	1.98	2.63
7.16	1.87	0.37	721.09	19.11	14.29	1.98	2.65
7.18	1.50	0.75	721.09	19.30	14.48	2.01	2.68
7.20	1.12	1.12	722.58	19.49	14.66	2.03	2.70
7.22	1.12	1.12	724.06	19.68	14.85	2.05	2.72
7.24	1.12	1.50	725.54	19.87	14.66	2.02	2.74
7.26	1.50	1.50	727.03	20.06	14.48	1.99	2.76
7.28	1.87	1.87	725.54	20.25	14.10	1.94	2.79
7.30	2.25	1.87	724.06	20.25	13.72	1.89	2.80
7.32	2.62	1.50	722.58	20.25	13.35	1.85	2.80
7.34	3.00	1.12	719.61	20.06	13.16	1.83	2.79

7.36	3.00	0.75	719.61	19.68	13.16	1.83	2.73
7.38	2.62	0.00	719.61	19.49	13.16	1.83	2.71
7.40	2.62	-0.37	721.09	19.11	13.35	1.85	2.65
7.42	2.25	-0.75	722.58	18.74	13.54	1.87	2.59
7.44	2.25	-0.75	724.06	18.74	13.54	1.87	2.59
7.46	2.62	0.00	725.54	19.11	13.35	1.84	2.63
7.48	3.00	0.37	725.54	19.49	13.16	1.81	2.69
7.50	3.00	0.75	727.03	20.06	12.60	1.73	2.76
7.52	3.75	0.75	728.51	20.25	11.84	1.63	2.78
7.54	4.12	0.37	727.03	20.25	10.72	1.47	2.79
7.56	4.87	-0.37	727.03	19.68	9.40	1.29	2.71
7.58	6.00	-1.50	724.06	19.11	8.08	1.12	2.64
7.60	7.50	-1.87	721.09	18.55	6.96	0.97	2.57
7.62	8.62	-1.50	716.64	18.74	6.20	0.87	2.61
7.64	8.62	-0.75	715.16	19.11	6.20	0.87	2.67
7.66	8.25	0.00	715.16	19.87	6.39	0.89	2.78
7.68	7.87	1.12	715.16	20.63	7.33	1.02	2.88
7.70	6.00	1.50	719.61	21.39	8.46	1.18	2.97
7.72	4.50	2.25	724.06	22.14	9.59	1.32	3.06
7.74	3.37	2.62	725.54	22.52	10.53	1.45	3.10
7.76	2.62	3.37	728.51	22.90	11.28	1.55	3.14
7.78	2.25	4.12	728.51	23.09	11.84	1.63	3.17
7.80	2.25	4.12	727.03	23.09	11.66	1.60	3.18
7.82	3.37	4.12	725.54	23.09	11.47	1.58	3.18
7.84	4.12	3.75	722.58	23.09	11.28	1.56	3.20
7.86	4.50	3.37	721.09	22.90	11.09	1.54	3.18
7.88	4.50	3.00	722.58	22.90	10.72	1.48	3.17
7.90	4.87	2.62	724.06	22.71	10.34	1.43	3.14
7.92	5.25	2.25	724.06	22.52	9.96	1.38	3.11
7.94	5.25	1.87	724.06	22.14	10.15	1.40	3.06
7.96	4.87	0.75	722.58	21.76	10.53	1.46	3.01
7.98	4.50	1.12	721.09	21.57	11.09	1.54	2.99
8.00	4.12	1.50	718.13	21.57	11.66	1.62	3.00
8.02	3.37	1.50	718.13	21.39	12.22	1.70	2.98
8.04	3.00	1.12	716.64	21.20	12.78	1.78	2.96
8.06	2.62	0.75	718.13	20.82	13.72	1.91	2.90
8.08	1.50	0.00	721.09	20.25	14.48	2.01	2.81
8.10	0.37	0.00	725.54	19.87	15.23	2.10	2.74
8.12	-0.37	0.37	728.51	19.49	15.79	2.17	2.68
8.14	0.00	0.00	728.51	19.11	15.79	2.17	2.62
8.16	0.37	0.00	728.51	18.74	15.79	2.17	2.57
8.18	0.75	0.00	727.03	18.36	15.79	2.17	2.53
8.20	0.75	0.00	725.54	18.17	15.60	2.15	2.50
8.22	1.12	0.00	725.54	17.98	15.42	2.13	2.48
8.24	1.12	0.00	724.06	17.79	15.04	2.08	2.46
8.26	1.12	-0.37	725.54	17.41	14.48	2.00	2.40
8.28	1.87	-1.12	724.06	17.03	13.72	1.89	2.35
8.30	2.62	-1.12	721.09	16.84	13.35	1.85	2.34
8.32	2.62	-1.12	719.61	16.65	12.97	1.80	2.31
8.34	2.62	-1.12	719.61	16.47	12.60	1.75	2.29
8.36	2.62	-1.12	721.09	16.09	12.41	1.72	2.23
8.38	2.62	-1.87	724.06	15.33	11.47	1.58	2.12
8.40	3.75	-3.00	727.03	14.38	10.34	1.42	1.98
8.42	5.25	-3.37	728.51	13.63	9.21	1.26	1.87
8.44	7.12	-3.00	725.54	13.82	8.27	1.14	1.90

8.46	7.50	-2.25	719.61	14.19	8.27	1.15	1.97
8.48	6.75	-1.87	716.64	14.76	8.65	1.21	2.06
8.50	5.62	-1.12	715.16	15.33	9.40	1.31	2.14
8.52	4.12	-0.37	718.13	15.71	10.34	1.44	2.19
8.54	2.25	0.00	721.09	15.90	11.28	1.56	2.20
8.56	1.12	0.00	727.03	15.90	11.84	1.63	2.19
8.58	0.75	0.00	730.00	15.90	12.22	1.67	2.18
8.60	1.50	0.00	730.00	15.90	11.84	1.62	2.18
8.62	2.25	0.00	728.51	15.71	11.47	1.57	2.16
8.64	3.37	-0.75	725.54	15.52	10.90	1.50	2.14
8.66	4.12	-1.50	722.58	15.14	9.96	1.38	2.10
8.68	5.25	-2.25	719.61	14.57	9.02	1.25	2.02
8.70	5.62	-2.25	719.61	14.19	8.08	1.12	1.97
8.72	6.37	-2.62	718.13	14.38	7.52	1.05	2.00
8.74	6.37	-2.25	719.61	14.57	7.52	1.05	2.02
8.76	5.62	-2.25	721.09	14.76	7.71	1.07	2.05
8.78	4.87	-1.87	721.09	14.95	8.08	1.12	2.07
8.80	4.12	-1.12	722.58	15.14	8.27	1.14	2.10
8.82	4.12	-0.75	724.06	15.33	8.46	1.17	2.12
8.84	4.12	-0.37	725.54	15.71	8.27	1.14	2.17
8.86	4.50	-0.37	727.03	15.90	7.90	1.09	2.19
8.88	4.87	0.00	727.03	16.09	7.52	1.03	2.21
8.90	5.62	0.00	724.06	16.28	7.33	1.01	2.25
8.92	6.00	0.00	724.06	16.28	7.33	1.01	2.25
8.94	5.62	-0.37	724.06	16.09	7.33	1.01	2.22
8.96	5.62	-0.75	724.06	16.28	7.14	0.99	2.25
8.98	6.00	-1.12	722.58	16.65	6.96	0.96	2.30
9.00	6.00	-0.37	722.58	17.22	6.77	0.94	2.38
9.02	6.37	0.37	721.09	17.79	6.77	0.94	2.47
9.04	6.00	1.12	719.61	18.74	7.52	1.05	2.60
9.06	4.87	1.87	719.61	19.49	8.46	1.18	2.71
9.08	3.37	2.62	721.09	19.87	9.59	1.33	2.76
9.10	2.25	3.37	724.06	20.25	10.34	1.43	2.80
9.12	1.50	3.37	727.03	20.25	10.72	1.47	2.79
9.14	1.50	3.00	730.00	20.06	10.72	1.47	2.75
9.16	2.25	2.62	728.51	20.06	10.34	1.42	2.75
9.18	3.00	2.25	728.51	19.87	9.78	1.34	2.73
9.20	4.12	1.87	727.03	19.30	8.84	1.22	2.65
9.22	5.25	1.12	724.06	18.74	7.90	1.09	2.59
9.24	6.75	0.75	719.61	18.55	6.96	0.97	2.58
9.26	7.12	0.75	718.13	18.55	6.58	0.92	2.58
9.28	7.12	0.37	716.64	18.55	6.58	0.92	2.59
9.30	6.37	0.37	716.64	18.55	6.96	0.97	2.59
9.32	5.25	0.75	719.61	18.55	7.71	1.07	2.58
9.34	4.12	1.12	721.09	18.55	8.65	1.20	2.57
9.36	3.00	1.50	724.06	18.55	9.40	1.30	2.56
9.38	2.62	1.87	725.54	18.36	9.96	1.37	2.53
9.40	2.62	1.50	725.54	18.17	10.53	1.45	2.50
9.42	3.00	1.12	724.06	17.79	11.09	1.53	2.46
9.44	2.62	1.12	724.06	17.41	11.66	1.61	2.40
9.46	1.87	1.12	722.58	17.03	12.03	1.66	2.36
9.48	1.87	0.37	724.06	16.47	12.22	1.69	2.27
9.50	1.87	-0.37	725.54	15.71	12.22	1.68	2.17
9.52	1.87	-0.75	727.03	15.14	12.03	1.65	2.08
9.54	2.62	-1.12	727.03	14.76	11.84	1.63	2.03

9.56	3.00	-1.87	728.51	14.19	11.28	1.55	1.95
9.58	3.75	-2.25	727.03	13.82	10.53	1.45	1.90
9.60	4.50	-2.25	724.06	13.82	9.96	1.38	1.91
9.62	5.25	-1.87	722.58	13.63	9.21	1.27	1.89
9.64	6.00	-1.50	718.13	14.00	9.02	1.26	1.95
9.66	5.62	-1.50	716.64	14.00	9.21	1.29	1.95
9.68	4.50	-1.50	718.13	14.00	9.96	1.39	1.95
9.70	3.37	-1.50	721.09	13.82	10.53	1.46	1.92
9.72	2.25	-1.50	724.06	13.63	10.90	1.51	1.88
9.74	2.25	-1.12	727.03	13.63	11.28	1.55	1.87
9.76	2.62	-1.12	727.03	13.63	11.28	1.55	1.87
9.78	3.00	-1.12	725.54	13.63	11.28	1.55	1.88
9.80	3.37	-1.12	724.06	13.63	11.28	1.56	1.88
9.82	3.75	-1.12	722.58	13.63	11.28	1.56	1.89
9.84	3.75	-1.12	722.58	13.82	11.28	1.56	1.91
9.86	4.12	-1.50	722.58	13.82	11.28	1.56	1.91
9.88	4.12	-1.50	722.58	14.00	11.09	1.53	1.94
9.90	3.75	-1.50	722.58	14.19	11.09	1.53	1.96
9.92	3.37	-1.12	724.06	14.38	11.28	1.56	1.99
9.94	3.37	-1.12	724.06	14.38	11.47	1.58	1.99
9.96	3.37	-1.12	724.06	14.38	11.47	1.58	1.99
9.98	3.37	-1.12	722.58	14.38	11.28	1.56	1.99
10.00	3.37	-1.12	724.06	14.76	11.09	1.53	2.04
Mean	3.69	-0.06	723.07	16.51	9.75	1.35	2.28
SD	2.00	1.83	3.03	3.10	2.86	0.39	0.43

VICTORIA UNIV. OF TECH. BIODEX COMPREHENSIVE REPORT - 2 SPEED

Name	: donu, i.	Clinician	: Liu	Joint	: Knee
ID	: 44444444	Referral	:	Pattern	: Extension/Flexion
Age	: 67	Calibration Date	: MAR 10, 1993 at 18:29	Treatment	:
Sex	: F	Test Date	: MAY 27, 1993	Involved Side	: L
Height	: 176 in	Settings	:	Contraction	: Concentric/Concentric
Weight	: 149 lbs	Data Reported	: Windowed	Mode	: Isokinetic

Extension		Uninvolved	Involved	Deficit(%)	Uninvolved	Involved	Deficit(%)
Number of Repetitions :		3.0	3.0	----	3.0	3.0	----
Speed	(deg/sec):	60.0	60.0	----	180.0	180.0	----
Peak Torque	(ft-lbs):	67.7	66.4	1.9	48.8	51.4	-5.3
Peak Torque "Rep"	(rep #):	3.0	3.0		3.0	3.0	-
Time to Peak Torque	(msec):	650.0	880.0		370.0	420.0	-
Angle of Peak Torque	(deg):	63.0	54.0		46.0	46.0	
Coefficient of Variance	(%):	21.5	12.4		24.2	25.6	
Torque @ 40.0 deg	(ft-lbs):	45.7	60.1		48.3	48.3	
Torque @ 0.2 sec	(ft-lbs):	0	0		18.3	12.7	
Torque/Body Weight	(%):	45.4	44.6		32.8	34.5	
Work/Body Weight	(%):	40.2	38.1		27.1	28.4	
Max Rep Work	(ft-lbs):	59.9	56.8	5.3	40.4	42.4	-4.9
Max Work "Rep"	(rep #):	3.0	3.0		3.0	3.0	
Total Work	(ft-lbs):	159.1	156.9	1.4	96.8	101.2	-4.5
Work First Third	(ft-lbs):	41.5	45.1		22.7	22.0	
Work Last Third	(ft-lbs):	59.9	56.8		40.4	42.4	
Work Fatigue	(%):	-44.4	-26.0		-78.0	-92.9	
Average Power	(watts):	46.8	45.3		65.0	71.1	

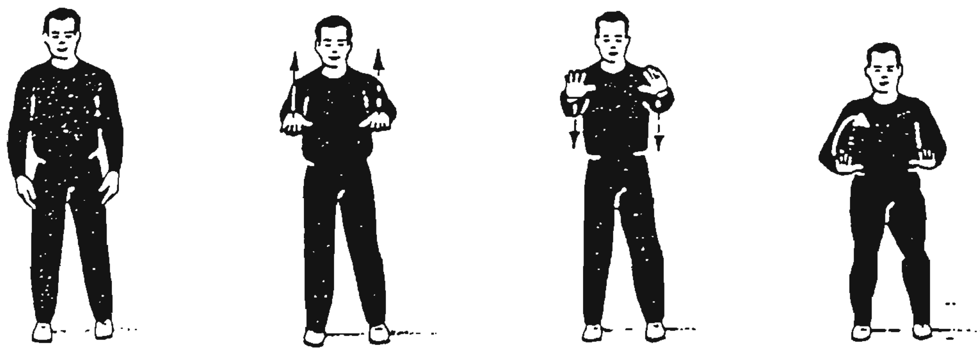
Flexion		Uninvolved	Involved	Deficit(%)	Uninvolved	Involved	Deficit(%)
Speed	(deg/sec):	60.0	60.0	----	180.0	180.0	----
Peak Torque	(ft-lbs):	32.6	33.5	-2.8	27.8	29.0	-4.3
Peak Torque "Rep"	(rep #):	3.0	3.0		2.0	3.0	
Time to Peak Torque	(msec):	880.0	1030.0		410.0	370.0	.
Angle of Peak Torque	(deg):	56.0	65.0		67.0	58.0	
Coefficient of Variance	(%):	18.9	17.6		16.0	24.7	
Torque @ 40.0 deg	(ft-lbs):	27.5	31.9		19.5	19.5	
Torque @ 0.2 sec	(ft-lbs):	8.6	16.1		23.2	17.4	
Torque/Body Weight	(%):	21.9	22.5		18.7	19.5	
Work/Body Weight	(%):	25.3	25.9		15.0	16.2	
Max Rep Work	(ft-lbs):	37.7	38.6	-2.2	22.3	24.2	-8.3
Max Work "Rep"	(rep #):	1.0	3.0		2.0	3.0	
Total Work	(ft-lbs):	103.7	99.7	3.8	60.5	52.7	13.0
Work First Third	(ft-lbs):	37.7	29.5		16.8	14.0	
Work Last Third	(ft-lbs):	36.8	38.6		21.3	24.2	
Work Fatigue	(%):	2.6	-30.9		-26.7	-72.4	-
Average Power	(watts):	32.0	30.6		45.6	35.9	
Maximum ROM	(deg):	85.0	86.0	-1.2	87.0	87.0	0
Anatomical ROM	(deg): From	6.0	5.0		4.0	4.0	
	To	91.0	91.0		91.0	91.0	

APPENDIX C

Cheng's 24 Style Tai Chi Exercise

Cheng 24 Style Tai Chi Chuan

Commencing form (1–4)



1 2 3 4

Parting the wild horse's mane on the left side (5–9)

5 6 7 8 9

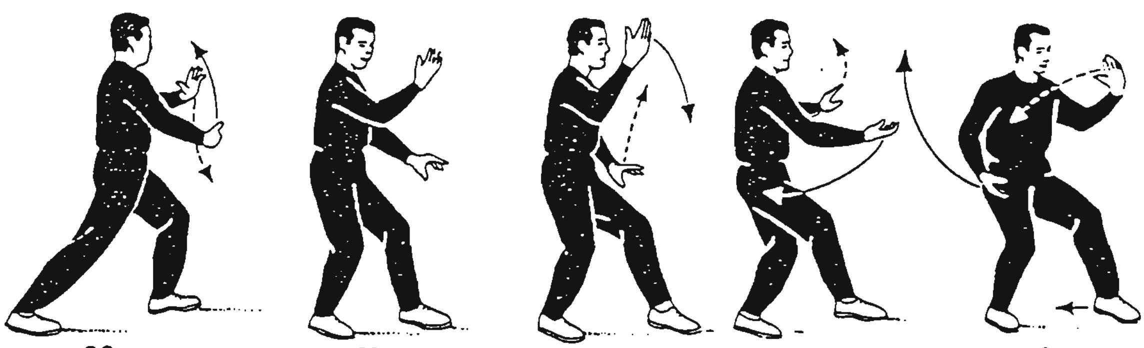
Parting the wild horse's mane on the right side (10–14)

10 11 12 13 14

Parting the wild horse's mane on the left side (15–19)

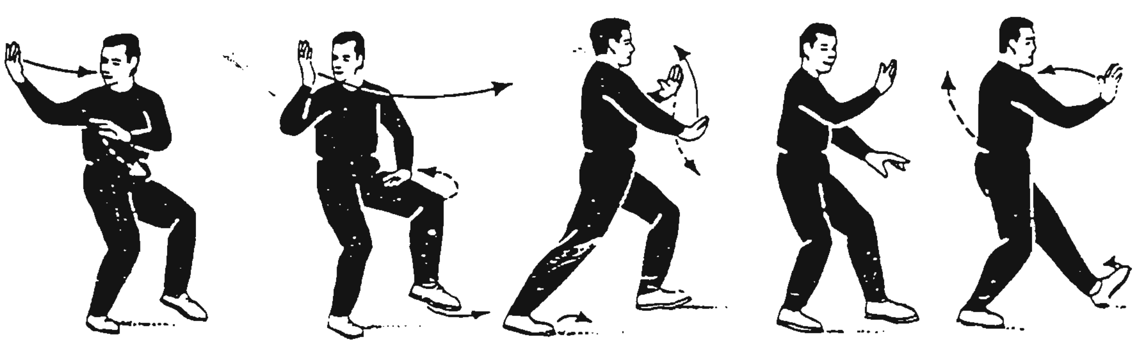
15 16 17 18 19

The white crane spreads its wings (20–22)



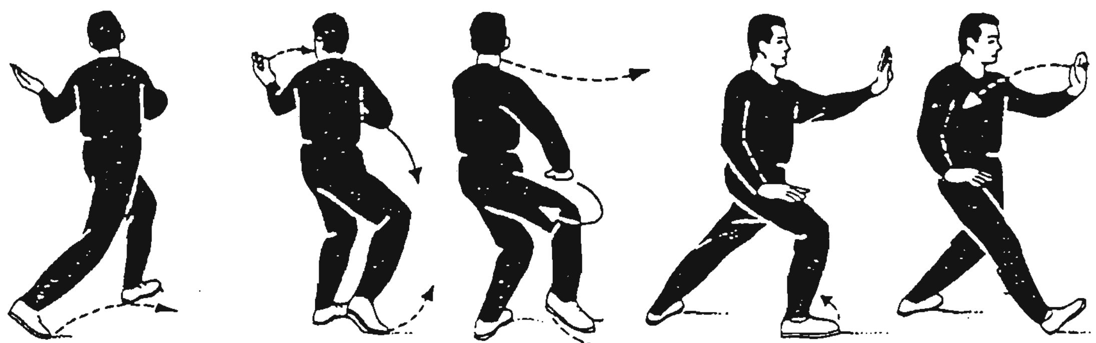
20 21 22 23 24

Brush knee and twist step on the left side (23–29)



25 26 27 28 29

Brush knee and twist step on the right side (30–34)



30 31 32 33 34

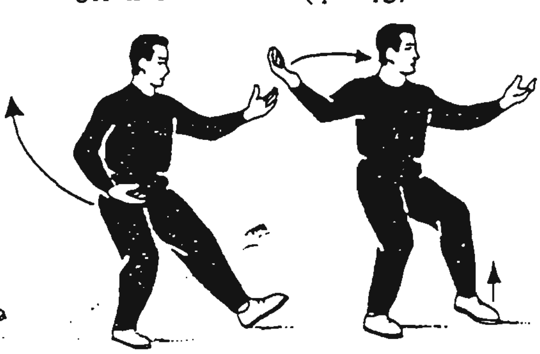
Brush knee and twist step on the left side (35–38)

35 36 37 38

The hand strums the lute (39–41)

39 40 41

Step back and whirl arm on the left side (42–45)



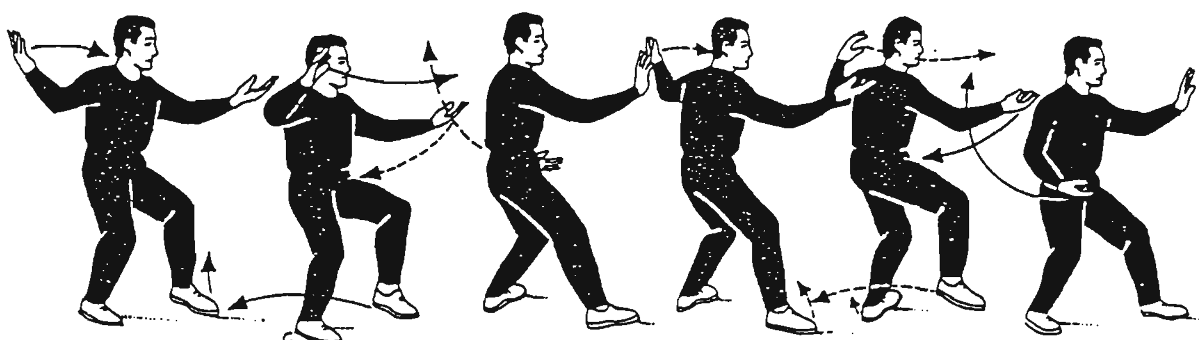
42 43

Step back and whirl arm
on the right side (46–48)

44 45 46 47 48

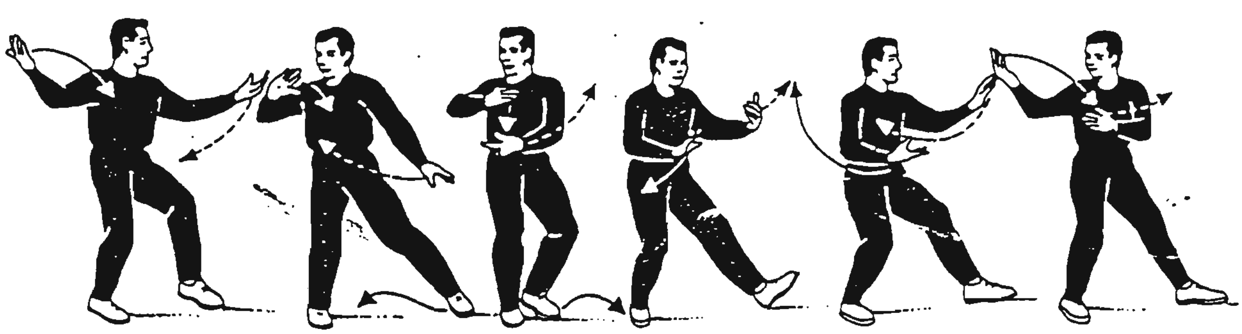
Step back and whirl arm
on the left side (49–51)

Step back and whirl arm
on the right side (52–54)

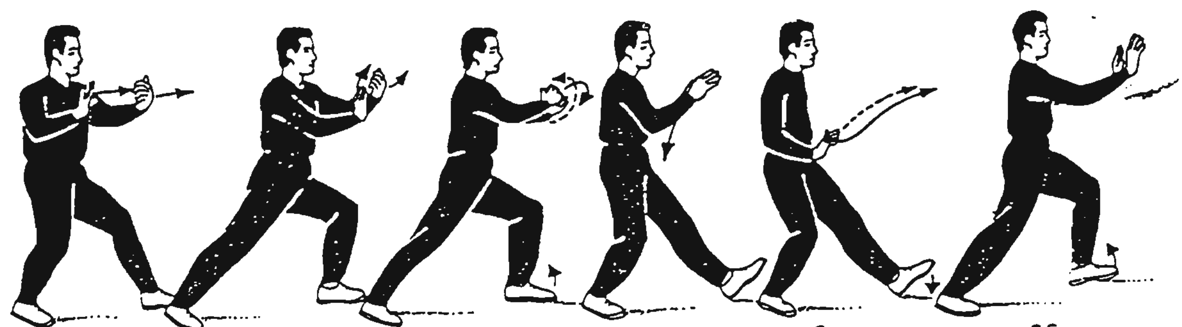


49 50 51 52 53 54

Grasp the bird's tail—left style (55–66)



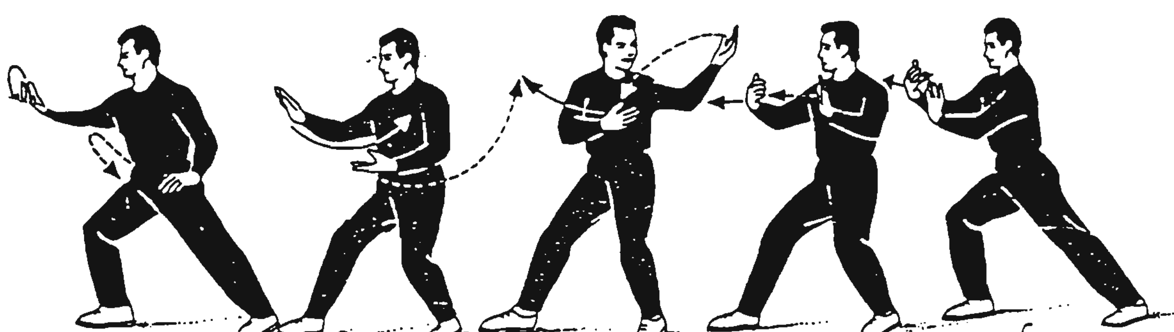
55 56 57 58 59 60



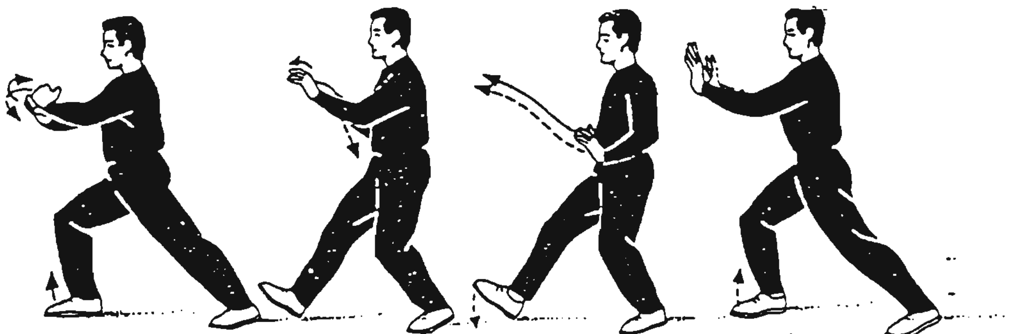
61 62 63 64 65 66

Grasp the bird's tail—right style (67–80)

67 68 69 70 71

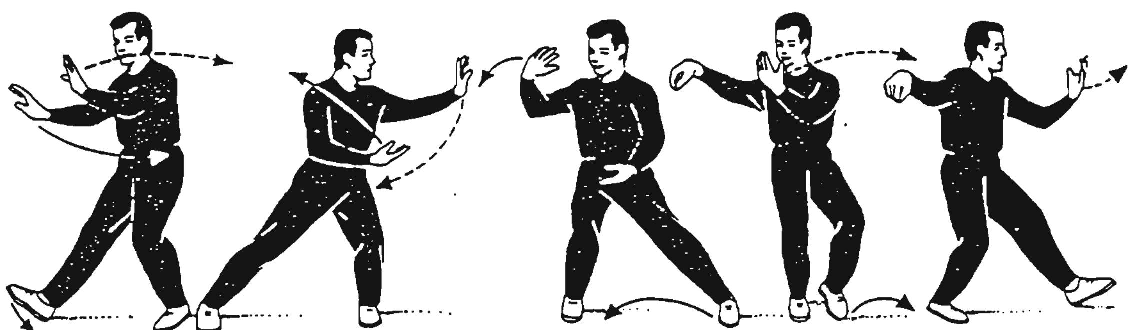


72 73 74 75 76



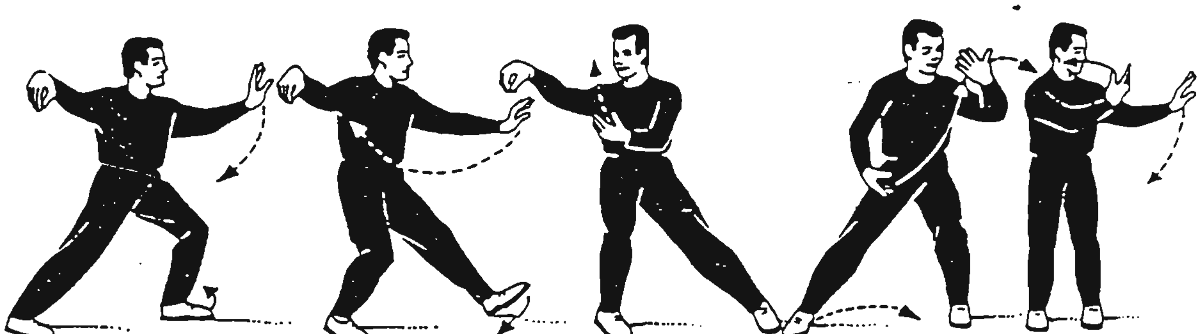
77 78 79 80

Single whip (81–86)

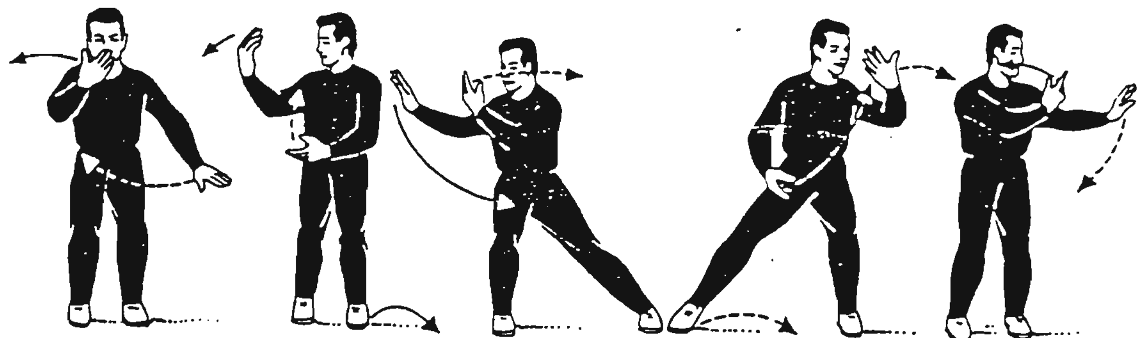


81 82 83 84 85

Wave the hands like clouds (87–100)



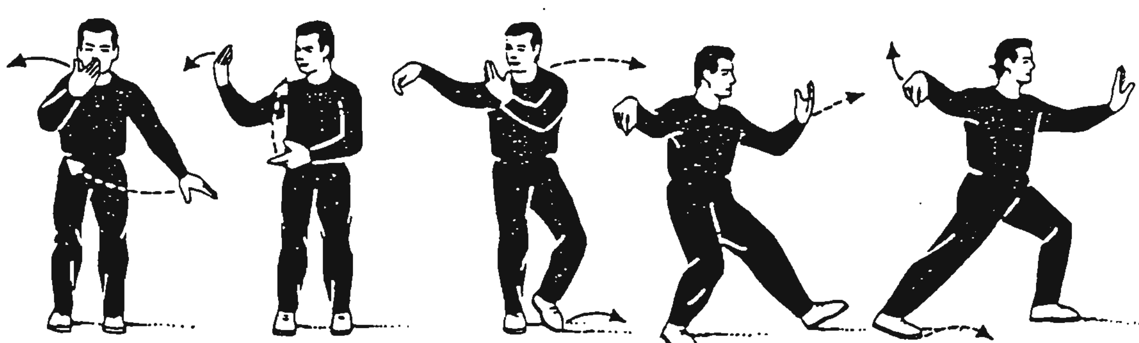
86 87 88 89 90



91 92 93 94 95

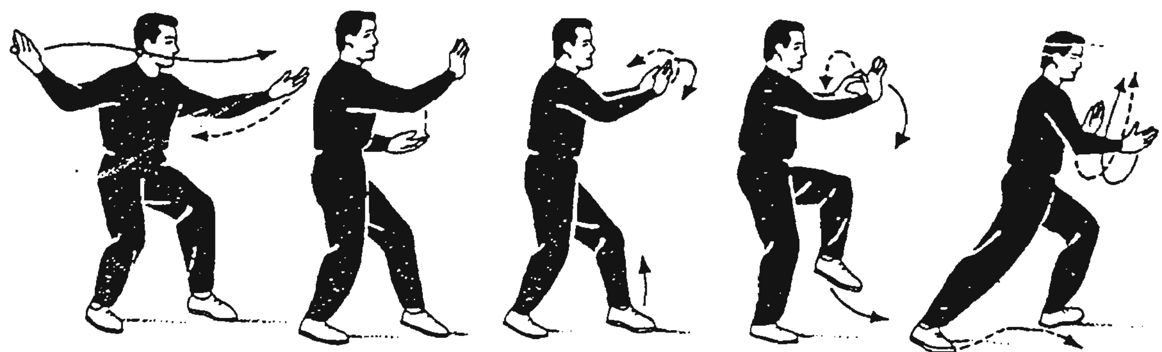
96 97 98 99 100

Single whip (101–5)



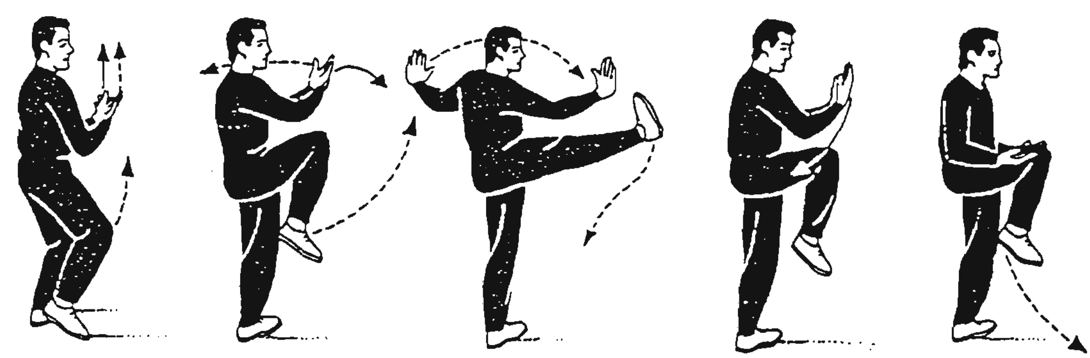
101 102 103 104 105

Pat the horse high (106–7) Kick with the right heel (108–13)



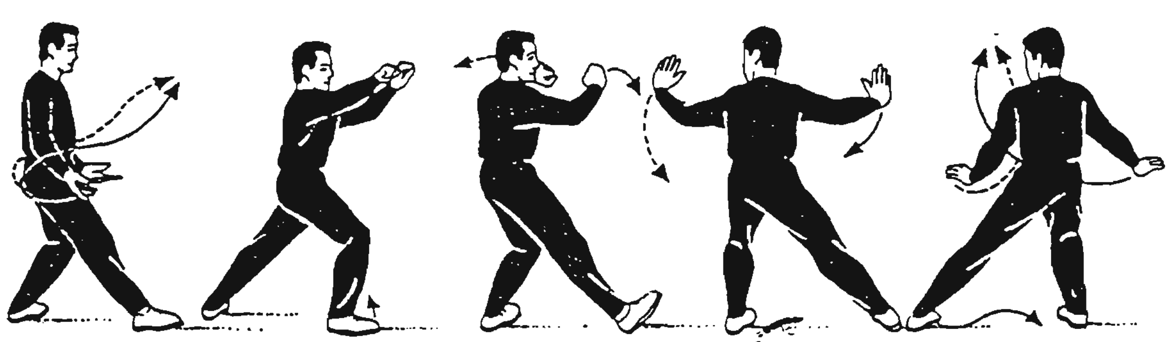
106 107 108 109 110

Strike opponent's ears with both fists (114–17)



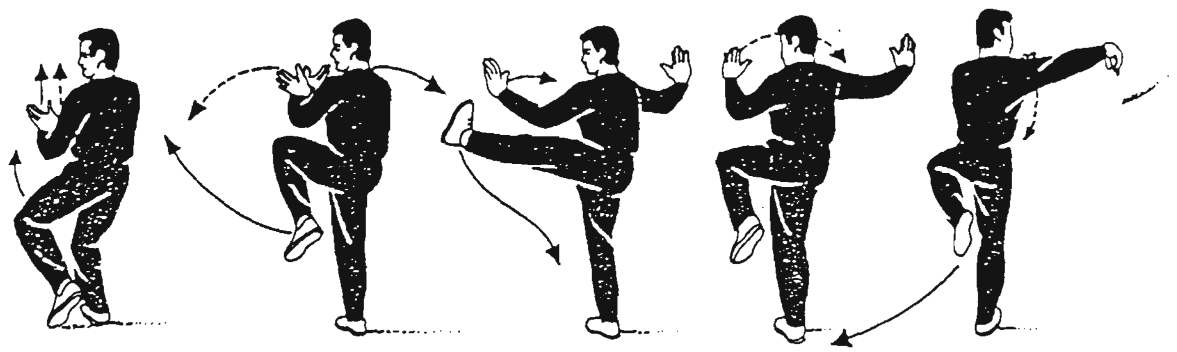
111 112 113 114 115

Turn and kick with the left heel (118–23)

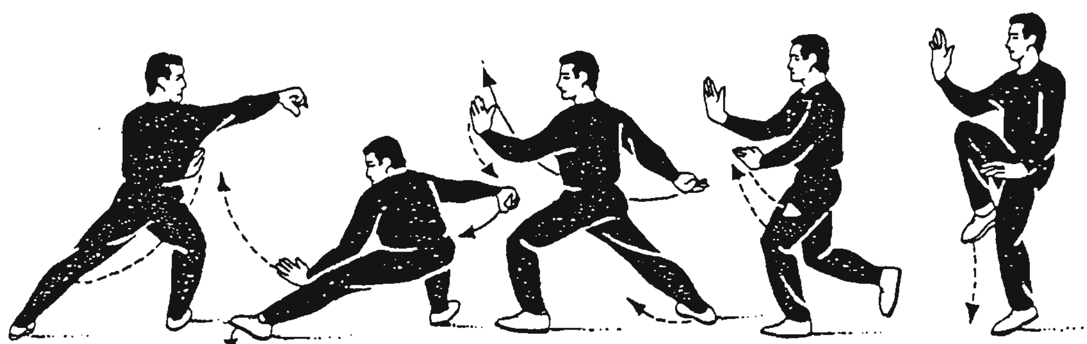


116 117 118 119 120

Push down and stand on one leg—left style (124–30)

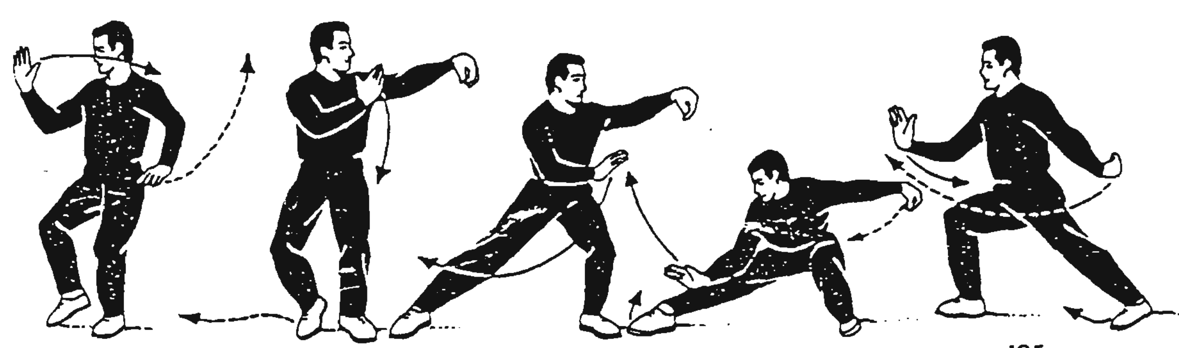


121 122 123 124 125



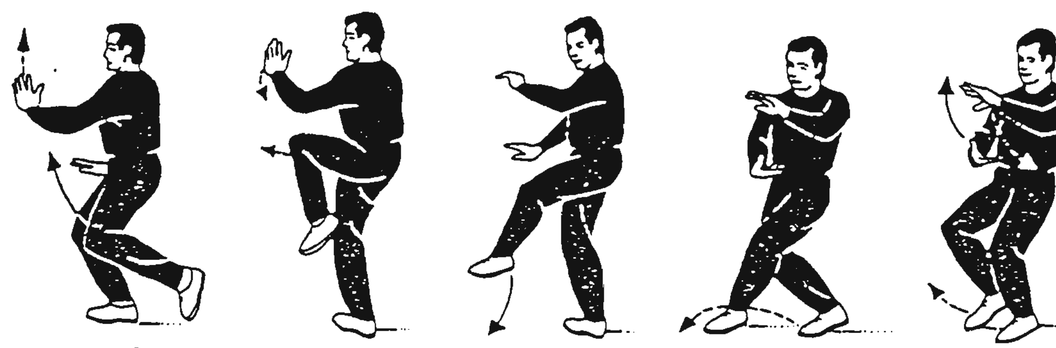
126 127 128 129 130

Push down and stand on one leg—right style (131–37)



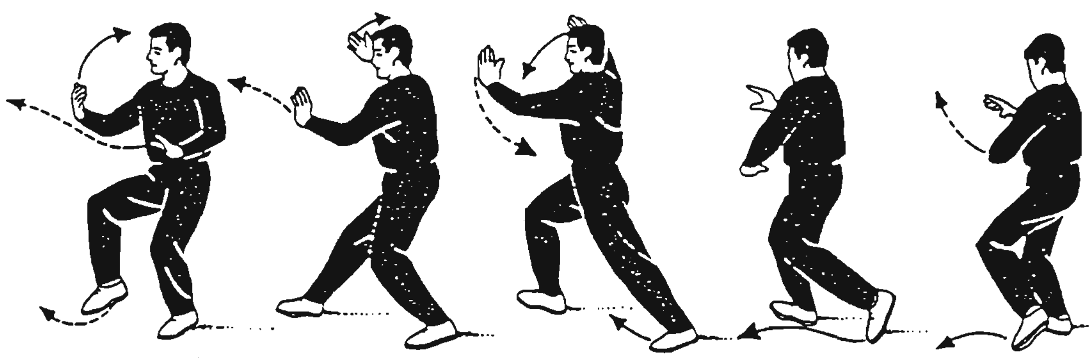
131 132 133 134 135

Work at shuttles—left style (138–42)



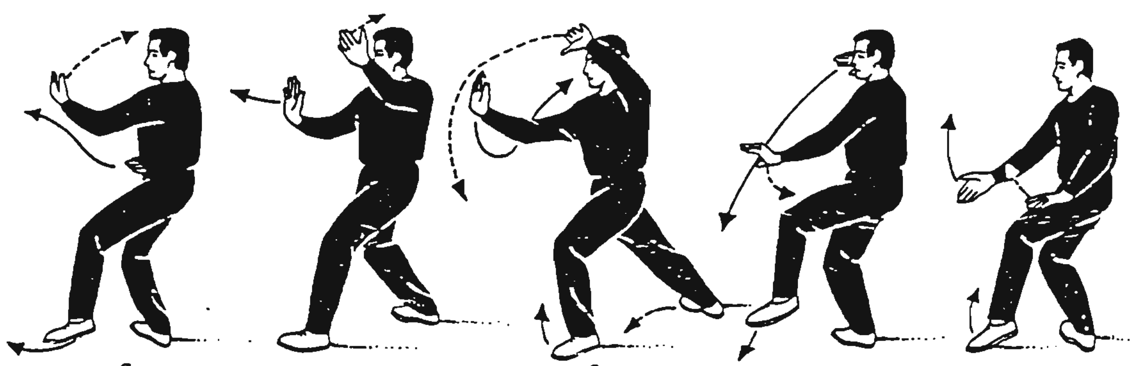
136 137 138 139 140

Work at shuttles—right style (143–48)



141 142 143 144 145

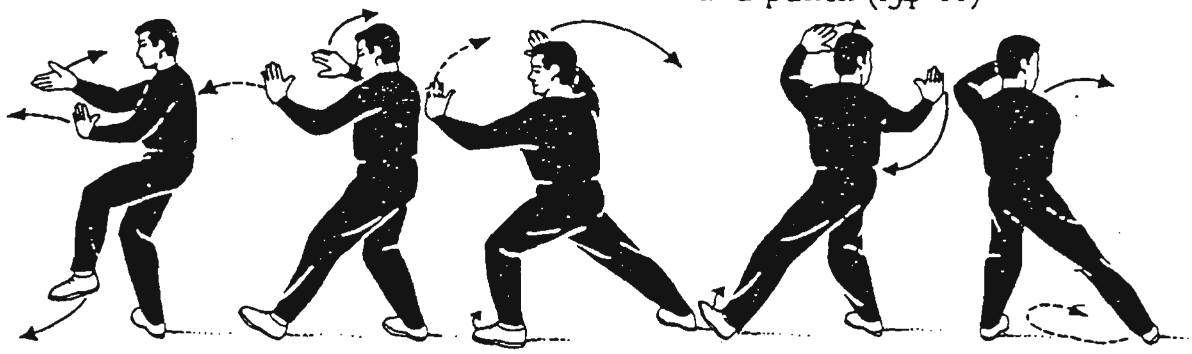
The needle at the bottom of the sea (149–50)



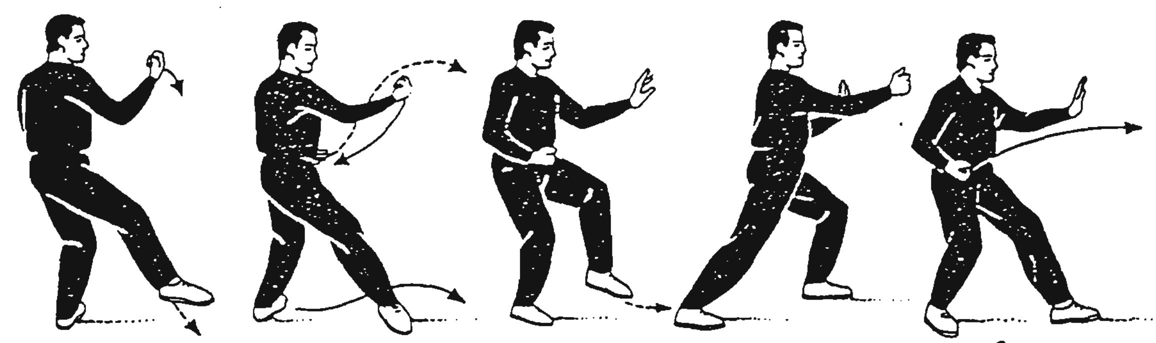
146 147 148 149 150

Flash the arm (151–53)

Turn, deflect downward, parry, and punch (154–60)



151 152 153 154 155

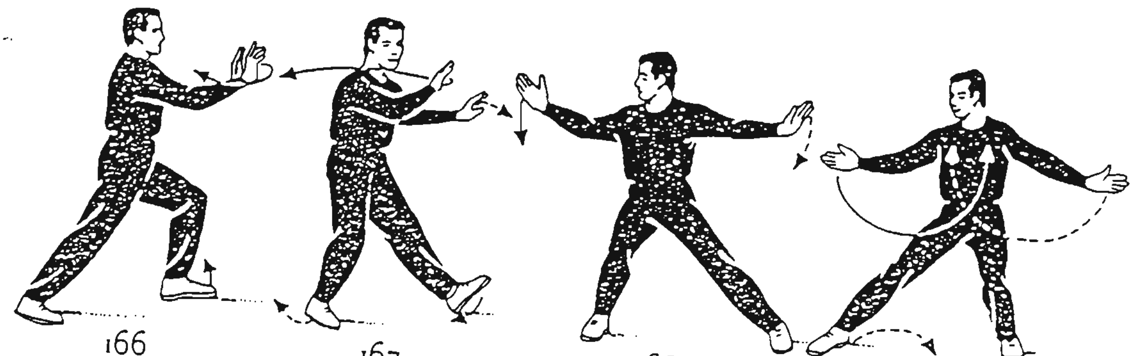


156 157 158 159 160

Apparent close-up (161–66)

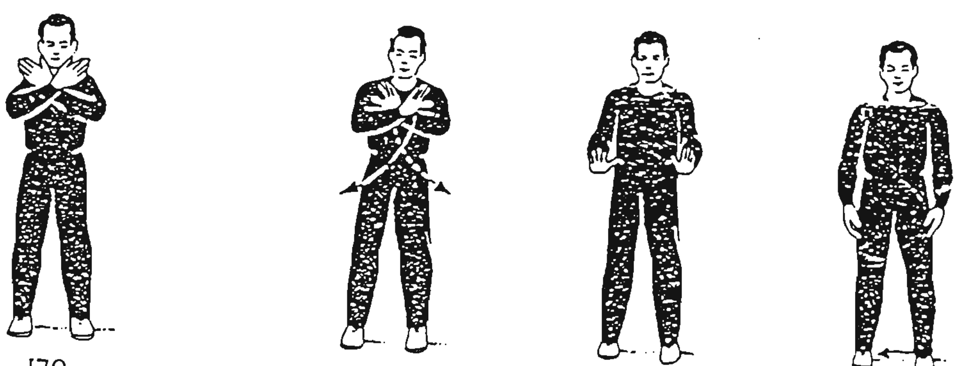
161 162 163 164 165

Cross hands (167–70)



166 167 168 169

Closing form (171–73)



170 171 172 173

APPENDIX D

1. Mean±SD of Forces and Moments in Upright Stance for the Young and the Elderly
2. Mean±SD of Peak Torque in Knee Extension and Flexion for the Young and the Elderly
3. Mean±SD of Peak Torque in Knee Extension and Flexion for the Training and Control Groups.
4. Mean±SD of Forces in Upright Stance for the Training and Control Groups.

The peak torque at different angular velocities for left leg of young group.

No.	Age (yer)	Height (cm)	Weight (Kg)	E60°. s^{-1} (N.m)	F180°. s^{-1} (N.m)	E180°. s^{-1} (N.m)	F60°. s^{-1} (N.m)
1	24	181	112.59	205.84	50.71	143.46	103.60
2	22	172	64.01	175.74	50.99	124.21	74.31
3	18	166	54.93	95.60	38.10	62.38	46.92
4	20	173	66.28	171.26	85.56	120.28	96.82
5	19	183	75.36	210.86	91.12	139.67	118.38
6	18	169	56.75	126.65	42.58	78.24	60.75
7	18	173	71.28	156.08	62.78	105.63	85.83
8	22	170	68.10	158.25	49.09	110.24	56.95
9	18	179	72.19	163.80	85.83	135.46	106.31
10	19	192	96.25	278.25	116.34	193.37	144.28
11	18	173	65.83	179.94	93.97	134.65	112.55
12	24	185	83.99	240.42	71.87	156.48	110.92
13	21	163	57.66	142.11	51.53	96.68	73.63
14	21	174	65.83	192.42	77.83	115.53	104.82
15	19	169	49.94	152.28	74.85	106.45	87.87
16	30	177	74.00	182.65	78.65	138.45	104.14
17	28	168	52.21	123.94	50.44	89.77	71.05
18	30	180	82.63	159.06	40.41	118.24	74.72
19	30	168	62.65	127.87	66.17	90.04	74.58
20	22	170	63.56	175.47	73.50	129.36	84.34
21	23	177	67.19	167.47	67.39	97.09	98.85
22	25	185	90.35	127.87	76.07	138.58	84.89
23	18	161	45.85	108.21	34.58	65.90	55.05
24	19	159	56.30	134.52	64.68	106.17	76.34
25	25	184	83.08	179.26	83.26	141.43	107.26
Mean	22.04	174	69.55	165.43	67.13	117.51	88.61
SD	4.05	8.20	15.45	40.71	20.15	29.42	22.89

E60°. s^{-1} = Knee extension at the angular velocities of 60°/sec.
E180°. s^{-1} = Knee extension at the angular velocities of 180°/sec.
F60°. s^{-1} = Knee flexion at the angular velocities of 60°/sec.
F180°. s^{-1} = Knee fxtension at the angular velocities of 180°/sec.

The peak torque at different angular velocities for right leg of young group.

No.	Age (yrs)	Height (cm)	Weight (kg)	E60°· s^{-1} (N·m)	E180°· s^{-1} (N·m)	F60°· s^{-1} (N·m)	F180°· s^{-1} (N·m)
1	24	181	112.59	248.00	134.52	80.28	29.56
2	22	172	64.01	156.75	120.14	75.53	44.88
3	18	166	54.93	96.68	63.19	50.17	40.47
4	20	173	66.28	177.77	129.36	121.90	99.80
5	19	183	75.36	195.40	130.85	117.02	95.06
6	18	169	56.75	125.02	85.02	64.95	44.61
7	18	173	71.28	148.35	99.39	87.73	55.46
8	22	170	68.10	152.41	103.60	72.68	52.34
9	18	179	72.19	166.25	136.82	96.28	78.65
10	19	192	96.25	272.96	191.47	146.72	138.18
11	18	173	65.83	189.84	144.01	108.75	78.92
12	24	185	83.99	250.59	162.04	124.48	103.06
13	21	163	57.66	151.60	100.21	77.29	47.60
14	21	174	65.83	196.21	130.85	110.24	79.19
15	19	169	49.94	152.28	106.45	94.92	80.28
16	30	177	74.00	188.48	130.58	115.80	81.50
17	28	168	52.21	122.18	86.92	88.00	69.02
18	30	180	82.63	163.40	106.85	55.32	52.88
19	30	168	62.65	136.41	101.29	93.02	63.05
20	22	170	63.56	194.24	142.11	77.70	72.55
21	23	177	67.19	152.69	86.65	103.06	76.48
22	25	185	90.35	151.74	127.46	97.23	73.77
23	18	161	45.85	136.96	103.19	73.50	58.44
24	19	159	56.30	130.99	57.22	80.82	52.34
25	25	184	83.08	196.66	154.31	123.26	90.58
Mean	22.04	174	69.55	168.79	117.38	93.47	70.34
SD	4.05	8.20	15.45	40.51	30.69	23.61	23.99

E60°. s^{-1} = Knee extension at the angular velocities of 60°/sec.

E180°. s^{-1} = Knee extension at the angular velocities of 180°/sec.

F60°. s^{-1} = Knee flexion at the angular velocities of 60°/sec.

F180°. s^{-1} = Knee fxtension at the angular velocities of 180°/sec.

The peak torque at different angular velocities for left leg of elderly group.

No.	Age (yrs)	Height (cm)	Weight (Kg)	E60°s.$^{-1}$ (N.m)	E180°s.$^{-1}$ (N.m)	F60°s.$^{-1}$ (N.m)	F180°s.$^{-1}$ (N.m)
1	65	170	74.00	109.97	67.12	81.09	35.80
2	63	168	65.83	86.78	52.88	54.24	34.58
3	78	160	53.12	51.26	33.09	31.19	21.40
4	74	175	86.26	106.64	69.30	60.48	33.76
5	66	155	59.93	54.10	38.10	10.03	15.49
6	65	154	54.93	27.66	20.48	16.14	8.14
7	59	165	56.75	66.04	41.49	32.54	24.95
8	68	165	74.00	73.36	47.60	30.78	20.75
9	70	155	67.19	71.05	49.63	41.22	30.65
10	62	160	62.20	97.50	48.82	62.78	48.54
11	63	165	68.10	66.58	69.77	46.38	41.49
12	56	165	57.20	89.36	62.65	57.77	41.49
13	64	165	65.38	70.11	58.44	22.24	18.98
14	64	174	69.00	89.90	81.36	48.68	36.94
15	63	156	56.75	105.90	71.60	54.92	45.15
16	63	170	73.09	120.24	76.48	69.70	35.80
17	67	170	54.03	91.67	77.83	63.05	56.55
18	64	170	59.93	104.55	64.55	64.95	48.82
19	60	165	52.21	114.04	74.72	58.04	53.43
20	60	165	59.93	107.07	82.44	50.44	46.38
21	67	176	67.65	90.04	69.70	45.43	39.32
22	60	165	61.29	110.11	77.65	56.41	49.22
23	60	178	59.23	86.51	78.11	39.60	32.00
24	70	155	64.14	57.22	61.29	17.90	19.53
25	74	175	74.00	109.84	70.24	29.70	45.15
Mean	65	165.60	63.85	86.24	61.60	45.83	35.35
SD	5.18	7.14	8.22	23.58	16.49	18.26	12.81

E60°. s^{-1} = Knee extension at the angular velocities of 60°/sec.
E180°. s^{-1} = Knee extension at the angular velocities of 180°/sec.
F60°. s^{-1} = Knee flexion at the angular velocities of 60°/sec.
F180°. s^{-1} = Knee fxtension at the angular velocities of 180°/sec.

The peak torque at different angular velocities for right leg of elderly group.

No.	Age	Height	Weight	E60°.s^{-1}	E180°.s^{-1}	F60°.s^{-1}	F180°.s^{-1}
	(yrs)	(cm)	(Kg)	(N.m)	(N.m)	(N.m)	(N.m)
1	65	170	74.00	106.45	66.58	78.78	40.68
2	63	168	65.83	83.26	50.17	41.76	33.20
3	78	160	53.12	51.80	36.07	22.37	19.12
4	74	175	86.26	97.23	73.50	38.78	22.65
5	66	155	59.93	60.34	46.38	8.14	14.92
6	65	154	54.93	50.17	27.39	21.97	15.04
7	65	165	56.75	61.83	40.95	23.87	21.02
8	68	164	74.00	82.58	59.66	32.27	17.90
9	70	155	67.19	66.99	46.38	32.68	25.90
10	62	160	62.20	96.68	58.31	61.16	47.87
11	63	165	68.10	66.99	51.26	44.75	34.44
12	56	165	57.20	100.48	52.34	53.70	18.85
13	64	165	65.38	82.44	53.56	23.19	2.61
14	64	174	69.00	81.50	81.80	36.61	36.61
15	63	156	56.75	91.80	65.77	54.10	45.83
16	63	170	73.09	129.77	84.61	45.43	12.61
17	67	170	54.03	92.75	72.55	63.73	61.43
18	64	170	59.93	99.80	62.65	81.63	62.10
19	60	165	52.21	103.60	81.77	65.36	45.83
20	60	165	59.93	109.02	92.21	52.88	45.02
21	67	176	67.65	91.80	66.17	44.21	37.70
22	60	165	61.29	89.87	69.97	59.39	40.27
23	60	178	59.23	64.68	66.44	29.83	25.09
24	70	155	64.14	61.16	55.60	22.24	19.93
25	74	175	74.00	114.99	74.44	28.75	47.60
Mean	65	166	64	85.51	61.45	42.70	32.49
SD	5	7	8	23.70	15.84	18.90	14.55

E60°. s^{-1} = Knee extension at the angular velocities of 60°/sec.

E180°. s^{-1} = Knee extension at the angular velocities of 180°/sec.

F60°. s^{-1} = Knee flexion at the angular velocities of 60°/sec.

F180°. s^{-1} = Knee fxtension at the angular velocities of 180°/sec.

Mean±SD of force and moment for left leg stance on force platform of elderly group.

No.	Age (yrs)	Height (cm)	Weight (Kg)	Fx (N)	Fy (N)	Fz (N.)	Mx (N·m)	My (N·m)
1	65	170	74.00	1.67	1.98	2.34	2.45	3.12
2	63	168	65.83	3.16	2.43	4.58	4.19	3.55
3	78	160	53.12	4.77	3.47	7.00	6.09	9.14
4	74	175	86.26	3.15	2.42	6.70	4.40	5.40
5	66	155	59.93	4.71	3.68	8.67	5.59	7.56
6	65	154	54.93	4.86	3.71	8.72	5.64	7.56
7	59	165	56.75	2.79	2.66	4.91	4.16	4.10
8	68	164	74.00	3.74	3.43	5.93	5.35	5.74
9	70	155	67.19	2.78	2.23	3.33	3.44	3.44
1	62	160	62.20	2.15	2.09	3.44	3.42	4.24
11	63	165	68.10	2.54	2.11	3.67	2.85	3.85
12	56	165	57.20	2.08	1.33	2.30	2.42	2.45
13	64	165	65.38	3.85	3.13	4.98	4.65	5.23
14	64	174	69.00	2.86	2.78	4.87	3.45	4.12
15	63	156	56.75	1.72	1.58	2.01	2.52	1.67
16	63	170	73.09	1.45	1.41	3.44	2.62	2.90
17	67	170	54.03	2.65	2.18	3.57	6.19	7.23
18	64	170	59.93	2.35	1.51	3.55	3.70	3.90
19	60	165	52.21	2.11	2.03	3.36	3.42	4.24
20	60	165	59.93	2.25	1.71	4.70	2.99	3.67
21	67	176	67.65	3.50	2.26	3.05	4.26	3.93
22	60	165	61.29	1.45	1.60	3.46	3.33	4.08
23	60	178	59.23	3.66	3.21	9.54	9.61	13.4
24	70	155	64.14	2.35	1.51	2.49	2.56	3.28
25	74	175	74.00	1.88	1.86	2.52	2.66	3.24
Mean	65	166	64	2.82	2.33	4.53	4.08	4.84
Stdev	5	7	8	1.01	0.74	2.13	1.65	2.51

Fx = Force on the X axis. Fy = Force on the Y axis. Fz = Force on the Z axis. Mx = Moment on the X axis. My = Moment on the Y axis.

Mean±SD of force and moment for right leg stance on force platform of elderly group.

No.	Age (yrs)	Height (cm)	Weight (Kg)	Fx (N)	Fy (N)	Fz (N)	Mx (N·m)	My (N·m)
1	65	170	74.00	1.87	1.96	2.65	3.20	3.13
2	63	168	65.83	3.10	2.45	4.56	4.20	3.57
3	78	160	53.12	4.49	2.19	3.28	4.89	3.13
4	74	175	86.26	2.58	1.89	8.78	7.04	7.64
5	66	155	59.93	4.53	3.02	7.03	4.54	5.30
6	65	154	54.93	4.66	4.44	10.60	4.53	5.43
7	59	165	56.75	2.84	2.82	5.34	3.91	3.51
8	68	164	74.00	3.20	3.59	7.00	4.80	3.87
9	70	155	67.19	2.46	3.07	2.63	3.18	2.95
1	62	160	62.20	1.90	1.45	3.24	4.26	2.39
11	63	165	68.10	1.91	2.56	2.68	2.79	3.95
12	56	165	57.20	1.59	2.08	2.88	2.16	2.76
13	64	165	65.38	2.84	2.96	3.56	3.88	4.99
14	64	174	69.00	2.98	3.23	3.87	3.98	3.82
15	63	156	56.75	2.01	1.98	2.12	3.45	2.89
16	63	170	73.09	1.71	1.51	3.32	3.46	2.35
17	67	170	54.03	2.82	2.40	3.24	5.35	7.21
18	64	170	59.93	2.34	1.82	2.94	2.98	3.55
19	60	165	52.21	2.54	2.89	3.05	3.32	3.45
20	60	165	59.93	2.08	2.38	3.46	3.33	4.04
21	67	176	67.65	2.35	1.95	6.70	4.44	4.44
22	60	165	61.29	1.77	1.59	2.65	5.66	3.71
23	60	178	59.23	3.10	3.33	4.56	7.40	8.94
24	70	155	64.14	3.16	2.43	4.58	4.16	3.55
25	74	175	74.00	1.94	1.84	2.86	3.42	3.02
Mean	65	166	64	2.67	2.47	4.30	4.17	4.14
SD	5	7	8	0.87	0.72	2.14	1.23	1.65

Fy = Force on the X axis. Fy = Force on the Y axis. Fz = Force on the Z axis.
Mx = Moment on the X axis. My = Moment on the Y axis.

Mean±SD of force and moment for right leg stance on force platform of young group

No.	Age (yrs)	Height (cm)	weight (Kg)	Fx (N)	Fy (N)	Fz (N)	Mx (N·m)	My (N·m)
1	24	181	112.59	1.22	1.11	2.39	2.62	1.86
2	22	172	64.01	1.52	1.48	1.88	3.19	2.51
3	18	166	54.93	1.76	1.64	2.13	2.55	2.71
4	20	173	66.28	1.65	1.35	2.52	2.45	2.32
5	19	183	75.36	1.19	0.95	1.60	2.42	1.81
6	18	169	56.75	1.35	1.67	2.08	3.13	2.83
7	18	173	71.28	1.19	1.26	1.41	3.85	2.28
8	22	170	68.10	1.59	1.42	2.09	2.63	2.33
9	18	179	72.19	1.59	2.16	3.00	2.80	2.48
10	19	192	96.25	1.39	1.61	2.21	3.89	2.74
11	18	173	65.83	0.95	1.16	1.60	2.88	2.72
12	24	185	83.99	1.82	1.34	1.44	2.24	2.12
13	21	163	57.66	1.24	1.36	1.45	2.31	2.42
14	21	174	65.83	1.17	2.35	2.64	3.24	2.89
15	19	169	49.94	1.23	1.24	2.14	2.63	2.85
16	30	177	74.00	1.71	1.84	1.96	2.53	2.58
17	28	168	52.21	1.12	1.35	2.31	2.65	2.44
18	30	180	82.63	1.19	2.01	2.62	2.15	2.42
19	30	168	62.65	1.01	1.04	1.99	2.10	2.11
20	22	170	63.56	1.54	1.32	2.41	2.18	2.63
21	23	177	67.19	1.25	1.26	1.54	1.68	2.46
22	25	185	90.35	1.17	1.45	1.66	1.55	2.45
23	18	161	45.85	1.12	1.18	2.14	2.35	2.49
24	19	159	56.30	1.35	1.28	2.15	2.14	2.88
25	25	184	83.03	1.16	1.53	2.41	2.35	2.68
Mean	22	174	70	1.34	1.45	2.07	2.58	2.50
SD	5	8	16	0.24	0.34	0.42	0.56	0.30

Fy = Force on the X axis, Fy = Force on the Y axis, Fz = Force on the Z axis, Mx = Moment on the X axis
My = Moment on the Y axis.

Mean±SD of force and moment for left leg stance on force platform of young group.

No.	Age (yrs)	Height (cm)	Weight (kg)	Fx (N)	Fy (N)	Fz (N)	Mx (N·m)	My (N·m)
1	24	181	112.59	1.23	0.98	1.18	2.36	2.44
2	22	172	64.01	1.38	1.09	2.56	2.65	2.33
3	18	166	54.93	1.34	1.27	1.48	2.39	2.03
4	20	173	66.28	1.71	1.63	2.12	3.28	3.02
5	19	183	75.36	1.19	1.21	2.42	2.72	1.93
6	18	169	56.75	1.11	1.50	2.13	2.33	2.57
7	18	173	71.28	1.21	1.49	2.52	2.67	2.05
8	22	170	68.10	1.45	1.14	1.93	2.40	2.19
9	18	179	72.19	2.01	2.11	1.89	2.40	1.57
10	19	192	96.25	1.83	1.51	2.62	2.95	3.52
11	18	173	65.83	1.23	1.13	1.86	3.20	1.63
12	24	185	83.99	1.84	1.20	1.55	2.48	2.30
13	21	163	57.66	1.65	1.12	2.35	3.25	2.40
14	21	174	65.83	1.19	1.26	1.89	1.37	1.98
15	19	169	49.94	1.27	1.56	2.53	2.36	2.48
16	30	177	74.00	1.12	1.24	1.89	3.25	2.98
17	28	168	52.21	0.98	1.15	2.45	2.56	3.13
18	30	180	82.63	1.19	1.15	2.24	2.23	2.16
19	30	168	62.65	0.99	0.94	2.31	1.34	2.12
20	22	170	63.56	1.14	1.91	2.54	2.37	2.18
21	23	177	67.19	1.35	1.24	1.88	2.87	2.92
22	25	185	90.35	1.54	1.25	2.45	3.21	2.45
23	18	161	45.85	1.19	0.81	1.96	2.04	2.14
24	19	159	56.30	1.03	1.16	2.16	2.18	2.49
25	25	184	83.08	1.25	1.56	2.33	2.41	2.82
Mean	22	174	70	1.34	1.30	2.13	2.53	2.39
SD	5	8	16	0.28	0.30	0.37	0.51	0.47

Fy = Force on the X axis, Fy = Force on the Y axis, Fz = Force on the Z axis, Mx = Moment on the X axis
My = Moment on the Y axis.

Peak torque of knee extension and flexion in pre-test and post-test for training group (n = 14)

No.	Age (yer)	Heigh (cm)	Weight (Kg)	tpe60°·s^{-1} (N·m)	tpe180°·s^{-1} (N·m)	tpf60°·s^{-1} (N·m)	tpf180°·s^{-1} (N·m)	tpoe60°·s^{-1} (N·m)	tpoe180°·s^{-1} (N·m)	tpof60°·s^{-1} (N·m)	tpof180°·s^{-1} (N·m)
1	65	170	74.00	109.97	67.12	81.09	35.80	128.82	82.17	99.94	50.27
2	63	168	65.83	86.78	52.88	54.24	34.58	101.29	66.72	61.02	46.51
3	78	160	53.12	51.26	33.09	31.19	21.40	55.60	40.82	36.41	33.41
4	74	175	86.26	106.64	69.30	60.48	33.76	105.63	72.58	69.16	45.83
5	66	155	59.93	54.10	38.10	10.03	15.49	69.83	51.12	24.27	21.56
6	65	154	54.93	27.66	20.48	16.14	8.14	47.19	39.78	28.48	20.15
7	59	165	56.75	66.04	41.49	32.54	24.95	80.55	50.44	36.85	30.10
8	68	164	74.00	73.36	47.60	30.78	20.75	88.28	51.26	44.61	28.61
9	70	155	67.19	71.05	49.63	41.22	30.65	74.17	55.60	45.61	34.82
10	62	160	62.20	97.50	48.82	62.78	48.54	104.28	66.58	63.75	52.16
11	63	165	68.10	66.58	69.77	46.38	40.49	75.80	87.94	56.10	43.06
12	56	165	57.20	89.36	62.65	57.77	41.49	95.73	67.94	59.84	45.98
13	64	165	65.38	70.11	58.44	22.24	18.98	99.26	74.34	38.37	35.80
14	64	174	69.00	89.9	81.36	48.68	36.94	99.11	85.36	57.92	38.78
Mean	65.5	163.9	65.3	75.7	52.9	42.5	29.4	87.5	63.8	51.6	37.7
SD	5.7	6.6	9.0	22.7	16.5	20.0	11.4	21.8	15.9	19.6	10.2

tpe = training group pre-test extension, tpf = training group pre-test flexion, tpoe = training group post-test extension, tpof = training group post-test flexion.
60°·s^{-1} = angular velocities of 60 degree in one second, 180°·s^{-1} = angular velocities of 180 degree in one second.

Peak torque of knee extension and flexion in pre-test and post-test for control group (n = 11)

No.	Age (yer)	Heigh (cm)	Weight (Kg)	cpe60°·s^{-1} (N·m)	cpe180°·s^{-1} (N·m)	cpef60°·s^{-1} (N·m)	cpf180°·s^{-1} (N·m)	cpoe60°·s^{-1} (N·m)	cpoe180 (N·m)	cpof60°·s^{-1} (N·m)	cpof180°·s^{-1} (N·m)
1	63.00	156.00	57.00	88.26	71.60	54.92	40.25	88.85	70.65	55.91	39.25
2	63.00	170.00	73.00	102.24	76.48	69.70	35.8	104.2	74.38	70.12	36.74
3	67.00	170.00	54.00	91.67	77.83	63.05	42.56	93.28	76.23	63.85	43.26
4	64.00	168.00	60.00	56.26	34.25	32.82	22.39	57.62	36.26	33.56	23.48
5	67.00	174.00	68.00	84.29	62.41	46.43	29.82	85.26	64.52	47.62	31.28
6	60.00	162.00	61.00	82.62	64.28	50.44	46.38	83.15	65.23	50.12	48.32
7	70.00	155.00	64.00	74.65	58.27	45.43	34.52	75.34	58.62	45.91	35.46
8	60.00	171.00	73.00	66.28	42.69	43.47	31.24	95.99	48.32	44.56	32.12
9	60.00	160.00	52.00	86.51	46.42	39.6	28.46	87.94	45.32	37.46	29.95
10	60.00	165.00	60.00	57.22	42.64	17.9	16.15	58.43	47.64	18.23	19.27
11	74.00	175.00	74.00	82.64	56.43	29.7	18.24	85.37	59.43	27.36	19.56
Mean	64.4	166.0	63.3	79.3	57.6	44.9	31.4	83.2	58.8	45.0	32.61
SD	4.7	6.9	7.8	14.4	14.7	14.9	9.8	14.5	13.0	15.4	9.33

cpe = control group pre-test extension, cpf = control group pre-test flexion, cpoe = control group post-test extension, cpof = contorl group post-test flexion.
60°·s^{-1} = angular velocities of 60 degree in one second, 180°·s^{-1} = angular velocities of 180 degree in one second.

Mean ± SD of force of static balance of pre-test and post-test for training group (n = 14).

No.	Age (yer)	Heigh (cm)	Weight (Kg)	TPRFx (N)	TPRFy (N)	TPRFz (N)	TPOFx (N)	TPOFy (N)	TPOFz (N)
1	65	170	74.00	1.67	1.98	2.34	1.42	1.86	2.12
2	63	168	65.83	3.16	2.53	4.58	2.84	2.13	4.10
3	78	160	53.12	4.77	3.47	5.00	3.96	2.96	5.89
4	74	175	86.26	3.15	2.42	4.70	2.98	2.16	5.17
5	66	155	59.93	4.71	3.78	6.67	4.12	3.14	6.68
6	65	154	54.93	4.86	3.81	6.72	2.27	2.16	4.14
7	59	165	56.75	2.79	2.66	4.91	2.28	2.48	2.97
8	68	164	74.00	3.74	3.43	4.93	2.34	2.08	2.98
9	70	155	67.19	2.78	2.33	3.33	1.94	1.92	2.96
10	62	160	62.20	2.15	2.19	3.44	1.92	2.01	3.22
11	63	165	68.10	2.54	2.21	3.67	1.98	1.34	2.31
12	56	165	57.20	2.08	1.83	2.30	1.48	1.36	3.42
13	64	165	65.38	1.45	1.71	3.44	1.43	2.96	3.68
14	64	174	69.00	3.85	3.13	4.98	3.45	2.96	4.46
Mean	65.5	163.9	65.3	3.1	2.73	4.4	2.5	2.3	3.9
SD	5.7	6.6	9.0	1.1	0.7	1.4	0.9	0.6	1.3

TPRFx = training group pre-test of force in X axis, TPRFy = training group pre-test of force in Y axis,
TPRFz = training group pre-test of force in Z axis, TPOFx = training group post-test of force in x axis,
TPOFy = training group post-test of force in Y axis, TPOFz = training group post-test of force in Z axis.

Mean ± SD of force of static balance of pre-test and post-test for control group (n = 11).

No.	Age (yer)	Heigh (cm)	Weight (Kg)	CPRFx (N)	CPRFy (N)	CPRFz (N)	CPOFx (N)	CPOFy (N)	CPOFz (N)
1	63.00	156.00	57.00	2.86	2.78	4.23	2.82	2.32	4.12
2	63.00	170.00	73.00	2.35	1.96	3.56	2.17	1.51	3.32
3	67.00	170.00	54.00	2.65	2.18	3.57	2.74	2.4	3.98
4	64.00	168.00	60.00	2.25	1.71	3.21	2.34	2.38	3.46
5	67.00	174.00	68.00	2.35	1.51	3.55	3.48	1.82	3.17
6	60.00	162.00	61.00	3.50	2.26	2.98	2.29	1.95	3.41
7	70.00	155.00	64.00	2.45	1.60	3.46	2.24	1.59	2.65
8	60.00	171.00	73.00	2.11	2.03	9.54	2.46	2.14	7.35
9	60.00	160.00	52.00	3.66	3.21	3.24	3.76	3.33	4.56
10	60.00	165.00	60.00	2.35	1.84	2.89	2.03	2.43	2.82
11	74.00	175.00	74.00	1.98	1.86	3.9	2.16	1.84	3.45
Mean	64.4	166.0	63.3	2.6	2.1	4.0	2.6	2.2	3.8
SD	4.7	6.9	7.8	0.5	0.5	1.9	0.6	0.5	1.3

CPRFx = control group pre-test of force in X axis, CPRFy = control group pre-test of force in Y axis,
CPRFz = control group pre-test of force in Z axis, CPOFx = control group post-test of force in x axis,
CPOFy = control group post-test of force in Y axis, CPOFz = control group post-test of force in Z axis,

APPENDIX E

1. The Original Data of ANOVA Analysis for Strength and Balance Between the Young and the Elderly.
2. The Original Data of Paired Student's T-Test Analysis for Strength and Balance Between Pre-Training and Post-Training.

YRE60, YRE180, YRF60 and YRF180 = the young group, right leg extensions and flexions at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively.

YLE60, YLE 180 YLF60 and YLF180 = the young group, left leg extensions and flexions at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively.

E'RE60, E'RE60 E'RF60 and E'RF180 = the elderly group, right leg extensions and flexions at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively.

E'LE60, E'LE180, E'LF60 and E'LF180 = the elderly group, left leg extensions and flexions at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively.

YR(Fx), YR(Fy), YR(Fz) = body sway forces on the axes of X, Y, and Z of the right leg for the young group respectively.

YL(Fx), YL(Fy), YL(Fz) = body sway forces on the axes of X, Y, and Z of the left leg for the young group respectively.

E'R(Fx), E'R(Fy), E'R(Fz) = body sway forces on the axes of X, Y, and Z of the right leg for the elderly group respectively.

E'L(Fx), E'L(Fy), E'L(Fz) = body sway forces on the axes of X, Y, and Z of the left leg for the elderly group respectively.

TPE60, TPF60, TPE180, TPF180 = knee extentions and flexions at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively (pre-training) for the training elderly group.

CPE60, CPF60, CPE180, CPF180 = knee extentions and flexions at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively (pre-training) for the control elderly group

TPOE60, TPOF60, TPOE180, TPOF180 = knee extentions and flexions at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively (post-training) for the training elderly group.

CPOE60, CPOF60, CPOE180, COPF180 = knee extentions and flexions at the angular velocities of $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$ respectively (post-training) for the control elderly group.

TPRFX, TPRFY, TPRFZ = body sway forces (pre-training) on the X,Y and Z axes of the training elderly group.

CPRFX, CPRFY, CPRFZ =body sway forces (pre-training) on the X,Y and Z axes of the control elderly group.

TPOFX, TPOFY, TPOFZ =body sway forces (post-training) on the X,Y and Z axes of the training elderly group.

CPOFX, CPOFY, CPOFZ = body sway forces (post-training) on the X,Y and Z axes of the control elderly group.

Anova: Single-Factor of RF 180 between Y & E`

Summary

Groups	Count	Sum	Average	Variance
YRF180	25.00	1758.61	70.34	575.71
E`RF180	25.00	812.23	32.49	211.64

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	17912.70	1.00	17912.70	45.50	0.00	4.04
Within Groups	18896.40	48.00	393.67			
Total	36809.10	49.00				

Anova: Single-Factor of static balance for Fx of left side						
Summary						
Groups	Count	Sum	Average	Variance		
YL(Fx)	25	33.42	1.34	0.08		
E`L(Fx)	25	70.48	2.82	1.02		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	27.47	1	27.47	50.24	0	4.04
Within Groups	26.24	48	0.55			
Total	53.71	49				
Anova: Single-Factor of Fx for right						
Summary						
Groups	Count	Sum	Average	Variance		
YR(Fx)	25	33.48	1.34	0.06		
E`R(Fx)	25	66.77	2.67	0.75		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	22.16	1	22.16	54.55	0	4.04
Within Groups	19.5	48	0.41			
Total	41.67	49				
Anova: Single-Factor of Fy for left						
Summary						
Groups	Count	Sum	Average	Variance		
YL(Fy)	25	32.61	1.3	0.09		
E`L(Fy)	25	58.31	2:33	0.55		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	13.21	1	13.21	41.39	0	4.04
Within Groups	15.32	48	0.32			
Total	28.53	49				

Anova: Single-Factor of Fy for right						
Summary						
Groups	Count	Sum	Average	Variance		
YR(Fy)	25	36.36	1.45	0.12		
E`R(Fy)	25	61.83	2.47	0.52		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	12.97	1	12.97	40.54	0	4.04
Within Groups	15.36	48	0.32			
Total	28.34	49				
Anova: Single-Factor of Fx between L & R for young						
Summary						
Groups	Count	Sum	Average	Variance		
YL(Fx)	25	33.42	1.34	0.08		
YR(Fx)	25	33.48	1.34	0.06		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	0	1	0	0	0.97	4.04
Within Groups	3.26	48	0.07			
Total	3.26	49				
Anova: Single-Factor of Fx between L & R in elderly						
Summary						
Groups	Count	Sum	Average	Variance		
E`L(Fx)	25	70.48	2.82	1.02		
E`R(Fx)	25	66.77	2.67	0.75		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	0.28	1	0.28	0.31	0.58	4.04
Within Groups	42.49	48	0.89			
Total	42.76	49				

Anova: Single-Factor of Fy between L & R for young						
Summary						
Groups	Count	Sum	Average	Variance		
YL(Fy)	25	32.61	1.3	0.09		
YR(Fy)	25	36.36	1.45	0.12		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	0.28	1	0.28	2.77	0.1	4.04
Within Groups	4.88	48	0.1			
Total	5.16	49				
Anova: Single-Factor of Fy between L & R in elderly						
Summary						
Groups	Count	Sum	Average	Variance		
E`L(Fy)	25	58.31	2.33	0.55		
E`R(Fy)	25	61.83	2.47	0.52		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	0.25	1	0.25	0.46	0.5	4.04
Within Groups	25.8	48	0.54			
Total	26.05	49				
Anova: Single-Factor of Fz between L & R in young						
Summary						
Groups	Count	Sum	Average	Variance		
YL(Fz)	25	53.24	2.13	0.14		
YR(Fz)	25	51.77	2.07	0.18		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	0.04	1	0.04	0.27	0.61	4.04
Within Groups	7.65	48	0.16			
Total	7.7	49				

Anova: Single-Factor of Fz between L & R in elderly						
Summary						
Groups	Count	Sum	Average	Variance		
E`L(Fz)	25	113.13	4.53	4.52		
E`R(Fz)	25	107.58	4.3	4.6		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	0.62	1	0.62	0.14	0.71	4.04
Within Groups	218.88	48	4.56			
Total	219.5	49				
Anova: Single-Factor of Fz for left						
Summary						
Groups	Count	Sum	Average	Variance		
YL(Fz)	25	53.24	2.13	0.14		
E`L(Fz)	25	113.13	4.53	4.52		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	71.74	1	71.74	30.77	0	4.04
Within Groups	111.89	48	2.33			
Total	183.62	49				
Anova: Single-Factor of Fz for right						
Summary						
Groups	Count	Sum	Average	Variance		
YR(Fz)	25	51.77	2.07	0.18		
E`R(Fz)	25	107.58	4.3	4.6		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	62.3	1	62.3	26.08	0	4.04
Within Groups	114.65	48	2.39			
Total	176.94	49				

Anova: Single-Factor of Y (Fz) between L & R						
Summary						
Groups	Count	Sum	Average	Variance		
YL (Fz)	25	53.24	2.13	0.14		
YR (Fz)	25	51.77	2.07	0.18		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	0.04	1	0.04	0.27	0.61	4.04
Within Groups	7.65	48	0.16			
Total	7.7	49				
Anova: Single-Factor of E\` (Fz) between L & R						
Summary						
Groups	Count	Sum	Average	Variance		
E\`L (Fz)	25	113.13	4.53	4.52		
E\`R (Fz)	25	107.58	4.3	4.6		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	0.62	1	0.62	0.14	0.71	4.04
Within Groups	218.88	48	4.56			
Total	219.5	49				
Anova: Single-Factor of L (Fz) between Y & E\`						
Summary						
Groups	Count	Sum	Average	Variance		
YL (Fz)	25	53.24	2.13	0.14		
E\`L (Fz)	25	113.13	4.53	4.52		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	71.74	1	71.74	30.77	0	4.04
Within Groups	111.89	48	2.33			
Total	183.62	49				

Anova: Single-Factor of R (Fz) between Y & E`

Summary

Groups	Count	Sum	Average	Variance
YR (Fz)	25	51.77	2.07	0.18
E`R (Fz)	25	107.58	4.3	4.6

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	62.3	1	62.3	26.08	0	4.04
Within Groups	114.65	48	2.39			
Total	176.94	49				

Anova: Single-Factor of YF180 between L & R

Summary

Groups	Count	Sum	Average	Variance
YLF180	25.00	1678.30	67.13	405.80
YRF180	25.00	1758.61	70.34	575.71

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	128.99	1.00	128.99	0.26	0.61	4.04
Within Groups	23556.23	48.00	490.75			
Total	23685.23	49.00				

Anova: Single-Factor of E`F60 between L & R

Summary

Groups	Count	Sum	Average	Variance
ELF60	25.00	1145.70	45.83	333.39
ERF60	25.00	1067.58	42.70	357.29

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	122.05	1.00	122.05	0.35	0.55	4.04
Within Groups	16576.18	48.00	345.34			
Total	16698.23	49.00				

Anova: Single-Factor of E`F180 between L & R

Summary

Groups	Count	Sum	Average	Variance
ELF180	25.00	883.41	35.34	164.00
ERF180	25.00	812.23	32.49	211.64

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	101.33	1.00	101.33	0.54	0.47	4.04
Within Groups	9015.23	48.00	187.82			
Total	9116.56	49.00				

Anova: Single-Factor of LF60 between Y & E						
Summary						
Groups	Count	Sum	Average	Variance		
YLF60	25.00	2218.16	88.73	514.07		
ELF60	25.00	1145.70	45.83	333.39		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	23003.41	1.00	23003.41	54.29	0.00	4.04
Within Groups	20338.84	48.00	423.73			
Total	43342.25	49.00				
Anova: Single-Factor of RF60 between Y & E`						
Summary						
Groups	Count	Sum	Average	Variance		
YRF60	25.00	2336.45	93.46	558.02		
E`RF60	25.00	1067.58	42.70	357.29		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	32200.62	1.00	32200.62	70.36	0.00	4.04
Within Groups	21967.43	48.00	457.65			
Total	54168.05	49.00				
Anova: Single-Factor of LF180 between Y & E`						
Summary						
Groups	Count	Sum	Average	Variance		
YLF180	25.00	1678.30	67.13	405.80		
E`LF180	25.00	883.41	35.34	164.00		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	12637.00	1.00	12637.00	44.36	0.00	4.04
Within Groups	13675.06	48.00	284.90			
Total	26312.07	49.00				

Anova: Single-Factor of YE180 between L & R

Summary

Groups	Count	Sum	Average	Variance
YLE180	25.00	2937.77	117.51	865.46
YRE180	25.00	2934.52	117.38	941.81

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.21	1.00	0.21	0.00	0.99	4.04
Within Groups	43374.53	48.00	903.64			
Total	43374.74	49.00				

Anova: Single-Factor of E`E180 between L & R

Summary

Groups	Count	Sum	Average	Variance
E`LE180	25.00	1524.96	61.00	271.88
E`RE180	25.00	1536.21	61.45	250.12

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.53	1.00	2.53	0.01	0.92	4.04
Within Groups	12528.13	48.00	261.00			
Total	12530.66	49.00				

Anova: Single-Factor of YF60 between L & R

Summary

Groups	Count	Sum	Average	Variance
YLF60	25.00	2218.16	88.73	514.07
YRF60	25.00	2336.45	93.46	558.02

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	279.85	1.00	279.85	0.52	0.47	4.04
Within Groups	25730.09	48.00	536.04			
Total	26009.94	49.00				

Anova: Single-Factor of LE 60deg/sec between Y & E						
Summary						
Groups	Count	Sum	Average	Variance		
YLE60	25.00	4135.80	165.43	1657.21		
E`LE60	25.00	2157.12	86.28	556.19		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	78303.11	1.00	78303.11	70.75	0.00	4.04
Within Groups	53121.66	48.00	1106.70			
Total	131424.77	49.00				

Anova: Single-Factor of RE60 between Y and E`						
Anova: Single-Factor						
Groups	Count	Sum	Average	Variance		
YRE60	25.00	4219.86	168.79	1596.66		
E`RE60	25.00	2137.94	85.52	429.96		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	86687.82	1.00	86687.82	85.55	0.00	4.04
Within Groups	48639.03	48.00	1013.31			
Total	135326.84	49.00				

Anova: Single-Factor LE180between Y & E`						
Summary						
Groups	Count	Sum	Average	Variance		
YLE180	25.00	2937.77	117.51	865.46		
E`LE180	25.00	1524.96	61.00	271.88		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	39921.00	1.00	39921.00	70.20	0.00	4.04
Within Groups	27296.13	48.00	568.67			
Total	67217.14	49.00				

Anova: Single-Factor RE180 between Y and E`						
Summary						
Groups	Count	Sum	Average	Variance		
YRE180	25.00	2934.52	117.38	941.81		
E`RE180	25.00	1536.21	61.45	250.12		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	39105.26	1.00	39105.26	65.62	0.00	4.04
Within Groups	28606.52	48.00	595.97			
Total	67711.78	49.00				

Anova: Single-Factor of YE60 between L & R						
Summary						
Groups	Count	Sum	Average	Variance		
YLE60	25.00	4135.80	165.43	1657.21		
YRE60	25.00	4219.86	168.79	1596.66		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	141.32	1.00	141.32	0.09	0.77	4.04
Within Groups	78093.03	48.00	1626.94			
Total	78234.35	49.00				

Anova: Single-Factor of E`E60 between L & R						
Summary						
Groups	Count	Sum	Average	Variance		
E`LE60	25.00	2157.12	86.24	556.19		
E`RE60	25.00	2137.87	85.51	429.91		
ANOVA						
Source of Variation						
	SS	df	MS	F	P-value	F crit
Between Groups	7.42	1.00	7.42	0.02	0.90	4.04
Within Groups	23666.43	48.00	493.05			
Total	23673.85	49.00				

- - - t-tests for paired samples - - -

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPF180	11	-.698	.017	31.4373	9.770	2.946
TPF180				28.5955	11.725	3.535

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
2.8418	19.818	5.975	.48	10	.645
95% CI (-10.476, 16.160)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPOE60	11	-.212	.532	83.2209	14.489	4.368
TPOE60				84.6764	23.955	7.223

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-1.4555	30.510	9.199	-.16	10	.877
95% CI (-21.958, 19.047)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPOE180	11	-.161	.636	58.7818	12.983	3.915
TPOE180				60.4555	15.998	4.824

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-1.6736	22.167	6.684	-.25	10	.807
95% CI (-16.569, 13.222)					

--- t-tests for paired samples ---

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPOF60				44.9727	15.346	4.627
	11	-.085	.804			
TPOF60				51.4727	21.716	6.548

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-6.5000	27.635	8.332	-.78	10	.453
95% CI (-25.071, 12.071)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPOF180				32.6082	9.328	2.813
	11	-.501	.116			
TPOF180				36.9527	11.265	3.397

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-4.3445	17.868	5.387	-.81	10	.439
95% CI (-16.352, 7.662)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPE60				79.3309	14.381	4.336
	11	.823	.002			
CPOE60				83.2209	14.489	4.368

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-3.8900	8.588	2.589	-1.50	10	.164
95% CI (-9.661, 1.881)					

--- t-tests for paired samples ---

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
TPE60	14	.938	.000	75.7364	22.744	6.078
TPOE60				87.5386	21.780	5.821

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-11.8021	7.910	2.114	-5.58	13	.000
95% CI (-16.371, -7.234)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
TPE180	14	.934	.000	52.9093	16.501	4.410
TPOE180				63.7607	15.873	4.242

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-10.8514	5.906	1.579	-6.87	13	.000
95% CI (-14.263, -7.440)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
TPF60	14	.962	.000	42.5400	19.949	5.332
TPOF60				51.5950	19.610	5.241

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-9.0550	5.445	1.455	-6.22	13	.000
95% CI (-12.200, -5.910)					

--- t-tests for paired samples ---

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
TPF180				29.4257	11.413	3.050
	14	.904	.000			
TPOF180				37.6457	10.185	2.722

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-8.2200	4.872	1.302	-6.31	13	.000
95% CI (-11.034, -5.406)					

--- t-tests for paired samples of balance ---

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPOFX	11	.497	.120	2.5900	.566	.171
CPRFX				2.5918	.544	.164

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.0018	.557	.168	-.01	10	.992
95% CI (-.376, .372)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPOFY	11	.726	.011	2.1555	.508	.153
CPRFY				2.0855	.512	.154

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
.0700	.377	.114	.62	10	.552
95% CI (-.184, .324)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPOFZ	11	.911	.000	3.8445	1.288	.388
CPRFZ				4.0118	1.873	.565

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.1673	.879	.265	-.63	10	.542
95% CI (-.758, .423)					

--- t-tests for paired samples ---

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
TPOFX	14	.817	.000	2.4579	.894	.239
TPRFX				3.1214	1.132	.303

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.6636	.654	.175	-3.80	13	.002
95% CI (-1.041, -.286)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
TPOFY	14	.494	.073	2.2514	.579	.155
TPRFY				2.6771	.718	.192

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.4257	.663	.177	-2.40	13	.032
95% CI (-.809, -.043)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
TPOFZ	14	.664	.010	3.8643	1.322	.353
TPRFZ				4.3579	1.360	.363

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.4936	1.100	.294	-1.68	13	.117
95% CI (-1.129, .142)					

- - - t-tests for paired samples - - -

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPRFX	11	.144	.672	2.5918	.544	.164
TPRFX				3.3018	1.091	.329

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.7100	1.147	.346	-2.05	10	.067
95% CI (-1.481, .061)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPRFY	11	-.265	.430	2.0855	.512	.154
TPRFY				2.8009	.684	.206

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.7155	.957	.289	-2.48	10	.033
95% CI (-1.359, -.072)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPRFZ	11	.006	.986	4.0118	1.873	.565
TPRFZ				4.5718	1.345	.405

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.5600	2.299	.693	-.81	10	.438
95% CI (-2.105, .985)					

--- t-tests for paired samples of strength ---

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPE60				79.3309	14.381	4.336
	11	-.331	.320			
TPE60				73.7218	25.024	7.545

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
5.6091	32.728	9.868	.57	10	.582
95% CI (-16.384, 27.602)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPE180				57.5727	14.655	4.419
	11	-.317	.342			
TPE180				48.9345	15.591	4.701

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
8.6382	24.552	7.403	1.17	10	.270
95% CI (-7.860, 25.137)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPF60				44.8600	14.880	4.487
	11	-.168	.622			
TPF60				42.4427	21.194	6.390

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
2.4173	27.863	8.401	.29	10	.779
95% CI (-16.306, 21.141)					

--- t-tests for paired samples ---

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPE180				57.5727	14.655	4.419
	11	.989	.000			
CPOE180				58.7818	12.983	3.915

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-1.2091	2.612	.787	-1.54	10	.156
95% CI (-2.964, .546)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPF60				44.8600	14.880	4.487
	11	.997	.000			
CPOF60				44.9727	15.346	4.627

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-.1127	1.237	.373	-.30	10	.769
95% CI (-.944, .719)					

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
CPF180				31.4373	9.770	2.946
	11	.996	.000			
CPOF180				32.6082	9.328	2.813

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
-1.1709	.986	.297	-3.94	10	.003
95% CI (-1.834, -.508)					