THE EFFECTS AND MECHANISMS OF WHOLE BODY VIBRATION TRAINING ON MUSCLE, BALANCE AND PHYSICAL PERFORMANCE IN COMMUNITY DWELLING INDIVIDUALS WITH SARCOPENIA

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The Effects And Mechanisms Of Whole Body Vibration Training On Muscle, Balance And Physical Performance In Community Dwelling Individuals With Sarcopenia

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CERTIFICATION OF ORIGINALITY

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Ning WEI

This thesis is dedicated to my husband Victor, my son Ethan and other family members for their supports of my study.

ABSTRACT

Sarcopenia is an age-related loss of skeletal muscle mass that predisposes seniors to falls, disability and mortality. Exercise training was proved to be effective for improving the muscle and physical performance in seniors with sarcopenia. In the past decade, a new style of training, whole-body vibration (WBV), has been reported as an effective approach to improve the neuromuscular, balance and functional performance in the healthy elderly people. However, the effects of WBV on muscle, balance and physical performance in the people with sarcopenia are still uncertain and there is no consensus on the optimal parameters with WBV training in previous studies. Furthermore, the mechanisms underlying the effects of WBV on muscle performance has not been well explored. Therefore, the present research was conducted that comprised two parts, the first and also the main study in this thesis was to investigate the effects of 36 sessions of WBV training on seniors with sacropenia and to compare three different WBV training frequency and duration for the subjects so as to identify the optimal training parameter.

Eighty seniors aged 65 years and above with sarcopenia were recruited and randomly assigned into 1 of 4 groups receiving either low frequency with long exposure time (LG: 20Hz and 720s per session), medium frequency with medium exposure time (MG: 40Hz and 360s per session), high frequency with short exposure time (HG: 60Hz and 240s per session) of WBV training or no intervention as control (CG). The WBV training consisted of 36 exercise sessions over a 12-week period. Assessments were conducted at baseline, mid-intervention (6 weeks of WBV), post-intervention (12 weeks of WBV), 6 and 12 weeks after cessation of training. The outcome assessments included ultrasound measurement of vastus medialis for its

cross-sectional area (CSA), knee extension isometric strength at 90° of flexion and isokinetic knee extensor peak torque at 60°/s and 180°/s, Timed-up-and-go test (TUG), Five-repetition sit-to-stand test (5STS), knee joint position (KJP), tandem stance, one leg standing (OLS) and 10-meter walk test with self-preferred and maximum speed.

Only MG group demonstrated significant increase in isometric knee extension (p=0.017) after 36 sessions of WBV training. Both LG and MG showed significant improvements in isokinetic knee extension at 180°/s (LG: p=0.001; MG: p=0.006), isokinetic knee extension at 60°/s (LG: p=0.041; MG: p=0.016), TUG (LG: p<0.001; MG: p<0.001), 5STS (LG: p=0.038; MG: p=0.001), self-preferred walking speed (LG: p=0.008; MG: p=0.029). Among the three training groups, only MG had significantly better performance than the CG in isokinetic knee extension at 180°/s (p=0.022), TUG (p=0.001), 5STS (p=0.008), self-preferred speed walking speed (p=0.040). For CSA and balance performance, there were no significant group differences after 36 sessions training.

No significant differences were found in muscle strength between post-intervention and 12-week follow-up assessments (p>0.05). Compared with baseline, all three training groups had significant improvements in isokinetic knee extension at 180°/s even after 12-week cessation of training (LG: p=0.01; MG: p=0.006; HG: p=0.015). The improvements in TUG and 5STS in LG and MG could not maintained for 12 weeks after training cessation (p<0.05). Only MG had significant difference from CG in isokinetic knee extension at 180°/s and TUG after 12-week cessation of training.

After completion of the main study, another study was conducted to investigate the possible mechanism of WBV training for the improvement of muscle performance with the MG training protocol. Ten subjects with sarcopenia were recruited and allocated into either MG WBV (n=5) or control group (n=5). Twitch interpolation test was performed for the quadriceps muscle of the dominant leg before and after a 12-week training programme to investigate the effect of WBV training on the voluntary activation of this muscle so as to explore the possible underlying effect associated with WBV at the neuromotor activation level.

After 12 weeks of WBV training, the interpolated muscle twitch ratio of WBV group was increased by 1.33% and the changes of interpolated muscle twitch ratio were significantly different between the two groups (p=0.044).

In general, WBV training was effective on improving muscle and physical performance in seniors with sarcopenia. The frequency/time combination of 40Hz and 360s has the best outcome among all other combinations tested in the main study of this thesis. The finding that WBV training would increase voluntary activation of quadriceps in seniors with sarcopenia implies that a possible mechanism of WBV training for muscle improvement would be central drive facilitation.

LIST OF RESEARCH OUTPUTS

A. Article accepted

1. Wei N, Pang M, Ng S, Ng G. Optimal frequency/time combination of whole body vibration training for improving muscle size and strength of people with age-related muscle loss (sarcopenia): a randomized controlled trial. Geriatrics & Gerontology International.

B. Articles in preparation

2. Wei N, Pang MYC, Ng SSM, Ng GYF. Optimal frequency/time combination of whole body vibration training for improving physical function of people with age-related muscle loss (sarcopenia): a randomized controlled trial.

C. Conference presentations

1. Wei N, Ng G. Combating sarcopenia in community dwelling seniors with whole body vibration training. The HKASMSS Student Conference in Sports Sciences, Medicine and Rehabilitation, Hong Kong, 30 November 2013.
2. Wei N, Pang MYC, Ng SSM, Lee RSY, Lau MCK, Ng GYF. Medium frequency of whole body vibration training improves muscle performance in people with sarcopenia: a 12-week RCT The 9th Pan-Pacific Conference on Rehabilitation cum 21st Annual Congress of Gerontology, Hong Kong, 29-30 November 2014.
3. Wei N, Pang MYC, Ng SSM, Lee RSY, Lau MCK, Ng GYF. Whole body vibration training with medium frequency improves muscle performance in

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LIST OF ABBREVIATIONS

10MWT	10-meter walk test
5STS	Five-repetition sit-to-stand
AL	Adductor longus
ANOVA	Analysis of variance
ASIS	Anterior superior iliac spine
BBS	Berg balance scale
BIA	Bioelectrical impedance analysis
BMI	Body Mass Index
Cm	Centimeter
CSA	Cross-sectional area
CG	Control group with no vibration
CT	Computed tomography
DXA	Dual-engery X-ray absorptionmetry
DHEA	Dehydroepiandrosterone
EMG	Electromyography
EWGSOP	European Working Group on Sarcopenia in Older People
HG	High frequency and short exercise duration group
Hz	Hertz
ICC	Intraclass correlation coefficient
ITT	Intention-to-treat

IWGS	International Working Group on Sarcopenia
KJP	Knee joint position
LG	Low frequency and long exercise duration group
LOCF	Last observation carried forward method
MG	Medium frequency and medium exercise duration group
Mm	Millimeter
MRI	Magnetic resonance imaging
MYH	Myosin heavy chain
M/s	Meter per second
OLS	One-leg stand
PAD	Peripheral arterial disease
SMI	Skeletal mass index
SPPB	Short physical performance battery
S	Seconds
RF	Rectus femoris
SA	Sartorius
TUG	Timed up-and-go test
TVR	Tonic vibration reflex
VI	Vastus intermedius
VM	Vastus medialis
WBV	Whole body vibration

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CHAPTER 1 INTRODUCTION

1.1 SARCOPENIA

1.1.1 Definition of sarcopenia

Sarcopenia, translated from Greek (sarx for flesh, penia for loss), was firstly used by Irwin Rosenberg (1997) to describe the muscle loss when people age. In 2011, researchers reached a consensus on the definition of sarcopenia that: “Sarcopenia is a complex syndrome that is associated with muscle mass loss alone or in conjunction with increased fat mass.” (Fielding et al., 2011). Like osteoporosis, which predicts the risk of bone fracture, sarcopenia is the predictor of frailty (Cooper et al., 2012; Morley et al., 2005), leading to decrease in quality of life.

After sarcopenia was introduced, Clark and Manini (2008) brought out a new term “Dynapenia” to describe the age-related loss of muscle strength. They advocated that “Sarcopenia” should be used to its original Greek meaning. In the past decades, since sarcopenia was usually used to describe the age-related loss of muscle mass and strength, old people with lower muscle mass but normal muscle strength were excluded from most previous studies. The reason for this mistaken usage of sarcopenia might be the concern of the strong relationship between muscle mass and muscle strength (Alizadehkhaiyat et al., 2014). Maughan et al. (1983) initially reported the cross-sectional area of mid-thigh was positively correlated with maximal voluntary force of knee extension at 90° in both young and old people. Alizadehkhaiyat et al. (2014) found there was a significant correlation between skeletal muscle mass and muscle strength in both men and women. However, Maughan et al. (1983) advocated muscle strength and muscle cross-sectional area could not be predictor for each other because of the wide variations in these two muscle characteristics. A study by Frontera et al. (2000a) supported this standpoint from another angle as they found the differences in knee extensors at 1.04 rad/s between young and older men still existed even after adjusting for muscle fiber size, which imply there were other mechanisms for age-related loss of muscle strength besides decreased muscle mass. For instance, the increased neural activation to the antagonists was speculated as a contributor to the age-related muscle strength (De Boer et al. 2007). Later, Goodpaster et al. (2006) found that although muscle mass and strength were correlated, the increase in muscle mass did not protect the subject from age-related loss of strength. Also, Mikhael et al. (2010) reported calf muscle strength increased after 13 weeks of training, but the cross-sectional area of mid-calf remained as that at baseline. These findings suggested the gain or loss of muscle mass from short-term training was not necessarily associated with the increase or decrease in muscle strength and vice versa. Thus, the term “Sarcopenia” should be used with caution to describe both age-related loss of muscle mass and strength. In this thesis, the term “sarcopenia” is only used according to its original meaning of age-related loss of muscle mass.

1.1.2 Diagnostic criteria for sarcopenia

Regarding the diagnosis of sarcopenia, low muscle mass was commonly used in the previous studies (Baumgartner et al., 1998; Chien et al., 2008; Janssen et al., 2002;

Sanada et al., 2010). However, the cutoff point for defining low muscle mass is still divergent due to the difference in devices, formulae, reference groups and cut-off points for calculating skeletal mass index (SMI) (Bijlsma et al., 2012).

For devices, computed tomography (CT), magnetic resonance imaging (MRI), dual-engery X-ray absorptionmetry (DXA) and bioelectrical impedance analysis (BIA) are used in the research laboratory and clinic to predict the skeletal muscle mass (Fielding et al., 2011). Considering the convenience and cost, the most popular devices are DXA (Sanada et al., 2010; Kim et al., 2012a; Lau et al., 2005) and BIA (Castillo et al., 2003; Chien et al., 2008; Tichet et al., 2008). Using DXA, the SMI is calculated according to the formula:

SMI=Appendicular muscle mass/height^2 (Sanada et al., 2010; Kim et al., 2012a; Lau et al., 2005).

Another formula established with BIA states:

SMI=(0.401 × (height^2/bio-impedance) + (3.825 × gender) – (0.071 × age) +5.102)/height^2(Chien et al., 2008; Janssen et al., 2000a).

However, there is no consensus on the cutoff point with each formula. In the study of Delmonico et al. (2007) using DXA, the cutoff point was defined as the lowest 20% of SMI in gender-specific study group, whereas Baumgartner et al. (1998) defined two standard deviations below the mean SMI of young male and female reference groups as the cutoff point.

European Working Group on Sarcopenia in Older People (EWGSOP) and International Working Group on Sarcopenia (IWGS) have put forward the diagnostic criteria for sarcopenia as low muscle mass (primary determinant) combining with low muscle function (muscle strength and physical performance) (Cruz-Jentoft et al., 2010; Fielding et al., 2011), though sarcopenia was distinguished from dynapenia in many researches in the past decade (Clark & Manini, 2008; Hofmann et al., 2015; Jenkins et al., 2015). Hitherto, there is no agreement for the tested position, device and cutoff point of muscle mass and strength measurements between EWGSOP and IWGS.

Although both EWGSOP and IWGS have recommended gait speed as an effective single variable for physical function, no consensus on method (the distance of walking test) and cutoff point has been proposed (Cruz-Jentoft et al, 2010; Fielding et al., 2011). The EWGSOP recommended to use <0.8m/s as threshold for sarcopenia (Cruz-Jentoft et al, 2010), while The IWGS sets the threshold as <1.0m/s (Fielding et al., 2011). In general, there is not a common agreement on the diagnosis for sarcopenia in the world. Thus, in this study, the individuals with low muscle mass alone would be classified as sarcopenia.

1.1.3 Epidemiology of sarcopenia

The prevalence of sarcopenia reported in previous studies varied due to different cutoff points and techniques were used for measuring muscle mass. In the US Third National Health and Nutrition Examination survey (1988-1994) involving 4504 adults aged beyond 60 years old, it was reported the prevalence of sarcopenia was 10% in women and 7% in men. BIA was used in that study to predict the muscle mass index (absolute muscle mass/height^2) and the cutoff points (-2SD) were 10.76kg/m^2 and 6.76kg/m^2 for men and women, respectively (Janssen et al., 2000a).

In 1998, Baumgartner et al. using DXA measurement found the prevalence of sarcopenia was over 50% in persons older than 80 years of age. Later, Melton et al. (2000) and Morley et al. (2001) using DXA found 52% of women and 28% of men older than 70 years old had sarcopenia and the prevalence for people younger than 70 years and those older than 80 years of age were 12% and 30%, respectively.

In Asia, most studies have used DXA, and the prevalence of sarcopenia in Hong Kong in 2005 was 12.3% for men and 7.6% for women (Lau et al., 2005). In 2010, the prevalence of sarcopenia in Japan was reported to be 56.7% in men and 33.6% in women (Sanada et al., 2010), while in 2012, only 12.4% of men and 0.1% of women was diagnosed to have sarcopenia in Korea (Kim et al., 2012a). With BIA measurement, Chien et al. (2008) found 23.6% of male and 18.6% of female suffered from sarcopenia in Taiwan. Despite the great variability in the prevalence of sarcopenia among different countries, it is clearly established that sarcopenia is a widespread problem in older population across Asia and the western countries.

1.1.4 Causes for sarcopenia

There are many factors that would induce sarcopenia in older people, such as ageing, lack of physical activities, chronic diseases, poor nutritional status, etc. The interactions among these factors are complicated, which is presented in Figure 1.

1.1.4.1 Age-related loss in muscle mass

The exact reasons for age-related loss of muscle mass are not clear. One possibility is a reduction in the total number of fibers within a muscle (Lexell et al., 1988). Loss of muscle fibers begins at about 25 years of age and the total number of muscle fibers would decrease by about 39% at age 80 (Bassey et al., 1992; Lexell et al., 1988; Newman et al., 2006). Another study showed that muscle fiber numbers began to decrease at 60 years of age, with 25% reduction in muscle fiber numbers at age 70 (Rantanen et al., 1999). At age 80, the atrophy would accelerate the loss of muscle fibers, which could be up to 50% of the original number (Lexell et al., 1988).

A possible reason for age-related decrease in total number of muscle mass is the age-related damage to the fibers with no subsequent regeneration. However, the evidence for this reason is unclear (Aniansson et al. 1986; Grimby et al. 1982). Neural input may be disrupted during aging (Vandervoor and McComas, 1986). Electromyographic data have revealed an age-related decrease in the number of active motor units and that the low-threshold motor units become larger (Baum, 2008). All evidence indicate the age-related denervation of muscle fibers, particularly the denervation of type II fibers, is an important reason for loss of muscle mass.

Another possible reason for age-related loss of muscle mass might be a preferential age-related atrophy of type II fibers (Larsson et al., 1978; Larsson, 1982), which leads to a progressive decrease in the type II to type I fiber area ratio (Lexell et al., 1988). Although the age-related decreases present in both type I and II muscle fibers (Lexell et al., 1988), the rate of loss of muscle fibers were different in these two fiber types. The slow contracting type I fibers have lower tension output but higher fatigue resistance and they are not seriously affected with aging (Grimby et al., 1982;

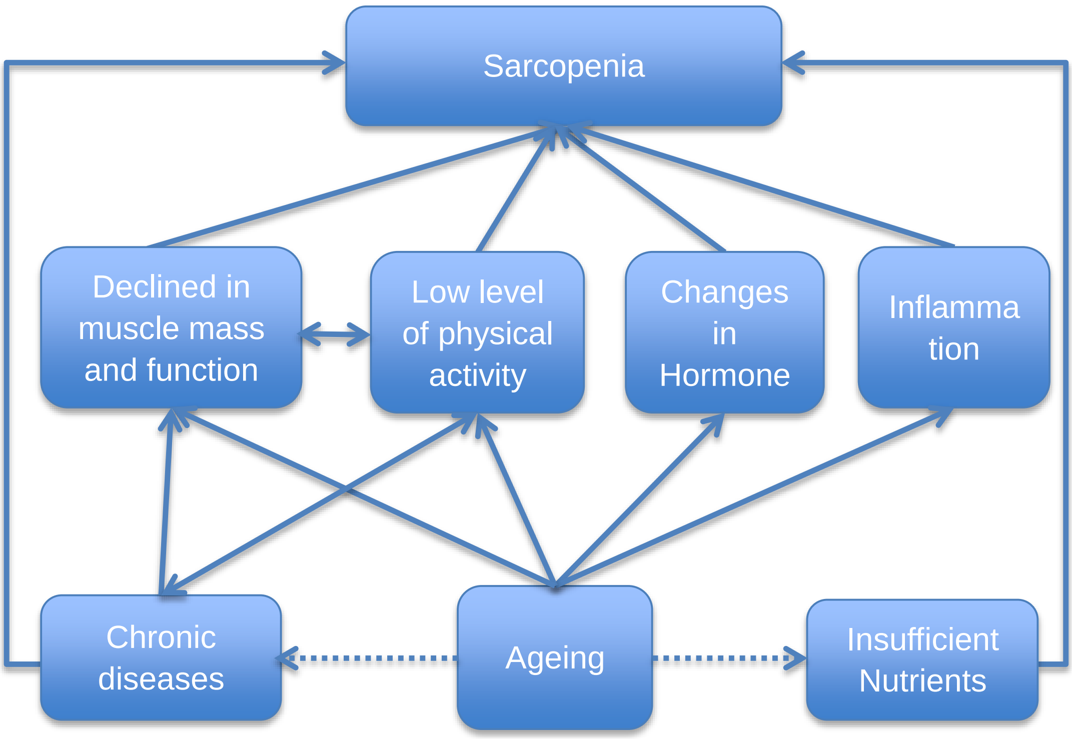

Figure 1: A hypothetical model of interactions among factors causing sarcopenia. Straight line: main reasons; Dash line: possible reasons.

Lexell et al., 1988). On the contrary, the type II fibers had 26% reduction from age 20 to 80 (Lexell et al., 1988), and 15% to 25% reductions in type IIa and IIb cross-sectional area (Coggan et al., 1990). In general, a large proportion of the age-related loss of muscle mass is resulted from the reduction in type II muscle fiber size (Lexell & Downham, 1992).

Besides the above reasons, the age-related changes in composition of muscle have been speculated as another reason for losing muscle mass as people get older. The muscles of older people aged 65–83 years contain less contractile tissue and more non-contractile tissue when compared with the skeletal muscle of younger people of 26–44 years of age (Kent-Braun et al., 2000). A greater percentage of non-contractile tissue such as fat and connective tissue would result in a decreased force production capability (Williams et al., 2002). However, connective tissue occupies only 2% of the cross-sectional area of muscle, thus, any change in connective tissues will unlikely have an effect on force production or overall mass of skeletal muscle (Faulkner et al., 1990).

1.1.4.2 Age-related loss of muscle function (strength and power)

Muscle strength is the maximal force that can be developed by the muscles performing a particular joint movement (Komi, 2002). It is an index of the muscle capacity. Normally, measuring the maximal voluntary force in both isometric and isokinetic contractions represent muscle strength (Enoka, 2002). Muscle strength plays an important role for mobility and poor muscle strength in the elderly significantly compromises their functional independence in walking speed, posture and balance control (Bassey et al., 1992). Older people with lower muscle strength reportedly have more difficulties in motor task and less physical activities (Rantanen et al., 1999).

Human muscle strength usually peaks between the age of 20 and 30 years and to some extent remains stable until the onset of the sixth decade of life. With increasing age, the human skeletal muscle morphology would change and this is often associated with functional decay, which is dramatically evident by the sixth decade and onward (Janssen et al. 2000b). A previous study with a 12-year follow-up period found significant declines ranging from 23.7% to 29.8% in peak torque knee extension and flexion at 60 °/s and 240 °/s. The loss of muscle strength at 240 °/s was slightly faster than at 60 °/s. Also, the study revealed muscle strength lost more than 2% per year in knee extensors and flexors from 65 to 77 years old (Frontera et al., 2000b). One longer follow-up study gave a whole picture of the changes in maximum handgrip strength along with age and found the relative loss of handgrip strength in men was 13.6% by the sixth decade of life, while after the seventh decade the decrease was 29.5% (Stenholm et al., 2012).

Some studies suggested men had greater decrease in muscle strength with aging (Delmonico et al., 2009; Stenholm et al., 2012). A study that followed up 1678 older participants for five years reported men had a 16.1% decrease in average maximum isokinetic knee extension at 60 °/s, whereas women had a 13.4% decrease (Delmonico et al., 2009). Another longitudinal study demonstrated that women had a slightly slower decrease in handgrip strength between 40 to 80 years old than men (Stenholm et al., 2012). The explanation for the gender difference in age-related loss of muscle strength might be the proportion of force generation by different types of fibers. In men, it was reported that type IIA fibers could generate larger force than type I fibers, while no difference between these two fiber types was observed in women (Frontera et al., 2000b). As the type II fiber decreased faster than type I fiber with aging, the muscle strength in men would present with greater decrease than in women.

Besides strength, studies have indicated that muscle power also plays an important role in the maintenance of mobility (Bean et al., 2003). Decreased power has been linked to an increase in the incidence of falls (Chan et al., 2007). Since leg muscle power can correct a displacement or movement error, to prevent a fall, an individual must have sufficient lower limb muscle power in the stabilizing leg to counteract the kinetic energy of the unbalanced individual (Skelton et al., 2002).

The per cent drop in muscle power per year is substantially larger than the year drop in isometric strength (Lauretani et al., 2003). Muscle power is the product of muscle strength and velocity of movement (power= force × velocity), a decrease in either component may lead to a diminished capacity to generate power (Mayson et al., 2008). However, it is not clear which of the two constituent components of muscle power is more important for mobility.

Sayers et al. (2003) showed that limb velocity might be an essential factor in predicting falls and increase in age is associated with a reduced capacity to produce force rapidly (Harridge et al., 1996; Korhonen et al., 2003). In the healthy elderly, it has been demonstrated that the ability to develop force rapidly is reduced compared with young individuals of both genders (Clarkson et al., 1981; Vandervoort & McComas, 1986). Furthermore, the ability to develop force rapidly is important for aged people in several tasks of daily life, such as walking and postural adjustment to prevent falls (Suetta et al., 2007). Therefore, both loss of muscle strength and decrease of force generation velocity contribute to the problems of mobility and balance of daily life in the elderly. Decreased force, velocity and power are not independent variables, and the interactions among them may aggravate disability.

1.1.4.3 Age-related decline in physical activity

As people get older, loss of muscle mass and function could adversely affect their participation in daily physical activities (Milanović et al., 2013; Rantanen et al., 1999). When compared the physical activity levels between young elderly (60-69 years) and old elderly (70-80 years), Milanović et al. (2013) found the total energy consumed in physical activity was less in the elderly, especially in women. They also pointed out the work-related physical activity significantly decreased in both men and women. Furthermore, Fukagawa et al. (1990) found the resting metabolic rate to have decreased in older people. Their results indicated the effectiveness of physical activity declined as one aged (Fukagawa et al., 1990).

On the other hand, the reduced physical activity may partly contribute to the loss of muscle mass and strength in the seniors. A number of studies have proved physical activity level was positively associated with muscle mass and strength (Hunter et al., 2000; Rantanen et al., 1999). Rantanen et al. (1999) found the active older women had the greater muscle mass and strength. Hunter et al. (2000) examined more than 200 Australian women aged from 20 to 89 years and found the active women had more lean muscle mass and isometric muscle strength than the age-matched inactive ones. Similar pictures were shown in older men. Thus, it is difficult to distinguish the cause and effect between loss of muscle mass and function (strength and power) and the decrease in physical activity of older people

1.1.4.4 Age-related changes in hormone

The concentration of testosterone in men decreases with age. A systematic review analyzing 88 original studies concluded the concentration of testosterone was lower in old people (Gray et al., 1991). Moreover, the rate of decline of testosterone was faster in older age, which showed a curvilinear relationship between concentration of testosterone and age (Harman et al., 2001).

Some studies reported the concentration of testosterone was correlated with lean muscle mass, muscle strength and power (O'Connell et al., 2011; Storer et al., 2008). One study that followed up the participants who had received monthly injection of testosterone found the increased concentration of testosterone resulted in a net gain in skeletal muscle mass, leg press strength and power (Storer et al., 2008). Although the concentration of testosterone was associated with the muscle mass and function, it did not correlate with physical function such as walking speed, stair climbing power and timed up-and-go test (TUG) (Storer et al., 2008). Meanwhile, O'Connell et al. (2011) found the positive effect of testosterone on skeletal muscle mass and strength disappeared at 6 months after the injection had ceased.

In women, the estrogen level at the late menopausal transition declined to half of the premenopausal concentration level (Burger et al., 2007). Meanwhile, the marked loss of muscle mass and strength in women occurs after menopause (Maltais et al., 2009). The relationship between estrogen level and loss of muscle mass and strength was suggested in previous studies. Rolland et al. (2007) conducted a prospective study in 49 postmenopausal women for 2-3 years revealed low concentration of estrogen was a predictor of loss of appendicular muscle mass and muscle strength.

Besides sex hormone, dehydroepiandrosterone (DHEA) is another contributor to sarcopenia. The level of DHEA was proved to be positively associated with muscle mass in previous studies (Maltais et al., 2009; Phillips et al., 1993). However, one study found no relationship between DHEA and muscle mass and body composition in elderly individuals aged between 60 and 80 years (Abbasi et al., 1998). Also, Nair et al. (2006) reported neither men nor women showed significant effect of DHEA on body composition. Considering the conflicting evidence on the effect of DHEA, it is uncertain as to the impact of DHEA on muscle mass in individuals with sarcopenia.

1.1.4.5 Age-related inflammation

In recent years, other factors underlying strength decline have been proposed. Aging is associated with an increase in levels of pro-inflammatory cytokines that may exert a catabolic effect on muscle that increases the risk of functional decline and frailty in the elderly (Schaap et al., 2006). One of the pro-inflammatory cytokines, IL-6, has an association with the loss of muscle strength. Schaap et al. (2006) showed that high levels of IL-6 were associated with a 3-fold increase in risk of strength loss compared with low IL-6 levels.

1.1.4.6 Chronic diseases

As people get older, the risk of having chronic diseases is higher than their younger counterparts (Gardner et al., 2001). Patients with chronic diseases, such as

Parkinson's disease, stroke and peripheral arterial disease (PAD), have lower physical activity level (Butler & Evenson, 2014; Dontje et al., 2013; Gardner et al., 2001). Dontje et al. (2013) reported more than 98% of patients with Parkinson's diseases was extremely inactive with their daily living. The stroke survivors consumed much less time on vigorous activities and assumed a more sedentary lifestyle than their counterparts unexposed to stroke (Butler & Evenson, 2014). The older subjects with PAD had 22% slower walking velocity than non-PAD elderly (Gardner et al., 2001). Thus, chronic diseases also have their roles in the development and pathogenesis of sarcopenia.

1.1.4.7 Nutritional factors

The changes in nutritional status in the aged population are an important cause for loss of muscle mass, which have been linked to the incidence of sarcopenia. Protein, vitamin D and antioxidant were mentioned as the major nutrients for muscle mass and function (Kaiser et al., 2010; Kim et al., 2010). Two review studies had concluded that the balance of protein, vitamin D and antioxidant was often not maintained in the elderly, which could induce sarcopenia in elderly subjects (Kaiser et al., 2010; Kim et al., 2010).

Insufficient protein intake is considered an important contributor to sarcopenia (Paddon-Jones et al., 2008). Houston et al. (2008) found the protein intake was strongly associated with total lean body mass and appendicular lean mass. Thus, the community-dwelling seniors with less protein intake were more likely to lose their lean muscle mass. The loss of lean mass in the high protein intake participants was only

60% of those in the low protein intake ones (Houston et al., 2008). Considering the positive association between protein and muscle mass, it is important to obtain an adequate protein intake in the diet of older population. One research study has revealed that the daily protein requirement for elderly people should be 1.14g per kilogram body weight per day, which was 1.5 times greater than that for the young individuals (Campbell et al., 1994). Rousset et al. (2003) followed up the nutritional values of the diet of 292 healthy French participants pointed out the protein intake of elderly men was significantly less than that of the young ones. Thus, the mismatch in the increase in physiological needs but decrease in intake of protein would lead to the insufficiency of protein in older individuals, which would lead to a greater loss of muscle mass resulting in sarcopenia.

Vitamin D has been regarded as the main factor of osteoporosis for many years (Wimalawansa, 2011). The relationship between vitamin D deficiency and frailty was confirmed in the US Third National Health and Nutrition Survey (Wilhelm-Leen et al., 2010). In this survey, people with 25-Hydroxyvitamin D serum concentration less than 15 ng/mL had nearly 4 times more risk in frailty than those without deficiency (Wilhelm-Leen et al., 2010). However, Mason et al. (2013) found serum 25-Hydroxyvitamin D was not the determinant of appendicular lean mass in women with sarcopenia. Also, one systematic review reported most improvements in muscle mass and function was obtained by combined supplement of vitamin D and calcium. There was no evidence that vitamin D alone had positive effect on muscle strength or physical function (Latham et al., 2003). The effect of vitamin D on muscle strength and physical function is still uncertain.

Antioxidants, though not as well studied as protein and vitamin D, are a relatively new focus for combating oxidative stress of older adults (Kim et al., 2010). Although several animal studies advocated the antioxidants were helpful to prevent the oxidative damage (Nunes et al., 2003; Rafique et al., 2004), there was no significant improvement found in muscle mass and function in the aged population. The use of antioxidants supplementation on sarcopenia prevention and treatment requires further study.

1.1.5 Consequences of sarcopenia

1.1.5.1 Physical performance

Decline in physical performance is the prime consequence of sarcopnia. A wide range of assessments was used to evaluate the physical performance of elderly with sarcopenia. Timed up-and-go test (TUG), five-repetition sit-to-stand test (5STS) and walking speed are the most common measurements. Also, they are the components of the short physical performance battery (SPPB), which was recommended as the standard measurement for physical performance in both clinical application and research purpose (Cruz-Jentoft et al., 2010).

The positive correlation between muscle function and physical performance was well established in previous studies (Hairi et al., 2010; Reid et al. 2008a). Hairi et al. (2010) stated that the prevalence ratio for functional limitation in people with poor muscle strength was 1.91. A systematic review analyzing the previous data reported that the mean time for completing TUG was extended from 8.1 to 11.3 seconds with the aging process (Bohannon, 2006). One study examined the sit-to-stand power of 556 Japanese elderly women concluded that the age-related decline in sit-to-stand power was in line with the decreased knee extension torque in people under 75 years old. At above 75 years of age, the decline in sit-to-stand power was more rapid than that in muscle strength (Kanehisa & Fukunaga, 2014).

Since muscle function is positively correlated with walking speed, gait speed is thus a common indicator of functional capacity (Rantanen et al., 1999). Normally, older adults with sarcopenia have slower self-preferred walking speed of less than 1.2 m/s, which is the minimum walking speed to cross the road in urban settings (Cruz-Jentoft et al., 2010; Fielding et al., 2011; Langlois et al., 1997). Due to their slow walking speed, the elderly with sarcopenia would withdraw from outdoor activities to avoid dangers, but such avoidance of daily outdoor activities will further compromise their physical capacities.

1.1.5.2 Balance

Balance is an ability to maintain the body within the base of support with minimal postural sway (Shumway-Cook et al., 1988). The coordination of vestibular, somatosensory and visual system is the basis for maintaining balance. Normally, balance includes both the static and dynamic concepts. The clinical tests used for assessing static balance mainly involve semi-tandem, tandem and one-leg stand (OLS), which were proved as valid and efficient measurements for predicting static balance (Suzuki et al., 2013). The TUG test was generally used as a clinical assessment for dynamic balance and mobility. Maximal reach of star excursion test for different directions during single-leg stand is also useful test for dynamic balance (Hrysomallis, 2011). Besides the above single tests, Berg Balance Scale (BBS) was widely used as a comprehensive tool for assessing static and dynamic balance, especially for the post-stroke patients (Blum & Korner-Bitensky, 2008). However, the shortcoming of BBS is it has ceiling and floor effects for assessing the elderly (Blum & Korner-Bitensky, 2008).

The impairment in balance would be a predictor of falls in the elderly. Desai et al. (2010) reported that elderly with history of falls showed significantly longer time for finishing balance tasks than those without fall history. The time of OLS was usually used for clinically predicting falls. MacRae et al., (1992) examined the one-leg stand time of 94 older adults and revealed the association between the time of OLS and falls was significant.

The relationships between muscle function and balance have been reported in previous studies. Pisciottano et al. (2014) stated the muscle strength of lower limb was negatively associated with BBS and TUG in elderly subjects. Another study confirmed the association by advocating the ankle muscle strength to be a predictor of fall in the elderly, even in young adults (Cattagni et al., 2014).

As muscle function decreased with age, the balance impairments could also be apparent in later life. The declined balance performance was usually observed in older population (Aslan et al., 2008; Desai et al., 2010; Michikawa et al., 2009). Compared to the middle-aged group, the elderly had shorter functional reach excursion and longer time in completing TUG and Sit-to-stand test (Aslan et al., 2008). Furthermore, time for standing with one leg decreased from 60 to 16 seconds in their sixth to eighth decades (Michikawa et al. 2009). Although there was no direct study investigating the balance performance in older people with sarcopenia, it is a logical prediction that the impairments in balance performance would also be an obstacle for improving quality of life in people with sarcopenia.

1.1.5.3 Proprioceptive-joint position

Proprioception is traditionally referred to as the conscious sensation, including the sense of limb position and movement, sense of tension and force, sense of effort and balance, which are essential for postural control and daily movements (Proske & Gandevia, 2012). It is well known that muscle spindles, as the principal proprioceptor for limb position and movement, detect the changes in muscle length and feedback to the central nervous system (Sherrington, 1906).

As people get older, the changes in muscle morphology (size, composition and architecture) could alter the muscle spindles reactions to contractions (Narici & Maganaris, 2007). Two studies in rat model reported the conduction speed of primary spindle nerve endings was slower in the aged animals, while the axonal diameter has concomitantly smaller (Kim et al., 2007; Miwa et al., 1995). Also, Swash and Fox (1972) dissected aged muscles of human being and found the number of intrafusal fibers had decreased, which are the major component of muscle spindles. The evidence indicated the main components of reaction time of muscle spinal to the muscle movement degenerated with age.

The degeneration in muscle spindles with age would cause a relative failure of position sense and control. One study compared the knee joint position sense between young and older adults and found the knee joint position sense to be negatively associated with age (Ribeiro & Oliveira, 2010). Another study had confirmed the negative association between muscle weakness and static ankle position sense in people aged between 60 and 69 years, while the association was not obvious in those older than 70 years (Butler et al., 2008). However, Verschueren et al. (2002) stated only the absolute error of dynamic position sense of ankle joint in the group aged between 70 and 75 years was significantly different from the young ones, while no difference was observed between young adults and people aged from 65 to 70 years. Since very few research studies had focused on the changes of proprioception in elderly subjects and even less on those with sarcopenia, it is unclear whether there was a specific treatment for proprioception in the people with sarcopenia.

The impairment in proprioception, especially the sense of limb position and movement would adversely affect the postural control and physical performance in older individuals (Hurley et al., 1998; Lord et al., 1999). Hurley et al. (1998) found a significant positive correlation between the absolute error of knee position sense test and functional performance in the elderly. Also, old people with impaired lower limb sensation had larger body sway during tandem test with eyes closed (Lord et al., 1999). Thus, improving the proprioceptive sense is one of the important goals for geriatric physical rehabilitation.

1.1.5.4 Fall risk

Sarcopenia was proved as a risk factor for falls in the elderly. Landi et al. (2012) reported more than 27% of elderly with sarcopenia in Italy had falls within a 2-year follow-up period, while the fall incidence for the elderly without sarcopenia was only 9%. A study conducted in Japan had also revealed sarcopenia was significantly related to histories of falls. Meanwhile, the authors found men with sarcopenia were nearly two times more vulnerable to fall than women with the same condition (Tanimoto et al., 2014).

1.1.5.5 Mortality rate

Mortality rate is an expression of the number of deaths in a specific population at a particular time (Porta, 2014), which constitutes to an important statistical measure in the epidemiological study. Sarcopenia also increases the mortality rate in older population. A 7-year longitude study reported old people with sarcopenia were strongly inclined to have a high risk of death (Landi et al., 2013). Furthermore, the incidence of sarcopenia was also significantly correlated to one-year mortality after discharging from acute care wards (Vetrano et al., 2014).

1.1.6 Treatments

1.1.6.1 Exercise

In view of the strong relationship between physical activity and muscle mass, it was proposed that non-medical intervention focusing on increasing physical activity would be beneficial for people with sarcopenia. In the previous studies, exercise was advocated to be the most effective physical intervention for slowing down or even reversing the age-related loss of muscle mass, muscle function, impaired balance and poor physical performance (Fielding et al., 2002; Fragala et al., 2014; Gonzalez et al., 2014; Liu et al., 2014; Montero-Fernández & Serra-Rexach, 2013; Pamukoff et al., 2014; Scanlon et al., 2014; Sipilä & Suominen, 1995).

The effect of exercise training for muscle mass was reported in some studies. With 18 weeks of intensive strength training, the cross-sectional area of quadriceps had increased by 4.5% in elderly women (Sipilä & Suominen, 1995). Moreover, a recent study found that after a 6-week progressive resistance training programme, the cross-sectional area of vastus lateralis and knee extension strength of the older subjects had increased by 7.4% and 32%, respectively (Scanlon et al., 2014).

It was also reported that resistance training could increase the muscle function (Reid et al., 2008b; Sayers et al., 2003; Thomson et al., 2015). Thomson et al. (2015) demonstrated that 12 weeks of resistance training could improve the isometric knee extensor strength in older people by more than 30% than that at baseline. Furthermore, the peak power of lower extremity significantly increased after both high- and low-velocity training in older adults (Sayers et al., 2003; Reid et al., 2008b). All the improvements in muscle mass, strength and power are strong evidence in support of applying resistance training to combat sarcopenia in older people.

Besides muscle function, postural balance and physical performance in the seniors were also improved after exercise training. Sayers et al. (2003) found that the dynamic balance improved by 8% after 16 weeks of resistance training. A recent study also reported after participating in a 6-week full-body progressive resistance training programme, the performance of single-leg stand was improved in older adults (Gonzalez et al., 2014). Very recently, Pamukoff et al. (2014) demonstrated a 6-week strength training programme improved the balance recovery performance in old people and Fragala et al. (2014) found the sit-to-stand performance to have significantly improved after 6 weeks of training and this improvement was maintained for more than

6 weeks after cessation of the training.

Exercise training was not only an effective intervention for the healthy elderly but also for those with chronic diseases. Paul et al. (2014) stated both knee and hip muscle strength increased after 12 weeks of resistance training in patients with Parkinson's disease. Lee and Kang (2013) reported both muscle strength and physical function improved after 3 and 6 weeks of exercise training. Moreover, a recent literature review concluded that appropriate exercise training could reduce the incidence of cardiovascular diseases (Gielen et al., 2015). Although a number of studies confirmed the positive effects of exercise training on muscle and physical functions, few clinical trials had investigated the changes in the elderly with sarcopenia. One study that followed up 177 individuals with or without sarcopenia for 12 months reported both groups of subjects showed an increased score in SPPB and faster walking speed after undergoing a 6-month regimen of aerobic, strength, balance and flexibility exercises (Liu et al., 2014).

1.1.6.2 Nutritional supplementations

In view of the importance of the protein on muscle mass, many researches applied the nutrient supplementations to treat age-related loss of muscle mass. The main nutritional supplementation was protein. In order to figure out the effects of protein intake on preserving muscle mass, some researchers conducted studies with protein supplementation for treating sarcopenia. Gryson et al. (2014) found the lean mass increased by 4.5% in the older participants after 16 weeks of 10g/day protein supplement. However, the effectiveness of protein supplementation for improving muscle mass had been challenged. Tieland et al. (2012) found no changes in skeletal muscle mass and muscle fiber size after protein supplementation in frail elderly (Tieland et al., 2012). Candow et al. (2006) stated no change on muscle mass after a 12-week programme of 0.9g per kilogram/week of protein supplementation.

For muscle strength, one study involving 6-month daily protein supplementation reported the knee extension strength was increased by nearly 20% in volunteers with protein supplementation, while the placebo group only showed less than 10% increase. Also, the score of SPPB for physical performance only increased in the protein supplementation group (Tieland et al., 2012). However, one study found no significant improvement in muscle strength after 12 weeks of protein supplementation. The inconsistence of the effects of protein supplementation on muscle mass and strength might be attributed to the difference in the amount and the duration of supplementation.

Studies have been conducted to examine whether the whey protein supplementation to exercise training could lead to the additional gain in muscle mass, strength and physical performance. Arnarson et al. (2013) reported 60g per week of whey protein supplementation did not induce additional improvements in lean body mass, quadriceps strength and physical performance in older individuals. Another study also confirmed that whey protein supplementation would bring no extra benefits on muscle and physical functions (Chalé et al., 2013). Moreover, one study found the group with additional soy and dairy intake had poorer performance in knee strength than that with usual protein intake (Thomson et al., 2015). Thus, the evidence is suggestive that usual daily protein intake would be adequate to maintain the daily activity.

One study examined 155 older Japanese people with sarcopenia and reported exercise and amino acid supplementation together would increase the leg muscle mass, knee extension strength and usual walking speed (Kim et al., 2012b). It is worth noting that the amino acid supplementation would be easily digested than soy and dairy source. However, there is limited evidence for supporting the positive effects of amino acid supplementation on combating sarcopenia. More studies are needed to shed new lights in this field.

Although the association between muscle function and vitamin D was evidenced in the previous studies (Wilhelm-Leen et al., 2010; Wimalawansa, 2011), there was still inconsistence in this association (Mason et al., 2013). No study had investigated the effect of vitamin D alone on muscle mass and strength. Latham et al. (2003) stated vitamin D should be taken with the other nutrients in order to improve muscle mass, strength and physical function. The effects of vitamin D supplementation on muscle, physical and balance performance are still unclear.

1.1.6.3 Hormone therapy

Many studies have investigated the effects of hormone therapy on muscle and physical functions. Srinivas-Shankar et al. (2010) found the frail elderly participants with 6 months of testosterone treatment had more increases in lean body mass and isometric knee extension peak torque than those with placebo treatment. A randomized clinical trial revealed that women with estrogen replacement therapy had greater cross-sectional area of quadriceps and isometric muscle strength than those without the therapy after adjusting for relevant confounders (Taaffe et al., 2005). Also, another study found the loss of lean muscle was reversed in women with sarcopenia after a 12-week hormone replacement therapy programme (Sørensen et al., 2001). However, Kenny et al. (2005) reported no significant increase in appendicular skeletal muscle mass, lean body mass, percentage body fat and physical performance after 3 years of estrogen therapy in the community-dwelling women. The explanation for this inconsistence might be due to the different types and amount of hormone as well as the physical condition of the participants. Further analysis should be performed to elucidate the effects of different hormonal treatments on muscle and physical functions in the aged population, especially for those with sarcopenia.

It is interesting that some hormonal treatments only increased the muscle mass, but not muscle strength or physical performance. Papanicolaou et al. (2013) revealed the lean muscle mass in older women with sarcopenia who had received a 6-month treatment programme of androgen receptor showed better performance than the placebo group, but not in muscle strength or physical performance. Similarly, Nass et al. (2008) found that fat-free mass increased in older adults after taking oral ghrelin mimetic for 12 months, but this increase did not result in the improvements in muscle strength or physical performance. An earlier study by Blackman et al. (2002) reported the older individuals with growth hormone supplement had improvement in lean muscle mass after 26 weeks of treatment, but not in muscle strength. According to the findings from the previous studies (Blackman et al., 2002; Nass et al., 2008; Papanicolaou et al., 2013), it seems that muscle mass was more sensitive to the changes of the concentration of sex and growth hormone. Thus, hormonal treatment might be an effective remedy for sarcopenia, but not for dynapenia (age-related loss of muscle strength). These findings further highlight the importance of distinguishing sarcopenia from dynapenia.

1.2 WHOLE BODY VIBRATION TRAINING

1.2.1 Basic characteristics

Whole body vibration (WBV) has become an increasingly popular exercise in recent years. There are basically two types of vibrations: vertical synchronous vibration and side-alternating vibration. In the vertical synchronous mode, both legs extend and stretch vertically simultaneously, and a linear acceleration is directed to the trunk. In the side-alternating mode, the right and left legs operate in anti-phase to one another and acceleration is indirectly applied to the trunk (Abercromby et al., 2007). These two WBV training modes were used in the previous studies to investigate the effects of WBV training programme on muscle performance (Abercromby et al., 2007; Mar ń et al., 2014; Pollock et al., 2012a). Only one study compared the effectiveness of these two modes by using the same frequency and amplitude (30Hz and 4mm) both in vertical and side-alternating WBV on 17 healthy adults and found that the vastus lateralis and biceps femoris had greater response to the side-alternating WBV than the vertical vibration mode (Abercromby et al. 2007). Although Abercromby and colleagues (2007) reported the side-alternating WBV could elicit greater muscle activity in vastus lateralis and biceps femoris, it could only prove that the side-alternating mode was more effective than the vertical mode when the vibration frequency was at 30Hz. Therefore, it is still uncertain as to whether the side-alternating WBV training mode was more efficient than the vertical mode due to limited evidence.

Besides the different vibration modes, the frequency, amplitude and daily exercise duration are proved to be important in WBV training as well (Cardinale & Bosco, 2003; Mar ń & Rhea, 2010). According to some previous studies, the frequency adopted for WBV generally ranged between 20Hz and 60Hz (Machado et al., 2010; Milanese et al., 2013) and the most common vibration amplitude was between 2mm and 5mm (Bautmans et al., 2005; Bogaerts et al., 2009). The duration for one exercise session (daily exercise time) ranged between 240 and 1060 seconds was found to be effective for training muscular strength (Mar ń & Rhea, 2010). Mar ń and Rhea (2010) advocated that higher frequency of vibration had more effects on muscle strength and power than lower frequency. However, considering the dose (the number of vibration) would also increase as frequency increased within the same duration of exercise, the gain in muscle strength and power at higher frequency could be due to the increased number of vibrations rather than the pure effect of frequency, which has not been controlled in any previous studies and this factor will be controlled in the present study.

Some studies examined the transmissibility of WBV on the human body (Friesenbichler et al., 2014; Pollock et al., 2010; Tankisheva et al., 2013). One of the studies found that the transmissibility of peak acceleration of side-alternating WBV was higher at 10Hz and lower at 28Hz in young healthy males (Friesenbichler et al., 2014). While another study reported 5Hz was the optimal frequency of side-alternating WBV for transmissibility of toe, ankle, knee, hip, and head (Pollock et al., 2010). The inconsistent findings of these two studies on the optimal frequency for effective transmissibility might be due to the different standing postures.

Friesenbichler et al. (2014) conducted the training without knee flexion, while Pollock et al. (2010) asked their subjects to stand on the WBV platform with 5-10 degrees of knee flexion. For the transmissibility of the vertical WBV training, Duc et al. (2014) found that 50Hz and 60Hz had higher input acceleration in knee and hip, while 20Hz was more efficient for transmissibility in ankle. However, Tankisheva et al. (2013) found no statistically significant difference on the transmissibility was among 30Hz, 35Hz, 40Hz and 50Hz. Considering the small sample size of only 8 subjects in the study of Tankisheva et al. (2013), it should be cautious to draw a conclusion based on their findings. According to the present evidence, the effectiveness of vibration transmissibility would be influenced by training intensity, standing posture and training mode.

1.2.2 The effects of WBV training in young populations

1.2.2.1 Short-term training effects

The effects of short-term WBV training (less than one week) on the muscle performance were investigated by different researchers in the past two decades. In 1999, Bosco and colleagues pioneered WBV as training to improve the muscle performance in the volleyball players. They found volleyball players with 10 minutes of vibration training programme had 6-8% increase in leg press power (Bosco et al., 1999). Later, a few other studies also investigated the effects of short-term WBV training in the trained individuals. One Norwegian study has demonstrated WBV training with 50Hz would elicit more than 4% increase in peak power outputs of squat jumps in power lifters. The EMG values of vastus medialis, vastus lateralis and rectus femoris also increased dramatically in the volunteers with WBV (Rønnestad et al., 2012). Cochrane and Stannard (2005) trained 18 female elite field hockey players with either 5 minutes of cycling or 5 minutes of side-to-side WBV at 26Hz to examine whether short-term WBV training had the effects on counter-movement jump, grip strength, and flexibility performance. The results of that study indicated the short-term WBV training was a better training approach than cycling on counter-movement jump and flexibility for their subjects. However, the grip strength did not change in the two groups after 5 minutes of training. Since both WBV and cycling training focused on the lower extremity, it is readily explainable that no alternation in grip strength was found after 5 minutes of training.

Later, many researchers began to investigate the effects of short-term WBV training in the untrained healthy young adults (Cormie et al., 2006; Despina et al., 2014; Erskine et al., 2007; Marín et al., 2014; Mileva et al., 2006; Wirth et al., 2011; Ye et al., 2014). Erskine et al. (2007) reported there was a significant increase in maximal isometric knee extension after 10 minutes of WBV training programme. Mileva et al. (2006) found dynamic muscle strength and power increased significantly after a single bout of WBV in young healthy adults, the activity of vastus lateralis and rectus femoris also increased in the WBV group. Besides the lower extremity, an earlier study from Switzerland examining the surface EMG of back and abdominal muscles found the abdominal muscles had more increase than the back muscles in the healthy young male individuals after 40 seconds of vertical WBV training with a parameter of 30Hz and

4mm, though these increases were not statistically significant. The authors concluded short-term WBV training could only induce low to moderate increase in trunk muscle activities (Wirth et al., 2011). It is concluded that short-term WBV training programme could induce the increase in muscle activities in the lower extremity in young adults.

The effects of short-term WBV training on balance and flexibility were only investigated in one study (Despina et al., 2014) that with 75 seconds of WBV training. They found sit and reach test had obvious improvement from 41.5cm to 42.7cm, while the maximum excursion showed no change (Despina et al., 2014). Moreover, no change was observed in proprioception after a single bout of WBV training (Hannah et al., 2013). Hannah et al. (2013) found there was no effect with 5 minutes of WBV on knee joint position sense in the healthy young individuals. The explanations for no improvement in balance were because: firstly, balance involves a complex coordination in the body, which could hardly be improved by only one bout of exercise; secondly, young adults already have very good balance, which is more difficult to be improved than that of the older ones. Thus, it is reasonable that there were no significant effects of short-term WBV training on balance in a young group of subjects.

Besides muscle performance, balance and flexibility, there were two studies that examined the oxygenation level (Mileva et al., 2006; Yamada et al., 2005). Yamada et al. (2005) revealed 3 minutes of squatting exercise with side-to-side WBV would decrease the muscle oxygenation level of vastus lateralis, which might be due to the increased oxygen utilization in the muscle, and this finding was parallel to the increased muscle activity. Furthermore, Mileva et al. (2006) found the rate of muscle deoxygenation was hastened in the higher speed contraction.

The effects of short-term WBV training on hormone in young adults were examined in two studies. Erskine et al. (2007) reported there was no change in testosterone and cortisol concentration after 10 minutes of WBV training programme. Another study also confirmed there was no alteration in testosterone after 20 minutes of WBV with vibration frequency of 30Hz. They had also found the level of insulin growth factor-1 had not changed (Cardinale et al., 2006). These reports did not support there was any effect of short-term WBV training on the endocrine system.

In conclusion, short-term WBV training programme would have positive effects on muscle function such as muscle strength and power. The muscle activity in the lower extremity was consistently greater in the WBV group than the sham group, which implied that WBV would induce tonic vibration reflex (TVR) to potentiate the neuromuscular performance (Cardinale & Bosco, 2003). Theoretically, vibration could affect the sensitivity of muscle spindle, which could improve the proprioception and balance (Eklund & Hagbarth, 1966). However, there was no study that reported the improvements in balance and proprioception after short-term WBV training programme. Considering the duration with short-term WBV training programme, it might be insufficient to elicit the changes in balance and proprioception, which might need longer term of training for enhancing the performance.

1.2.2.2 Long-term training effects

The effects of long-term WBV training programme (training lasts for more than one week) were conflicting among previous studies. Some studies advocated the long-term WBV training programme could change the body composition (Item et al., 2011), improve muscle performance (Fort et al., 2012; Lamont et al., 2009), balance

(Fort et al., 2012) and flexibility (Karatrantou et al., 2013). Item et al. (2011) reported, after 16 sessions of side-alternating WBV with frequency at 30Hz, the lean muscle mass of thigh increased by 4% and the cross-sectional area of vastus lateralis for myosin heavy chain (MYH) isoform in both type 1 and type 2 fibers increased by 16.7% and 13.8% in young females, respectively (Item et al., 2011). The above findings support that long-term WBV training programme would be effective to increase the muscle mass and cross-sectional area of fibers of vastus lateralis.

Regarding the muscle function, Fort et al. (2012) reported after 8 weeks of high-intensity (10 sessions/week) vertical WBV training (25-30Hz, 4mm), the counter-movement jump and one-leg hop height in the basketball players increased by 6.47% and 10.12%, respectively, and the lateral deviation of the center of pressure during single leg standing with eyes closed decreased by 22.2% after training. Also, Delecluse et al. (2003) found the peak torque of isometric and isokinetic knee extension had increased by 16.6% and 9%, respectively, in young adults after 36 sessions of WBV with frequency ranged from 35Hz to 40Hz and amplitude from 2.5mm to 5mm. However, Item et al. (2011) found no improvements in maximal power in knee extension and counter-movement jump after 16 sessions of side-alternating WBV with frequency at 30Hz. In the study of Item et al. (2011), the muscle power measurement was conducted in the non-dominant leg of young subjects, which might be the reason for the no statistically significant improvement in muscle power. Based on the above evidence, the long-term WBV training programme could increase the lean muscle size and the muscle strength of isometric and isokinetic knee extension.

Comparisons have been made between WBV and conventional resistance training.

One study trained 36 young men for 12 sessions of squat training programme with or without high-frequency WBV found the percentage change of jump height and peak power of deep squat had significantly increased in the training group with WBV (Lamont et al., 2009). However, another study with longer training duration of 72 sessions revealed no difference between WBV training and conventional resistance training in the peak torque of isokinetic knee extension in the young subjects (Roelants et al., 2004a). The finding of Lamont et al. (2009) suggested that WBV training programme could induce additional benefits to the conventional squat training, while Roelants et al. (2004a) revealed WBV training programme was as effective as the conventional resistance training to improve the muscle strength in the young adults. Although WBV training programme is not better or more effective than the conventional resistance training, it is an efficient approach for training muscle strength due to its training duration was less than 30 minutes, which was much shorter than one hour that was adopted in the conventional resistance training.

1.2.3 The effects of WBV training in older population

1.2.3.1 Short-term training effects

The effects of short-term WBV on muscle performance, balance, flexibility and physical functions in older individuals have been studied by some researchers (Carlucci et al., 2010; Carlucci et al., 2015; Tsuji et al., 2014). It was reported that muscle activities in vastus medialis, vastus lateralis, rectus femoris and gastrocnemius lateralis were greater in the WBV group than the sham group (Carlucci et al., 2015).

After 90 seconds of vertical WBV training, the time for completing TUG was significantly shorter than that at baseline. However, there was no group difference between the participants with and without WBV in TUG, sit-and-reach and functional reach in older people (Tsuji et al., 2014). The positive effect of short-term WBV on balance was not supported in some studies. Carlucci et al. (2010) found that 9.5 minutes of vertical WBV had no positive effect on the deviation distance of the center of pressure. The explanations for the unchanged balance performance and hormone concentration in older subjects after short-term WBV training programme are the same as in young adults. The main reason is the balance and hormone could not be altered during such short duration.

Similar to the studies conducted in young adults, there was no effect with WBV on growth hormone and testosterone concentration in older population (Cardinale et al., 2010). Furthermore, one study pointed out that a 10-min WBV exercise would increase skin temperature and blood flow in the lower extremity in the elderly (Lohman et al., 2012). It is noticeable that the skin blood flow increased by 4.5 fold after WBV intervention, which might cause the side effects on some particular groups of people (Lohman et al., 2012). Therefore, it should be cautious when conducting WBV on the elderly with severe cardiovascular diseases.

1.2.3.2 Long-term training effects

Some researchers advocated long-term WBV could increase the muscle mass in the elderly (Bogaerts et al., 2007; Fjeldstad et al., 2009; Kennis et al., 2013; Roelants et al., 2004b). Both Bogaerts et al. (2007) and Kennis et al. (2013) reported the muscle mass increased after one year of vertical WBV in older men and women. With examining the muscle size, Machado et al. (2010) found that after 10 weeks of vertical WBV training, the cross-sectional area had increased by 8.7% in vastus medialis and 15.5% in biceps femoris, but no increase was found in vastus lateralis.

Effect of WBV on body fat in older individuals was also studied (von Stengel et al., 2012; Verschueren et al., 2004). von Stengel et al. (2012) found that both body fat percentage and abdominal fat mass had significantly decreased after 18 months of WBV training programme. Verschueren et al. (2004) reported fat mass had decreased by 2.4% after 6 months of WBV training programme, though it was not significant. Fjeldstad et al. (2009) reported the WBV training group had more significant decrease in the total per cent body fat than the non-WBV group. However, one study stated muscle mass remained unchanged after 18 sessions of WBV training programme (Bautmans et al., 2005). Considering the insufficient training sessions and short duration for each training session (2-4 minutes) in Bautmans et al. (2005) study, it is unlikely that there could be change in muscle mass after training.

According to the above studies, WBV training could increase the lean muscle mass and size in older people with sufficient training period. It is noticeable that WBV training to be as effective as the conventional resistance training since there was no significant difference between WBV training and conventional resistance training on the change of muscle size and mass after training, which was reported in most studies (Fjeldstad et al., 2009; Kennis et al., 2013; von Stengel et al., 2012; Verschueren et al., 2004). Although WBV training did not appear to be more effective than the conventional resistance training, it should be a more efficient, convenient and safe training approach for older population.

The influence of long-term WBV training on muscle performance, such as muscle activity, strength, power and speed of movement, were reported as the primary findings in many studies (Bemben et al., 2010; Kennis et al., 2013; Verschueren et al., 2004). When compared to the control group, significant increases were presented in isometric knee extension at 130° and isokinetic knee extension at 100°/s after 24 weeks of vertical WBV training programme (Verschueren et al., 2004). Gómez-Cabello et al. (2013) stated the improvement in muscle strength in the lower body was only found in the WBV group, but not in the control group. Moreover, Machado et al. (2010) found muscle power was preserved in the WBV group but not in control group, which had significantly decreased after 10 weeks of training. However, Bautmans et al. (2005) and Raimundo et al. (2009) reported no significant improvement in muscle strength after 18 and 96 sessions of WBV training programme, respectively. For the study conducted by Bautmans et al. (2005), the training duration was very short thus this could explain for the unchanged muscle strength. For the study conducted by Raimundo et al. (2009), the frequency used in WBV training programme was only 12.6Hz, which was much lower than the other studies. Therefore, it is postulated the low vibration frequency might be difficult to elicit any significant improvement in muscle strength in older people.

Most studies compared the effects of WBV and conventional training revealed both training approaches could induce the improvements in muscle strength and power. However, there was no significant difference between these two approaches in most aspects of muscle performance, such as isometric knee strength, power and counter-movement jump height (Bogaerts et al., 2007; Kennis et al., 2013; Rees et al., 2008; Roelants et al., 2004b; von Stengel et al., 2012; Verschueren et al., 2004). Although without significant difference, WBV seemed to be more efficient than the conventional training in some studies (Bemben et al., 2010; Rees et al., 2008; Roelants et al., 2004b; von Stengel et al., 2012). Bemben et al. (2010) reported, after 8 months of training, the hip abduction strength had increased by 116% in the training group with WBV, while only 61% increase was found in the training group without WBV. Furthermore, von Stengel et al. (2012) found the isometric strength of trunk flexion only significantly increased in the WBV group, but not in the group with resistance training. Roelants et al. (2004b) reported that when compared with resistance training group, only WBV group showed significant increase in speed of knee extension movement at low resistance. Rees et al. (2008) demonstrated significant increases in ankle plantar flexor strength and power only in the WBV training group, but not in the group with resistance training.

However, some studies revealed WBV was not as efficient as the conventional training for the isometric and isokinetic muscle strength in older individuals. Bogaerts and colleagues (2007) reported the fitness-training group had more increase in isometric muscle strength than the vertical WBV training group. Later, in 2009, they also stated the fitness training group had better performance in oxygen uptake and isometric strength than the vertical WBV group (Bogaerts et al., 2009). A study that followed up the participants for one year after one year of training completion found that most improvements dissipated in both WBV and fitness training groups within one year after training cessation, except for the isometric strength, which was preserved in the resistance training group (Kennis et al., 2013). In that study, the fitness group received a comprehensive training programme, including cardiovascular, resistance, balance and flexibility exercises for 60-90 minutes per session, while the WBV group only conducted training for 40 minutes, which also included the warm-up and cool-down components. Therefore, the fitness-training group had larger training intensity than the WBV group. Considering the comprehensive training programme used in the above three studies and the longer training duration for one session, it may not be a valid conclusion that WBV training was less beneficial than the comprehensive training programme.

The positive effects of long-term WBV training on balance in older population were reported in many studies (Bogaerts et al., 2011; Bruyere et al., 2005; Cheung et al., 2007; Rees et al., 2009; Stolzenberg et al., 2013a; Zhang et al., 2014). Bruyere et al. (2005) reported the score of Tinetti test had significantly increased after 18 sessions of physical therapy with WBV training. Bogaerts et al. (2011) found sway velocity only improved in the WBV group, but not in the control group. Also, the movement speed, maximum point excursion and directional control in the balance test were only improved in the WBV group, but not in the control group (Cheung et al., 2007). Both Rees et al. (2009) and Stolzenberg et al. (2013a) reported one-legged postural steadiness improved after long-term WBV training. The balance confidence was also increased in the frail elderly after WBV training (Zhang et al., 2014). Based on these studies, it is concluded that long-term WBV training programme could improve the balance performance in older population.

Most studies reported the positive effects of long-term WBV training in physical performance (Bautmans et al., 2005; Bruyere et al., 2005; Machado et al., 2010; Pollock et al., 2012a; Zhang et al., 2014). Bautmans et al. (2005) and Bruyere et al. (2005) compared the older adults with and without WBV training and found that those with WBV had better performance in TUG. Machado et al. (2010) found the time for completing TUG was decreased by 9% in the WBV training group, while no change was observed in the control group. Beaudart et al. (2013) demonstrated that the time for completing TUG had decreased by 1.14 seconds in the WBV training group, while the time had increased by 0.41 second in the control group. The effect of long-term WBV training programme on the TUG test was consistently positive in older people.

Furthermore, the positive effect of long-term WBV training on sit-to-stand test was reported in the study of Runge et al. (2000). It is reported that the time for completing sit-to-stand test had decreased by 18% after 24 sessions of WBV training. However, Iwamoto et al. (2012) found no change in performance of sit-to-stand test after 24 sessions of WBV training. The explanation for the inconsistence might be the different frequencies. Runge et al. (2000) used 27Hz in the WBV training programme, while Iwamoto et al. (2012) only used 20Hz, which might be inadequate to stimulate the sit-to-stand performance. The study conducted by Raimundo et al. (2009) also proved that the WBV with low frequency (12.6Hz) could not improve the sit-to-stand performance.

Walking speed had significantly increased in older people trained with WBV (Gómez-Cabello et al., 2013; Pollock et al., 2012a). Gómez-Cabello et al. (2013) found that the walking speed had increased by more than 0.1m/s after 33 sessions of WBV training. Pollock et al. (2012a) reported the walking speed had increased by 36% in the group with WBV training programme, while the group without WBV training programme only increased by 18.1%. The walking speed in the study of Raimundo et al. (2009) had only increased by 5.5%. The reason for this undetectable change would be the small frequency leading to the low intensity of training, which could not cause a significant change after training. In conclusion, the long-term WBV training with adequate frequency and training duration could improve the physical performance in older people.

1.2.4 Effects of WBV training on chronic diseases

Long-term WBV training was used for treating many skeletal diseases, such as osteoporosis, hip fracture and degenerative knee problems. Women suffering from osteoporosis receiving 72 sessions of WBV training had significant increase in peak power of counter-movement jump (Stolzenberg et al., 2013b). For patients with hip fracture, 8 months of WBV training increased wall squat and chair raise test by 120% and 10.5%, respectively, and bone mineral density was preserved after training, but no significant improvement in balance was found in the subjects (Beck & Norling, 2010).

Simão et al. (2012) found improvements in BBS and walking speed after 36 sessions of WBV training in the patients with knee osteoarthritis. In comparing WBV training on a stable platform with conventional training on balance board, Trans et al. (2009) found only the participants trained with WBV on a stable platform had demonstrated significant increase in isokinetic knee extension and flexion, while proprioception improved only in the group with balance board training, but not in the group with WBV stable platform training. It is a readily explainable finding since the balance board is specialized for training body balance. For total knee arthroplasty, Johnson et al. (2010) reported the time for completing TUG decreased by 84.3% in the WBV group after 36 sessions of training, which was slightly greater than the resistance training group, which showed a decrease of 77.3%.

For people with chronic stroke, the effects of long-term WBV training on muscle, physical performance and balance were divergent. Some studies advocated long-term WBV training had positive effects in the participants with chronic stroke. Lau et al. (2012) reported an improvement in BBS, dynamic postural control, walking ability, and isometric knee flexion and extension strength after 24 sessions of WBV training. Similar findings were reported in another study with 18 sessions of training (Tankisheva et al., 2014). However, Mar ń et al. (2013) conducted 36 sessions of WBV training and found no effects of training programme on muscle thickness, isometric muscle strength and BBS. The inconsistency between these two studies might be due to the different training protocol. Lau et al. (2012) trained the subjects for 24 sessions of dynamic exercise with WBV frequency ranged between 20Hz and 30Hz, while the subjects in the study of Mar ń et al. (2013) only had static standing throughout the training programme with frequency ranged from 5Hz to 21Hz. For spasticity, Tankisheva et al. (2014) recently reported long-term WBV training did not have effect in modulating the muscle tone. While Miyara et al. (2014) using short-term WBV training of 5 minutes found Ashworth scale to have decreased and the range of motion of lower-extremity and walking speed to increase after training.

After several sessions of WBV training, the self-preferred walking speed had significantly increased by 13% in the patients with chronic obstructive pulmonary disease (Furness et al., 2014), while the patients with diabetes did not show improvements in physical performance (Del Pozo-Cruz et al., 2013). For people with Parkinson’s disease, their balance performance improved after 30 sessions of WBV training, but no difference was found between WBV and resistance training groups (Eberbach et al., 2008).

According to these studies, WBV training could be an alternative therapy for treating many chronic diseases. Although it was suggested to be effective on these conditions, no evidence was found to support WBV training was more beneficial than the conventional resistance training (Eberbach et al., 2008; Johnson et al., 2010; Stolzenberg et al., 2013b). However, considering special conditions of the patients with these diseases, who might have difficulty to participate in conventional resistance training at initial stage of physical therapy, WBV training is considered relatively safe, comfortable and more controllable than conventional resistance training.

1.2.5 Optimal parameters for short-term WBV training

Previous studies had tried to explore the optimal parameters of WBV exerceise. Some of the authors advocated high frequency and large amplitude to be optimal for increasing muscle activity and strength (Krol et al., 2011; Lienhard et al., 2014; Marín et al., 2014; Rønnestad, 2009; Tankisheva et al., 2013). Rønnestad (2009) found only 50Hz of WBV training could increase the loading of one repetition maximum of leg extensors in half squat, while 20Hz and 35Hz had no effect on knee extensors strength. Krol et al. (2011) stated the peak of activity in the leg muscles occurred when vibration frequency was 60Hz and amplitude was 4mm. Also, Lienhard et al. (2014) compared 4 frequencies (25Hz, 30Hz, 35Hz and 40Hz) and 2 amplitudes (1.2mm and 2mm) of vertical WBV and found 40Hz with 2mm could enhance the activity of most muscles of the lower limbs. One interesting study that implemented WBV training only on one leg reported 50Hz of vibration frequency could elicit the increase in the muscle activity of vastus laterlis both in stimulated and non-stimulated leg better than 30Hz (Marín et al., 2014). According to these findings, it is plausible that reasonably high frequency and amplitude would be more effective than the lower ones. However, the study by Adams et al. (2009) reached an interesting result that low frequency with low amplitude showed similar effects as the high frequency with high amplitude in peak power of counter-movement jump. Meanwhile, they found no difference between high and low amplitude as the frequency was at 40Hz, while high amplitude had greater peak power than that at low amplitude when the frequency was increased to 50Hz (Adams et al., 2009). Also, Ye et al. (2014) found that the trunk extension strength had increased after training with the frequency at 25Hz, while the subjects received training with 40Hz had decreased in endurance of trunk extensor muscles. Thus, it is of doubt whether high frequency and large amplitude was consistently associated with greater improvements in muscle performance.

Recently, studies had demonstrated there were different optimal frequencies for different muscles (Di Giminiani et al., 2013; Pollock et al., 2010). Di Giminiani et al. (2013) compared 9 frequencies (0Hz, 20Hz, 25Hz, 30Hz, 35Hz, 40Hz, 45Hz, 50Hz and 55Hz) and found that 30Hz and 55Hz were the optimal frequencies for improving muscle activity of vastus lateralis, whereas the lateral gastrocnemius responded better at 30Hz than the other frequencies (Di Giminiani et al., 2013). This agreed with the report by Pollock et al. (2010) that with side-alternating WBV training at 6 frequencies (5Hz, 10Hz, 15Hz, 20Hz, 25Hz and 30Hz) and two amplitudes (2.5mm and 5.5mm), the combination of 30Hz and 5.5mm was found to associate with the greatest EMG activity in tibialis anterior, soleus and biceps femoris, but not with gluteus maximus, which had the same response to different frequencies and amplitudes. Furthermore, there was a depression in muscle activity of rectus femoris in 15-25Hz (Pollock et al., 2010). These two studies have shed light on the possibility for exploring the optimal frequency and amplitude. The optimal frequency and amplitude may need to be determined for each muscle individually. However, it is extremely complex and inefficient to train individual muscles in the clinical scenario. Therefore, it is essential to explore the most effective frequency for improving muscle performance as a whole instead of individual muscles.

However, not all studies agreed that different frequencies and amplitudes would have an effect on muscle activity and performance. Gerodimos et al. (2010) reported no differences among 3 frequencies (15Hz, 20Hz and 30Hz) and 3 amplitudes (4mm, 6mm and 8mm) on peak power of squat jump. An explanation for no difference in the study by Gerodimos et al. (2010) might be the insufficient level of stimulation. The frequencies used in that study were lower than the other studies that reported the different combinations of WBV training had effects on muscle performance. Although the study of Amstrong et al. (2010) conducted WBV training with a sufficiently wide frequency range (30Hz, 35Hz, 40Hz and 50Hz), it was still reported no difference in counter-movement jump height for all groups. As the same training intensity, the change of jump height might be more difficult to be detected than the change of muscle activity, which was measured in the studies that found the effects of different frequencies on muscle performance (Krol et al., 2011; Lienhard et al., 2014).

Besides frequency and amplitude, the total exposure time is an important parameter of WBV training protocol. The exposure time of each session was used to present the total amount of time involved in a training session. In order to explore the most efficient exposure time, the duration per set of exercise and number of sets, were discussed in some studies. Da Silva-Grigoletto et al. (2011) revealed 60 seconds was the optimal set duration for 6 sets of vertical WBV training to improve the performance of counter-movement and squat jumps. The participants with 30 and 90 seconds of exercise showed decreases in jump performance (Da Silva-Grigoletto et al., 2011). Moreover, they pointed out the session with 6 sets was the most effective design for muscle performance. Therefore, the optimal exposure time might be 360 seconds for one session (Da Silva-Grigoletto et al., 2011). However, Adams et al. (2009) found no difference in muscle performance between the groups with session duration of 30, 45 and 60 seconds. Considering extremely short duration in one session in that study, it is understandable that no effect of training duration was found.

All the above findings on the optimal training duration only consider the vertical WBV training mode. Only one study by Stewart et al. (2009) investigated the optimal duration for side-alternating WBV training mode and advocated the optimal set duration for side-alternating WBV to be 120 seconds. The longer durations (240 and 360 seconds) induced the decreases by 2.7% and 6% in knee extensor strength, respectively, which might be due to muscle fatigue after such long training bout (Stewart et al., 2009). Therefore, it was clear that the optimal training duration should be determined for the vertical and side-alternating WBV training modes differently.

Besides the parameters discussed above, Da Silva-Grigoletto et al. (2009) investigated the optimal rest interval and discovered both 1-minute and 2-minute recovery time could significantly increase power output and height in counter-movement and squat jumps. The increase in jump performance among the participants with 2 minutes of recovery time was greater than those with 1 minute. No significant improvement was found in the 3-minute group. Thus, they advocated a

2-minute recovery period between sets would be the optimal choice (Da Silva-Grigoletto et al., 2009).

The different platform designs of WBV machine and leg posture during exercise would influence the effects of training. Knee bending was the common posture in the WBV training. It attenuates the acceleration from feet to head, which would reduce the load on the spine, thus maintain the safety of WBV training. For the side-alternating WBV, smaller knee flexion angle would induce greater response of muscle activity of vastus lateralis and biceps femoris (Abercromby et al., 2007). However, one study with vertical WBV reported there was no difference between high squat (knee flexion angle was 45°) and deep squat (knee flexion angle was 70°) in muscle activity (Tankisheva et al., 2013). The results of the study of Tankisheva et al. (2013) need to be treated with caution due to the small sample size and short exposure time.

Not as many studies investigated the optimal parameters for the short-term WBV training in young adults, only few researchers explored the optimal frequency of short-term vertical WBV training in older adults. Giombini et al. (2013) reported the mean optimal frequency of short-term vertical WBV, determined by EMG of muscle response, was 33Hz. Carlucci et al. (2015) found that compared with middle aged and young women, the optimal frequency for muscle activities in vastus medialis, vastus lateralis, rectus femoris and gastrocnemius lateralis were lower in older women. However, one study applying the same acceleration with different parameters (30Hz and 2.5mm, 46Hz and 1.1mm) reported no difference in the muscle activity between the different combinations of frequency and amplitude (Marín et al., 2012). It is noticeable that the exposure time in the study of Marín et al. (2012) was only 15 seconds, which might not be sufficient for reflecting the difference between the two frequencies.

1.2.6 Optimal parameters for long-term WBV training

Few studies were conducted to explore the optimal frequency and amplitude for the long-term WBV training. Petit et al. (2010) trained 32 healthy young male subjects with vertical WBV for 18 sessions and found only high frequency (50Hz) with high amplitude (4mm) could enhance the muscle performance in knee muscle strength. Chen et al. (2014) tried to determine the optimal frequency and amplitude of the long-term WBV under identical acceleration, failed to demonstrate any effect of frequency in jump height, impulse and displacement area of the body center of pressure. However, they reported the participants with low frequency (18Hz) had increased the muscle activity of rectus femoris in the counter-movement jump, whereas the muscle activity had decreased in high frequency (32Hz). Since only two studies have explored the optimal frequency and amplitude of long-term WBV training, it is premature to draw a conclusion on the optimal frequency for training protocol.

Besides frequency and amplitude, Furness and Maschette (2009) conducted a 6-week side-alternating WBV training programme with 15-25Hz found 3 sessions per week to be the most beneficial protocol for TUG, sit-to-stand test and Tinetti test score. von Stengel et al. (2011) compared one-year of vertical and side-alternating WBV training found both of them could induce more than 20% increase in leg strength. However, there was no difference between those two WBV training modes on leg strength (von Stengel et al., 2011). Considering the different frequencies and amplitudes used in vertical and side-alternating WBV training (side-alternating: 12.5Hz and 12mm; vertical: 35Hz and 1.7mm), it is still difficult to conclude that vertical and side-alternating WBV had similar influence in muscle strength in older people.

1.3 RATIONALE OF THE STUDY

Sarcopenia is an age-related loss of muscle mass has become a prevalent problem in older population (Ronsenberg, 1997). As muscle mass loses with age, older people with sarcopenia would have declined muscle strength to maintain the minimum walking speed, balance and daily physical activity (Cruz-Jentoft et al., 2010; Fielding et al., 2011). One of the serious consequences is fall (Landi et al., 2012), which could lead to the chronic bed rest or even death (Landi et al., 2013).

Sarcopenia is caused by multiple factors, including both intrinsic and extrinsic. Intrinsic factors mainly refer to age-related changes in the musculoskeletal and endocrine systems (Delmonico et al., 2009; Gray et al., 1991). Extrinsic factors primarily involve malnutrition and inactivity (Paddon-Jones et al., 2008; Rantanen et al., 1999). To analyze the causes of sarcopenia, it is clear that exercise training, nutritional supplementation and hormone injection would be the effective treatment for the condition (Fielding et al., 2011; Gryson et al., 2014; Srinivas-Shankar et al., 2010). Among these three treatments, exercise training is the most economical, controllable and approachable in the daily life.

In the past decade, the positive effects of WBV training on improving muscle mass (Item et al., 2011; Machado et al., 2010), muscle strength (Roelants et al., 2004a; Verschueren et al., 2004), physical performance (Bruyere et al., 2005) and balance (Fort et al., 2012) were reported in both young and older people in most previous studies. Considering the frail condition of older people with sarcopenia and the relatively good efficiency of WBV training, it would be realistic to use WBV training to the people with sarcopenia to improve their physical conditions. However, this hypothesis has not been proved in the past as no study had applied WBV training for combating the sarcopenia. It is meaningful for the clinical practice to examine whether the WBV training is effective for managing sarcopenia.

As stated in section 1.2.5 and 1.2.6, many studies had tried to explore the optimal parameters of the WBV training (Chen et al., 2014; Petit et al., 2010; Ye et al., 2014). Some researchers concluded higher frequency could induce greater improvements than the lower ones as the exposure time was fixed (Lienhard et al., 2014; Marín & Rhea, 2010; Marín et al., 2014). As noted, the production of the frequency and duration is the total number of vibrations. It is obvious that the higher frequency would result in larger number of vibrations, which would increase the dose that would influence the outcomes of training. Thus, it is doubtful whether the higher frequency could obtain better performance when the total number of vibrations was the same. As the importance of frequency and exposure time for the total number of vibrations determine the dosage, it would be meaningful to find the optimal combination of these two determinants. Therefore, it is essential to explore the optimal combination of frequency and exposure time of WBV training for improving physical condition of the elderly with sarcopenia.

1.4 OBJECTIVES

The specific objectives of this thesis were stated as below:

(1) To examine the effect of a 12-week WBV training programme for developing muscle performance, physical performance and balance in elderly subjects with sarcopenia (Chapter 3-5).

(2) To explore the optimal combinations of frequency and exposure time on muscle performance, physical performance and balance in elderly subjects with sarcopenia (Chapter 3-5).

(3) To determine whether the changes associated with a 12-week WBV training programme could be maintained for 3 months after cessation of training (Chapter 3-5).

(4) To identify a possible underlying neuromotor mechanisms of the effect of a 12-week WBV training programme on muscle strength improvement (Chapter 6).

1.5 HYPOTHESES

The hypotheses for the study are as follow:

(1) A 12-week WBV training programme is effective for improving muscle performance, physical performance and balance in elderly subjects with sarcopenia.

(2) Different combinations of frequency and exposure time would affect the muscle performance, physical performance and balance in elderly subjects with sarcopenia.

(3) The changes associated with a 12-week WBV training programme could be maintained for 3 months after cessation of training

(4) There is an effect of a 12-week WBV training programmme on the voluntary activation of quadriceps muscle.

CHAPTER 2 TEST-RETEST RELIABILITY OF THE OUTCOME MEASUREMENTS

2.1 INTRODUCTION

In this chapter, the test-retest reliability of measurements for assessing muscle size, strength, physical performance and balance were examined in the people with sarcopenia. Although reliability of the measurements used in the main study were well established in previous studies (Allen et al., 1995; Goldberg et al., 2012; Katoh & Isozaki, 2014; Ries et al., 2009; Segura-Ortí & Martínez-Olmos, 2011; Whittaker & Emery, 2014; Wong & Ng, 2010), the level of reliability of these measurements in older people with sarcopenia had not been reported in the past. Therefore, it is necessary to establish the reliability of these measurements for this population.

2.2 METHODS

2.2.1 Subjects

Subjects aged 65 years or above with no uncontrolled medical conditions attending the Elderly Health Centers of Department of Health, Hong Kong, were invited to go through a non-invasive screening test of bioelectrical impedance measurement so as to estimate their absolute skeletal mass. An established formula (Chien et al., 2008; Janssen et al., 2000a) was used to calculate the skeletal mass as follow:

Skeletal mass = [0.401 × (height^2/bio-impedance) + (3.825 × gender index) – (0.071 × age) + 5.102]; Gender index for male = 1; female = 0

Absolute skeletal mass was converted to skeletal mass index by dividing with the square of body height. Male and female participants with skeletal mass index less than 8.87kg/m^2 and 6.42kg/m^2, respectively, were classified as sarcopenia (Chien et al., 2008) and were invited to participate in this study. Subjects with metal implants, severe heart problem, neuro-degenerative diseases, peripheral vascular disease, vestibular disorders or severe osteoporosis with fractures within 1 year prior to the study were excluded from this study. All subjects gave their written consent (Appendix I or II) before participating in the study. The procedures were reviewed and approved by the Human Ethics Review Board of the Hong Kong Polytechnic University prior to commencement of the study.

2.2.2 Study design

Two sessions of measurements were conducted at the same time on two separate days. The interval of the testing sessions was 7 days apart. One researcher conducted the two sessions of measurements. The test-retest reliabilities were examined in this pilot study.

2.2.3 Outcome variables

2.2.3.1 Muscle mass assessment

The cross-sectional area (CSA) of vastus medialis (VM) of the dominant leg was measured with ultrasound imaging. The dominant leg was the leg used to kick a ball. Participants were positioned in supine lying and a custom-made ankle stabilizer was applied at the dominant ankle to keep the leg in neutral alignment (Figure 2). The B-mode of An Aixplorer® ultrasound unit (Supersonic Imaging, Aix-en-Provence, France) was used to capture the CSA of VM at the lower 1/3 of the leg (the length from anterior superior iliac spine to the medial side of knee joint line space) above the base of patella (Figure 3). Three images were captured for calculating the average CSA of VM.

2.2.3.2 Muscle strength assessment

The dominant knee extension strength was evaluated with an isokinetic dynamometer (Cybex Norm, Henley Healthcare, Nauppauge, NY, USA) (Figure 4). Isometric strength was measured at a knee angle of 90° whereas dynamic contraction performance was measured at two angular speeds of 60°/s and 180°/s. Participants were seated on an isokinetic exercise chair with hip at 80° of flexion and knee axis aligned with the dynamometer axis of rotation. The trunk and the tested leg were firmly secured by straps to the chair. Each participant performed two trials with submaximal effort for familiarization followed by three maximum contractions for the actual data collection. A recovery period of 60 seconds between each testing session was given. The maximum value of peak torque in the three trials was recorded for data analysis.

Figure 2: A custom-made ankle stabilizer. The ankle stabilizer was applied at the dominant ankle to keep the leg in neutral alignment for muscle size measurement.

Figure 3: Ultrasound probe placed at 1/3 of the leg above the base of patella. The leg length was from anterior superior iliac spine to the medial side of knee joint line space.

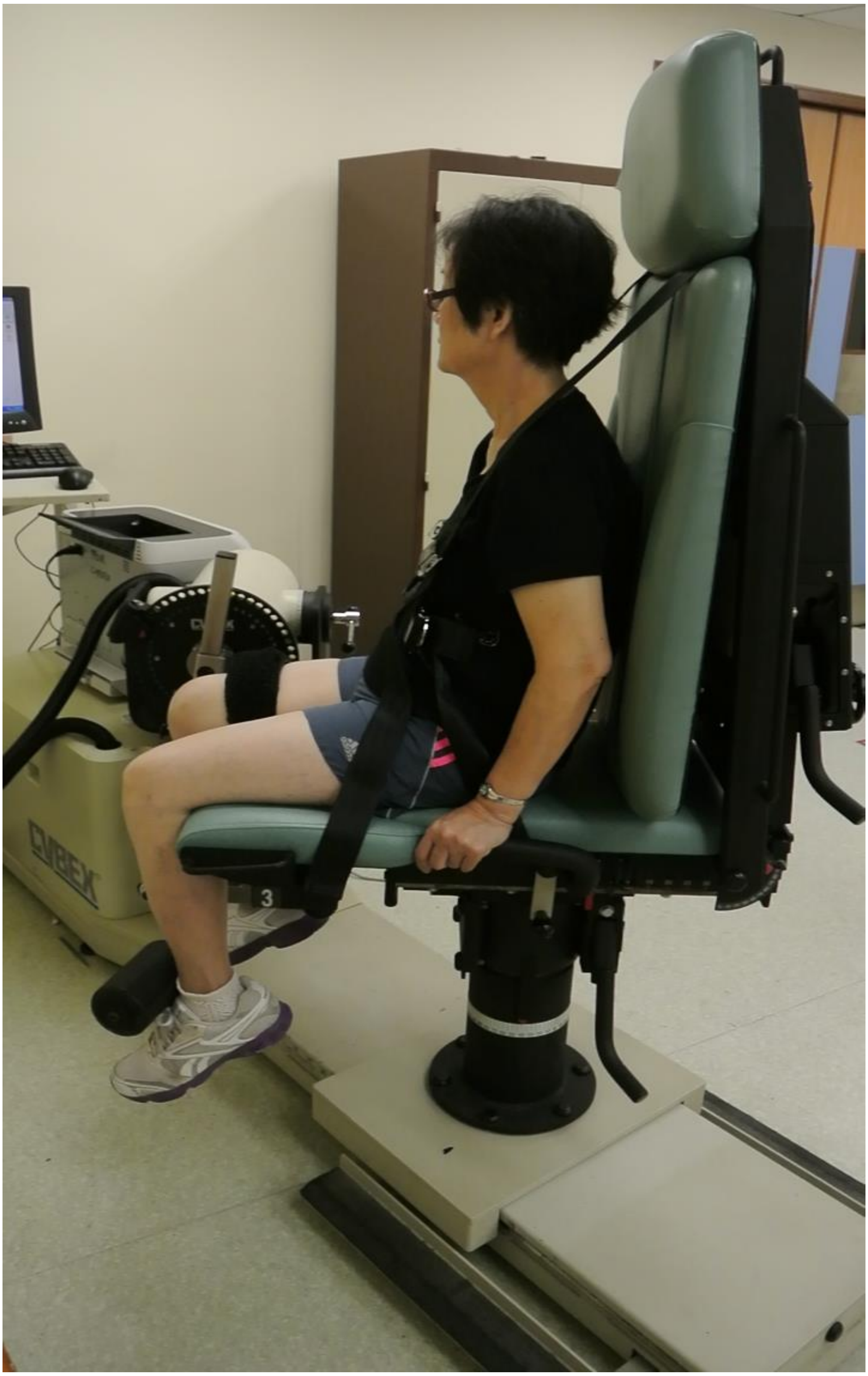

Figure 4: Maximal isometric knee extension at 90°. A participant was seated on an isokinetic exercise chair with hip at 80° of flexion and knee axis aligned with the dynamometer axis of rotation. The trunk and the thigh of the tested leg were firmly secured by straps to the chair.

2.2.3.3 Knee joint position (KJP)

Passive repositioning test was used to measure the knee joint position sense. Participants were blindfolded and seated on an isokinetic chair (Cybex Norm, Henley Healthcare, Nauppauge, NY, USA) with knee flexed (Wong & Ng, 2010). An inflatable air splint (Model 70-008, Svend Andersen, Haarlev, Denmark) was applied to the lower leg to eliminate the tactile clue (Barrack et al., 1983). The position channel of the isokinetic dynamometer was connected to a digital microprocessor that displayed real-time joint angle with an accuracy of 0.1°. A remote control switch connected to a digital microprocessor was given to the subject for indicating the knee joint angle.

During the test, the researcher would hold the participant's dominant leg and placed it in one of five positions (20°, 30°, 40°, 50° and 60°) for five seconds in random and the participant would be asked to memorize that position. Then the leg was returned to the resting position (90° of knee flexion). After 10 seconds, the researcher would move the participant's leg at an angular speed of around 0.5°/s (Barrett, 1991) and the participant would press the remote control button when he/she perceived that the knee had reached the tested angle (Figure 5). Three trials were conducted and the mean difference between the tested angle and the angle indicated by the participant was calculated (Fremerey et al., 2000).

Figure 5: Setup for knee joint position test. A participant was seated on an isokinetic exercise chair with hip at 80 ° of flexion and knee axis aligned with the dynamometer axis of rotation. An inflatable air splint was applied to the lower leg to minimize sensory input.

2.2.3.4 Timed-up-and-go test (TUG)

The timed-up and go test (TUG) measured the time taken by an individual to stand up from an arm chair, walk a distance of 3 meters, turn and walk back to the chair, and sit down (Podsiadlo & Richardson, 1991) (Figure 6). The participant wore their regular footwear and used their customary walking aid (none, cane, walker) to finish this test in their normal pace. No physical assistance was given during the test. The participant practiced the test twice before the actual measurement. Three trials were performed for actual measurement and the average time of the three trials were used for data analysis.

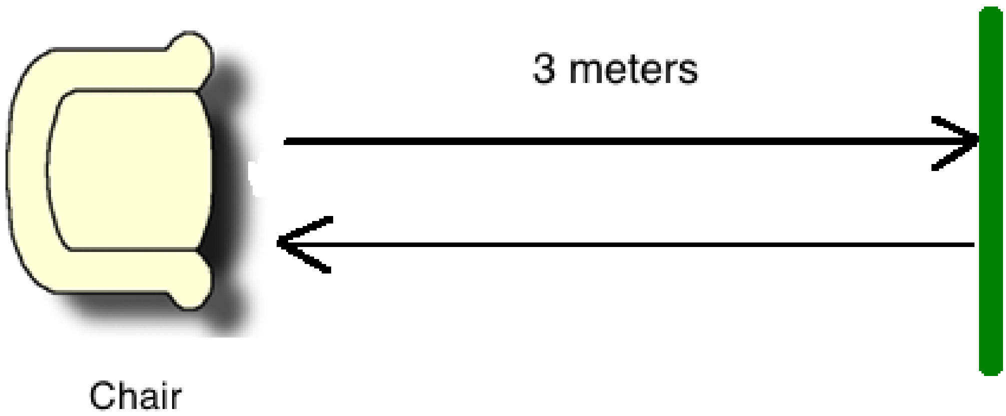

Figure 6: Time up-and-go test (TUG).

2.2.3.5 Five-repetition sit-to-stand test (5STS)

The test was conducted with the participant sitting on a chair of 43-47cm high with back leaning against the backrest, arms crossed in front of the chest and feet comfortably rested on the floor. The test was demonstrated to the participant by the researcher before data collection. During each trial, the participant would need to perform sit-to-stand for five times as quickly as possible. Timing began when the researcher said “start” and stopped when the participant's buttocks reached the seat after the fifth stand. The average time of three trials was calculated and used for data analysis.

2.2.3.6 10-meter walk test (10MWT)

This was assessed at both self-preferred and maximum walking speeds. The self-preferred walking speed was recommended as a practical parameter for diagnosis of sarcopenia (Cruz-Jentoft et al., 2010). The time was measured only for the middle 6 meters (Wolf et al., 1999) (Figure 7). The first and last two meters were to let the participant accelerate and decelerate. Timing would start and stop as the leading feet passed the 2-meter and 8-meter marks, respectively. Walking aid could be used in this test. The average walking speed of the three trials was recorded and used in data analysis.

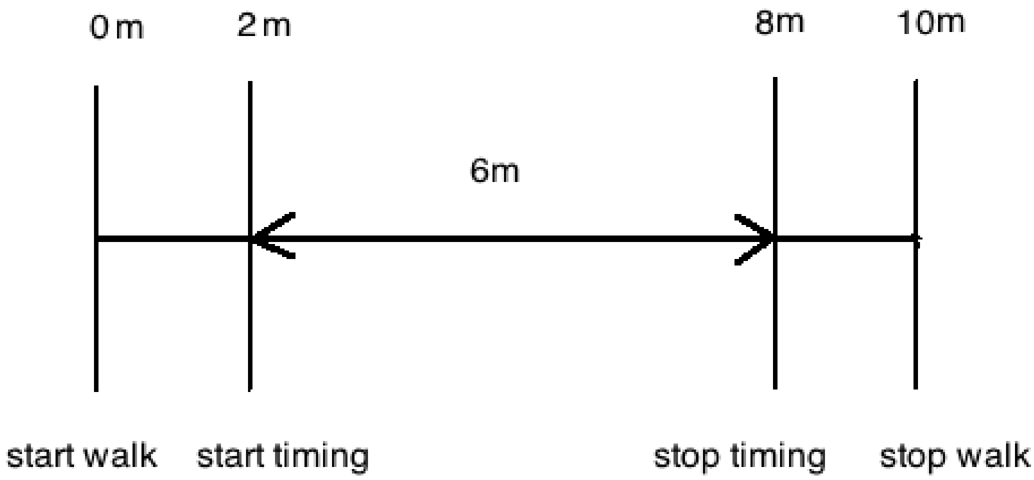

Figure 7: The 10-meter walk test (10MWT).

2.2.3.7 Tandem stance test

This is a recommended test in the short physical performance battery by European Working Group on Sarcopenia in Older People as an assessment component for physical performance of sarcopenia (Cruz-Jentoft et al., 2010). Participants were instructed to stand with their arms down by the sides and eyes fixed on a marked point at the eye level. Three trials were allowed for this test. Timing started when the participant has acquired a steady stance with feet in tandem and stopped when the steadiness could not be maintained or the participant moved either foot. The target standing time was set as 30 seconds. If a participant could not hold the tandem stance for this long, the best performance of the three trails was recorded for analysis. One minute of rest was given between trials.

2.2.3.8 One-leg stand (OLS)

Each participant was instructed to start in a position with a comfortable base of support with arms by the sides of the trunk and then stand unassisted on the dominant leg with eyes open or closed (two conditions). The OLS was timed from the instance when a foot was lifted from the floor until that foot touched the ground or the other leg. Three trials were performed with each condition (eyes open or closed). One minute of rest was given between each trial. The target standing time was set as 30 seconds. If a participant could not hold the one leg stand position for this long, the best performance of the three trials was recorded for analysis.

2.2.4 Statistical analysis

The absolute value of each variable was presented as mean and standard deviation. Test-retest reliability of muscle strength, tandem stance test and OLS was evaluated by intraclass correlation coefficient (ICC) of model (3,1) and model (3,3) was used to analyze the reliability of all other measurements. The 95% confidence interval was also reported.

2.3 RESULTS

Seven subjects (Age: 76±5 years; Height: 158.7±7.1 cm; Weight: 57.3±6.8kg; BMI: 22.8±2.6; Male: n=3; Female: n=4) participated in this pilot study of evaluating the test-retest reliability of the measurements used in the main study. The ICC (3,1) ranged from 0.75 to 0.99 (Table 1), which revealed the measurements had good (ICCs between 0.61 and 0.80) or excellent (ICCs between 0.81 and 1.0) test-retest reliability (Pittenger, 2003)

2.4 Discussion

The purpose of this pilot study was to determine the test-retest reliability of the muscle size, strength, TUG, 5STS, 10MWT, KJP, tandem stance test and OLS in older people with sarcopenia. Test-retest reliability is essential for the consistency of same participant for a particular test (Weir, 2005). It was recommended that the clinically acceptable test-retest reliability should be larger than 0.70 (Nunnally & Bernstein, 1994). In the present study, the test-retest reliability of all measurements was above

0.70. Therefore, all measurements were reliable for evaluating physical conditions in the people with sarcopenia. There was one limitation in this pilot study. The absolute reliability was not examined. However, the absolute reliability would not influence the results of main study since the effect of the absolute reliability would be eliminated in the comparisons of repeated measurements.

	Test 1	Test 2		
	Mean (SD)		ICC	95%CI
CSA of VM (cm^2)	4.32(1.25)	4.17 (1.01)	0.92	0.532, 0.986
Peak torque of isometric knee extension (Nm)	98.29 (42.65)	97.57 (40.63)	0.99	0.910, 0.997
Peak torque of knee extension at 180 °/s (Nm)	35 (19.11)	35.43 (17.99)	0.99	0.962, 0.999
Peak torque of knee extension at 60 °/s (Nm)	60.43 (28.65)	62.57 (27.12)	0.97	0.814, 0.995
TUG (s)	14.83 (2.74)	14.17 (2.83)	0.95	0.729, 0.992
5STS (s)	13.70 (3.88)	13.28 (3.62)	0.95	0.696, 0.991
10MWT at self-preferred speed (m/s)	0.95 (0.13)	0.91 (0.08)	0.90	0.443, 0.984
10MWT at maximum speed (m/s)	1.39 (0.23)	1.43 (0.19)	0.95	0.682, 0.991
KJP （degree）	6.36 (4.07)	5.23 (3.78)	0.75	-0.442, 0.957
Tandem test (s)	21.43 (11.07)	25.43 (8.54)	0.84	0.075, 0.973
OLS with eyes open (s)	13.90 (10.41)	18.50 (10.79)	0.89	0.376, 0.982
OLS with eyes closed (s)	5.85 (5.99)	3.64 (3.48)	0.84	0.061, 0.972

Table 1: The test-retest reliability of all outcome measurements. ICC: Intraclass correlation coefficient; 95%CI: 95% Confidence Interval; CSA: cross-sectional area; VM; vastus medialis; TUG: Timed up-and-go test; 5STS: Five-repetition sit-to-stand test; 10MWT: 10-meter walking test. KJP: knee joint position. OLS: one-leg stand.

CHAPTER 3 MAIN STUDY DESIGN

3.1 SUBJECTS

The recruitment of participants was held in the Shatin Elderly Health Center of Department of Health. The diagnosis for sarcopenia was reported in section 2.2.1. After recruitment, participants were randomly divided into 4 groups by a computer program (Research Randomizer Form), namely, (a) low frequency and long exercise duration group (LG), (b) medium frequency and medium exercise duration group (MG), (c) high frequency and short exercise duration group (HG), and (d) control group with no vibration (CG). The procedures of the study were reviewed and approved by the Human Ethics Review Board of the Hong Kong Polytechnic University prior to commencement of the study. Each participating subject gave voluntary informed written consent before joining the study (Appendix I or II).

3.2 INTERVENTIONS

All WBV training sessions were held at the Sports Training Laboratory of Department of Rehabilitation Sciences of Hong Kong Polytechnic University and supervised by a researcher. Training was implemented at 3 days/week for 12 weeks. The training of each day comprised 14,400 vertical vibrations, which were divided into four sessions with each session comprising 3,600 repetitions of vibration. No warm-up exercises were given before WBV training. Five minutes of rest were given between training sessions to avoid over exertion of the participants.

The WBV parameters for HG were 60Hz × 240 seconds, MG were 40Hz × 360 seconds and LG were 20Hz × 720 seconds. The peak-to-peak amplitude was set at 4mm for all training groups. During training, the participants stood barefoot with knee joint flexed by 60° on the platform of WBV machine (Fitvibe excel, GymnaUniphy NV, Bilzen, Belgium) and hands holding onto the rail in front for support (Figure 8). A soft mat supplied by Fitvibe manufacturer was placed on the vibration platform during all training sessions according to the recommendation of the manufacturer. A manual goniometer was used to monitor the knee joint angle before and after each training session. All participants were advised to keep their lifestyle and physical activities as usual during the study period.

3.3 OUTCOME MEASUREMENTS

The outcome measurements were described in section 2.2.3. The CSA of vastus medialis was used to test muscle mass. Isometric and isokinetic knee extension were used to test muscle performance. TUG, 5STS and 10MWT were used to test physical performance. KJP, tandem stance and OLS were used to test balance. All outcome variables were conducted by the researcher who supervised WBV training. Except for the twitch interpolation measurement, the outcome measurements were conducted for all subjects for five times, which were separately conducted at pre- (week 0), mid- (week 6), post-intervention (week 12), mid-follow-up (week 18) and final follow-up (week 24).

Figure 8: Participant standing on the whole body vibration platform during the training session.

3.4 STATISTICAL ANALYSIS

Kolgomorov-Smirnov test was used to examine whether the data followed a normal distribution. To compare the baseline characteristics of the four groups, one-way ANOVA (for data with normal distribution) and Kruskal-Wallis test (for data with non-normal distribution) were conducted.

Two-way repeated measures ANOVA (time × group) was used to analyze the raw data for examining the effects of WBV on muscle size, strength, balance and physical function. Contrast analysis would be conducted to analyze the raw data to examine the within-group changes of each group.

Percentage change from baseline (mid-term minus pre; post minus pre; mid-follow-up minus pre; follow-up minus pre)/pre × 100 in outcome variables were calculated. Between-group differences were tested using one-way ANOVA with Bonferroni post hoc to analyze the percentage changes from baseline. The last observation carried forward method (LOCF) of intention-to-treat (ITT) analysis was used for data analysis (Partney & Watkins, 2009).

Descriptive analyses were reported as means ± standard deviation. SPSS 20.0 (SPSS Inc., Chicago, Illinois, USA) was used for statistical analysis. Significance level was set at $p<0.05$, unless otherwise state.

CHAPTER 4 RESULTS OF MAIN STUDY

4.1 SUBJECTS

Eighty participants were recruited for baseline assessments. Among them, 70 had completed the study. The subjects comprised 17 in LG, 17 in MG, 18 in HG and 18 in CG. Ten withdrew from this study (Figure 9) with six due to accidental falls not related to this study, one due to a surgery planned before this study, two due to other health problems (Pneumonia and knee pain), and one moved to another country to live with her son midway into the study.

No side effect was reported from the participants during and after training. Except CSA, isometric knee extension, KJP, tandem and OLS, most outcome variables were normal distribution. Baseline characteristics of the four groups for the ITT analysis are summarized in Table 2-4. There was no significant difference at baseline between groups in physical characteristics and all the outcome variables ($p>0.05$).

4.2 CSA OF VM

There was no significant time ($F_{4,304}=1.172$, $p=0.32$) or time × group interaction effect ($F_{12,304}=0.52$, $p=0.902$) in CSA of VM (Figure 10). No significant within-group differences were found in CSA of VM in any of the four groups at the five assessment time points ($p>0.05$) (Table 5 and 6). Also, no significant between-group difference was found in CSA of VM at all assessment time points ($p>0.05$).

Although without statistical significance, all training groups showed an increase in CSA after 36 sessions of WBV training, while control group had a decrease. In the

12-week follow-up period, subjects in both training groups and control group showed

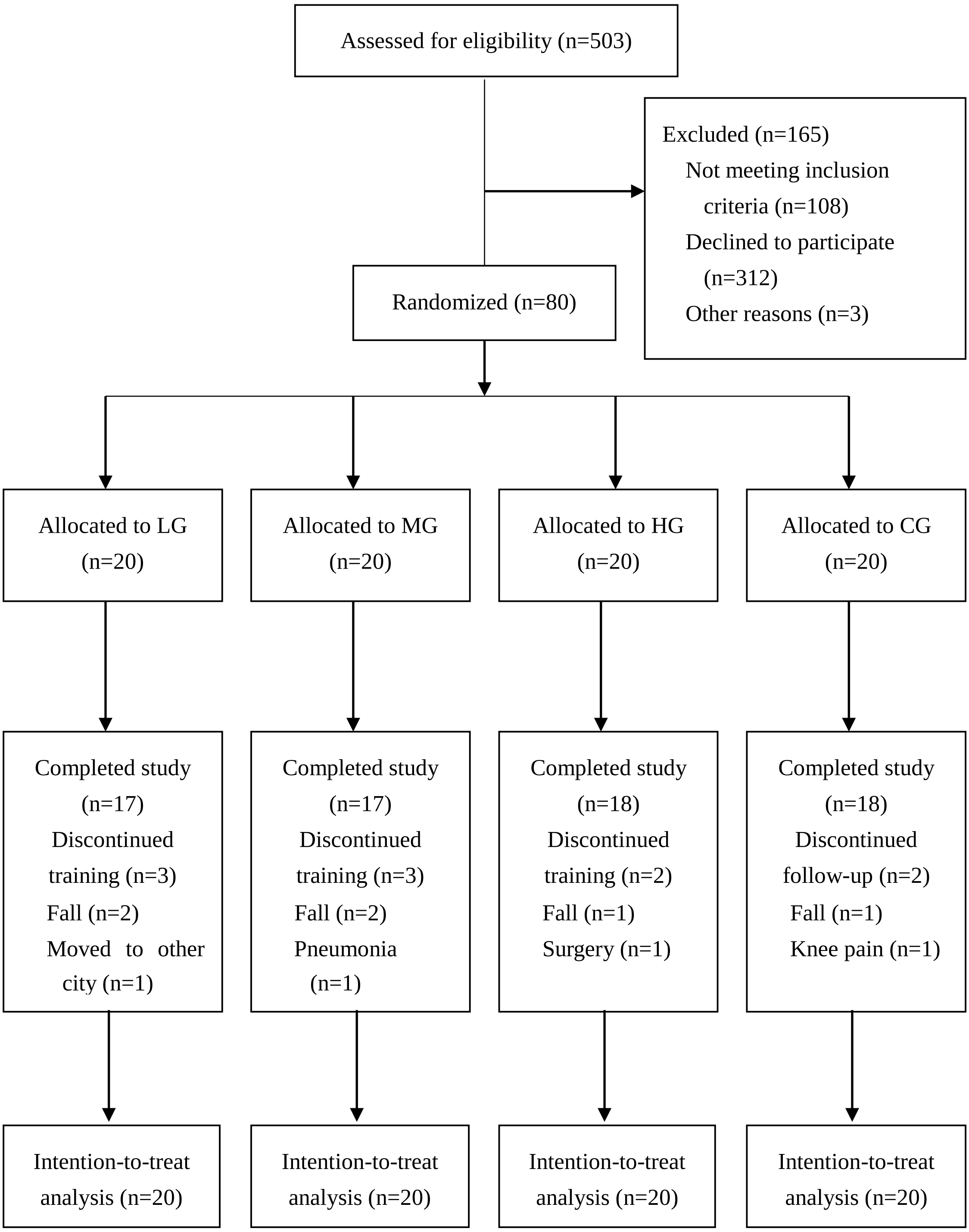

Figure 9: Flowchart of subject group assignment for the study.

	LG (n=20)	MG (n=20)	HG (n=20)	CG (n=20)	p value
Percentage of males	35%	35%	25%	25%	
Age (yrs)	78(4)	75(6)	74(5)	76(6)	0.114
Height (cm)	153.4(8.4)	156.1(8.8)	152.9(8.7)	152.1(8.3)	0.482
Weight (kg)	56.3(10.3)	56.9(6.40)	56.6(9.4)	55.3(8.4)	0.947
BMI (kg/m^2)	23.85(3.41)	23.44(2.47)	24.22(3.56)	23.83(2.65)	0.885
SMI (kg/m^2)	6.57(1.37)	6.44(1.03)	6.33(1.28)	6.39(1.31)	0.941

Table 2: The demographic characteristics of the participants at baseline assessment (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; BMI: Body mass index; SMI: Skeletal mass index. The p values were for between-group comparisons.

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	LG (n=20)	MG (n=20)	HG (n=20)	CG (n=20)	p value
CSA of VM (cm^2)	4.17(1.29)	4.13(1.21)	4.28(1.35)	4.25(1.19)	0.980
Peak torque of isometric knee extension (Nm)	70.6(24.98)	86.30(32.99)	81.10(26.37)	82.30(26.06)	0.330
Peak torque of knee extension at 180 °/s (Nm)	26.05(13.43)	27.90(17.26)	28.45(11.86)	33.30(12.10)	0.398
Peak torque of knee extension at 60 °/s (Nm)	54.50(25.56)	55.35(26.92)	55.05(18.34)	56.30(17.26)	0.995

Table 3: The muscle performance of the participants at baseline assessment (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; CSA: cross-sectional area; VM; vastus medialis. The p values were for between-group comparisons.

	LG (n=20)	MG (n=20)	HG (n=20)	CG (n=20)	p value
TUG (s)	13.36(2.62)	13.58(2.61)	12.06(2.92)	12.28(2.76)	0.207
5STS (s)	14.11(7.02)	12.96(2.83)	11.93(2.14)	11.54(3.42)	0.235
10MWT at self-preferred speed (m/s)	0.94(0.13)	0.96(0.19)	1.08(0.22)	1.03(0.17)	0.064
10MWT at maximum speed (m/s)	1.38(0.29)	1.37(0.31)	1.44(0.27)	1.45(0.23)	0.738
KJP	5.29(2.38)	4.84(2.50)	4.74(2.95)	4.55(2.61)	0.831
Tandem test (s)	20.81(20.97)	24.73(9.68)	24.13(10.66)	22.75(10.94)	0.655
OLS with eyes open (s)	10.46(9.79)	14.26(9.93)	13.62(12.09)	17.56(12.49)	0.260
OLS with eyes closed (s)	1.04(1.89)	3.32(3.77)	2.93(3.77)	3.81(3.74)	0.061

Table 4: The physical and balance performance of the participants at baseline assessment (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; TUG: Timed up-and-go test; 5STS: Five-repetition sit-to-stand test; 10MWT: 10-meter walking test. KJP: knee joint position. OLS: one-leg stand. The p values were for between-group comparisons.

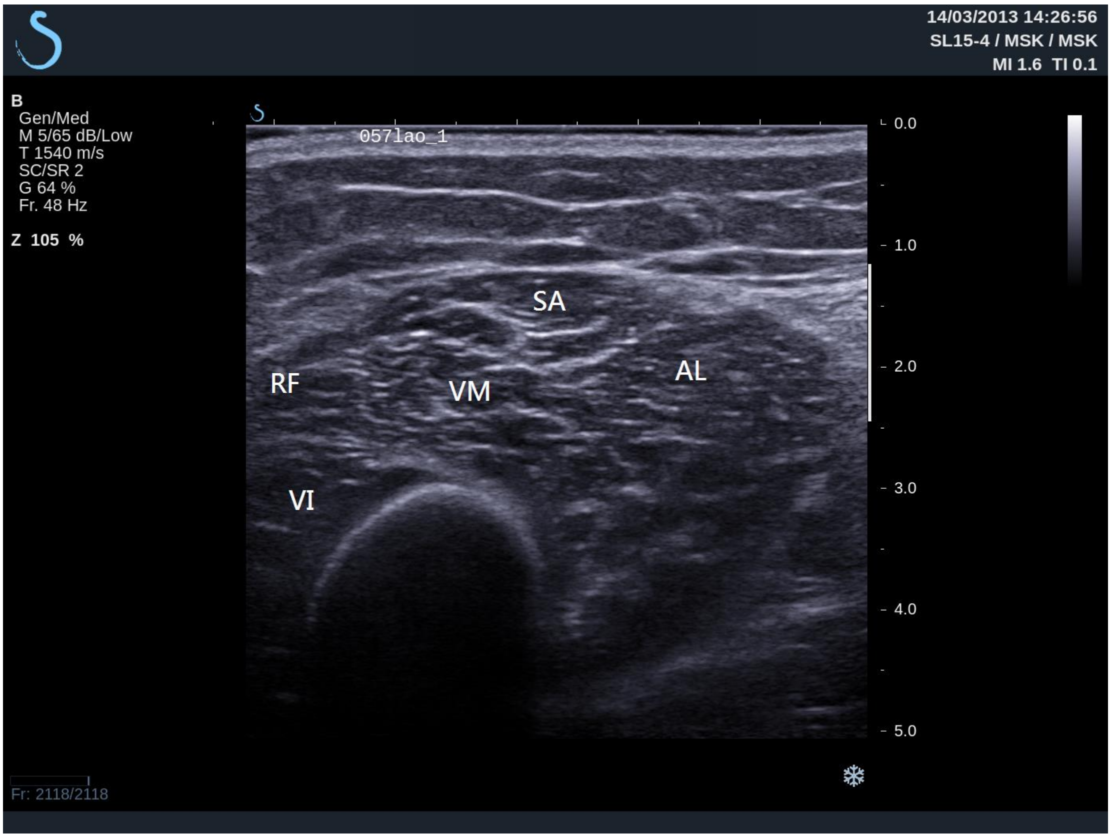

Figure 10: Ultrasound image of 1/3 of the leg length above the base of patella. The length is from anterior superior iliac spine (ASIS) to the medial side of joint line space. RF: Rectus femoris; VI: Vastus intermedius; SA: Sartorius; VM: Vastus medialis; AL: Adductor longus.

	LG (n=20)		MG (n=20)		HG (n=20)		CG (n=20)	
	Mid	Post	Mid	Post	Mid	Post	Mid	Post
CSA of VM (cm^2)	4.14(1.19)	4.20(1.41)	4.14(1.23)	4.18(1.23)	4.28(1.32)	4.26(1.30)	4.19(1.12)	4.11(1.23)
Peak torque of isometric knee extension (Nm)	76.05(25.95)	80.35(24.54)	91.25(23.98)	94.50(34.09)*	89.85(29.56)	90.25(30.67)	82.00(24.16)	81.00(22.99)
Peak torque of knee extension at 180 °/s (Nm)	30.8(13.53)**	33.55(14.07)**	33.25(13.69)	38.60(19.18)**	32.20(10.99)	31.25(13.25)	34.75(12.26)	33.15(13.19)
Peak torque of knee extension at 60 °/s (Nm)	55.80(21.47)	59.45(22.92)*	60.50(19.62)	66.60(27.43)*	60.60(18.30)*	59.25(20.20)	54.20(15.65)	58.50(20.59)

Table 5: The within-group changes on muscle performance in the training period (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; CSA: cross-sectional area; VM; vastus medialis. Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions). The p values were for within-group comparisons versus baseline; * $p<0.05$ and ** $p<0.01$.

	LG (n=20)		MG (n=20)		HG (n=20)		CG (n=20)	
	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up
CSA of VM (cm^2)	4.14(1.32)	4.14(1.36)	4.14(1.20)	4.13(1.09)	4.20(1.38)	4.16(1.36)	4.12(1.28)	4.11(1.27)
Peak torque of isometric knee extension (Nm)	77.35(23.53)*	77.90(23.50)	93.90(33.49)	92.15(31.55)	92.85(34.64)	89.20(34.31)	82.90(24.97)	82.85(23.91)
Peak torque of knee extension at 180 °/s (Nm)	33.75(14.40)**	31.00(13.35)*	35.50(16.28)	37.05(16.99)**	32.20(12.21)	33.95(13.52)*	33.95(15.68)	32.1(8.87)
Peak torque of knee extension at 60 °/s (Nm)	57.50(21.12)	55.50(22.99)	66.70(26.41)**	62.35(23.05)**	62.20(21.56)*&	59.35(22.29)	56.70(19.29)	55.85(17.04)

Table 6: The within-group changes on muscle performance in the follow-up period (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; CSA: cross-sectional area; VM; vastus medialis; Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * $p<0.05$ and ** $p<0.01$, the p values were for within-group comparisons versus baseline; & $p<0.05$, the p values were for within-group comparisons versus post-intervention assessment.

a decrease in CSA of VM without statistical significance ($p>0.05$).

4.3 MUSCLE STRENGTH

4.3.1 Isometric knee extension

There was a significant time effect ($F_{4, 304}=5.15$, $p<0.001$) but not time × group interaction effect ($F_{12, 304}=0.836$, $p=0.614$) in peak torque of isometric knee extension. All three training groups showed more than 15% increase in isometric knee extension peak torque after completing the training sessions. Significant within-group improvement in isometric knee extension was found in MG ($F_{1, 19}=6.822$, $p=0.017$) (Table 5). In the mid-follow-up period, only MG had maintained the improvement, while the other groups showed no significant difference from their respective values measured at baseline. In the 12-week follow-up period, no significant decrease was found in all groups (Table 6).

4.3.2 Isokinetic knee extension at 180 °/s

There were significant time ($F_{4, 304}=10.104$, $p<0.001$) and time × group interaction effects ($F_{12, 304}=2.529$, $p=0.003$) in isokinetic knee extension peak torque at 180 °/s. Both LG and MG had significant improvements in this outcome parameter after 36 training sessions (LG: $F_{1, 19}=16.712$, $p=0.001$; MG: $F_{1, 19}=9.372$, $p=0.006$). During the first half of the training period, only LG had significant increase ($F_{1, 19}=8.342$, $p=0.009$), while both LG and MG had significant increase in the second half of the training period (LG: $F_{1, 19}=6.718$, $p=0.018$; MG: $F_{1, 19}=8.337$, $p=0.009$) (Table

5).

Even there were slight decrease in the follow-up period, all three training groups showed better performance at the end of the follow-up period than at baseline (LG: $F_{1, 19}$=8.218, p=0.010; MG: $F_{1, 19}$=9.518, p=0.006; HG: $F_{1, 19}$=7.126, p=0.015) (Table 6).

Between-group difference in percentage change was significant between MG and CG at post-intervention (mean difference: 66.616, 95%CI: 4.29 to 128.94, p=0.03) and 12-week follow-up completion (mean difference: 54.085, 95%CI: 1.93 to 106.24, p=0.038) (Figure 11).

4.3.3 Isokinetic knee extension at 60 °/s

There was a significant time effect ($F_{4, 304}$=7.084, p<0.001) but not time × group interaction effect ($F_{12, 304}$=1.469, p=0.134) in isokinetic knee extension peak torque at 60 °/s. Both LG and MG showed significant improvements in this outcome parameter after 36 training sessions (LG: $F_{1, 19}$=4.827, p=0.041; MG: $F_{1, 19}$=7.056, p=0.016) (Table 5).

Although without a statistically significant improvement after completion all the training sessions, HG showed a significant increase in the first half of the training period ($F_{1, 19}$=6.055, p=0.024) and first half of the follow-up period ($F_{1, 19}$=4.828, p=0.041), while LG had significant increase in the second half of the training period ($F_{1, 19}$=6.656, p=0.018). MG decreased more than 10% in the second half of the follow-up period ($F_{1, 19}$=6.271, p=0.022), but the muscle performance of this group at the follow-up assessment time point was still better than that at baseline ($F_{1, 19}$=8.952, p=0.007) (Table 6).

Between-group differences were found only in the MG and CG comparison at mid-intervention (mean difference: 28.00, 95%CI: 2.69 to 53.31, p=0.022) and at mid-follow-up (mean difference: 31.50, 95%CI: 0.92 to 62.08, p=0.040). The differences between MG and CG at post-intervention and the follow-up time point were not significant (Post-intervention: mean difference: 34.49, 95%CI: -0.97 to 69.95, p=0.061; follow-up: mean difference: 22.33, 95%CI: -0.93 to 45.59, p=0.067) (Figure 12).

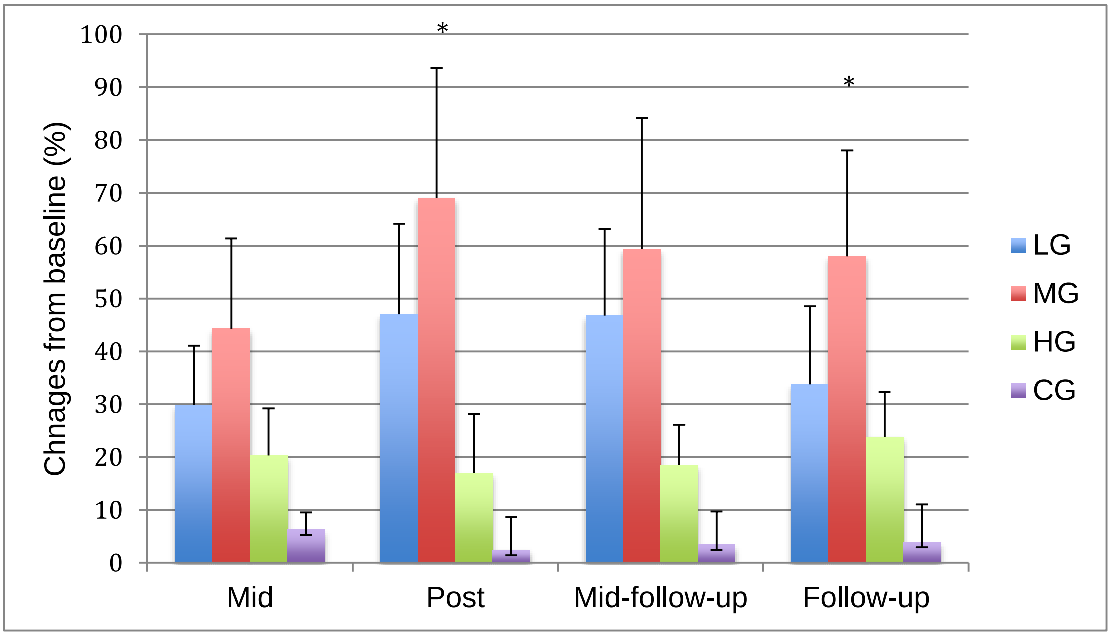

Figure 11: The group differences in percentage changes of knee extension strength at 180 °/s. LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions); Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * p<0.05 vs. CG.

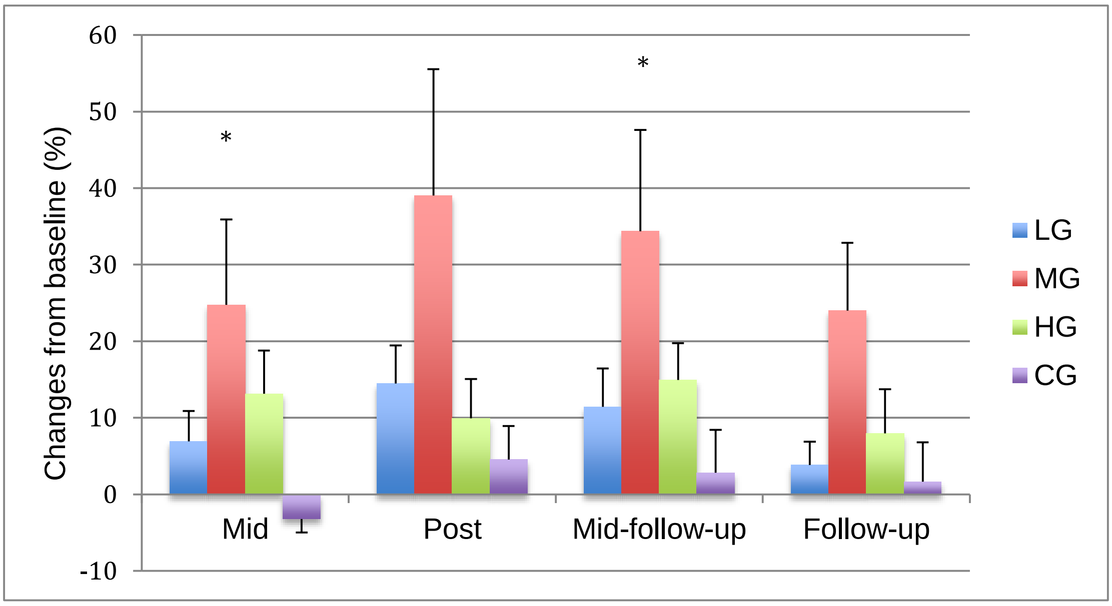

Figure 12: The group differences in percentage changes of knee extension strength at 60°/s. LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions); Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * p<0.05 vs. CG.

4.4 PHYSICAL PERFORMANCE

4.4.1 TUG

There were significant time effect ($F_{4, 304}$=13.413, p<0.001) and time × group interaction effect ($F_{12, 304}$=3.333, p<0.001) in TUG. Both LG and MG showed significant improvements in this outcome parameter after 18 (LG: $F_{1, 19}$=10.761, p=0.004; MG: $F_{1, 19}$=8.386, p=0.009) and 36 training sessions (LG: $F_{1, 19}$=23.468, p<0.001; MG: $F_{1, 19}$=20.492, p<0.001). Meanwhile, the time spent for TUG had also significantly decreased in MG during the second half of the training period ($F_{1, 19}$=9.605, p=0.006) (Table 7).

At the 12-week follow-up assessment, both LG and MG showed significantly longer time than that measured immediately after training (LG: $F_{1, 19}$=16.584, p=0.001; MG: $F_{1, 19}$=13.984, p=0.001). In LG, the increase in time for TUG had mainly occurred in the second half of the follow-up period ($F_{1, 19}$=20.665, p<0.001), whereas in MG, the increase was in the first half of the follow-up period ($F_{1, 19}$=27.501, p<0.001). Although the time for performing TUG became longer after cessation of training, both LG and MG could maintain their improvements than at baseline (LG: $F_{1, 19}$=22.853, p<0.001; MG: $F_{1, 19}$=12.190, p=0.002). No statistically significant difference was found in HG and CG during the training and follow-up period (p>0.05) (Table 8).

	LG (n=20)		MG (n=20)		HG (n=20)		CG (n=20)	
	Mid	Post	Mid	Post	Mid	Post	Mid	Post
TUG (s)	12.26(2.85)**	11.72(2.76)**	12.31(2.01)**	11.32(1.72)**	11.88(2.35)	11.54(2.25)	12.85(3.96)	12.38(3.21)
5STS (s)	12.56(5.45)	11.75(5.26)*	11.12(2.32)**	10.46(2.28)**	11.08(2.24)*	11.05(2.20)*	11.84(3.36)	11.40(2.99)
10MWT at self-preferred speed (m/s)	0.98(0.12)*	1.01(0.15)**	1.00(0.13)	1.05(0.16)*	1.07(0.17)	1.07(0.15)	1.03(0.17)	1.02(0.17)
10MWT at maximum speed (m/s)	1.44(0.28)*	1.48(0.23)*	1.46(0.27)**	1.48(0.27)	1.49(0.24)	1.47(0.26)	1.43(0.30)	1.46(0.27)

Table 7: The within-group changes on physical performance in the training period (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; TUG: Timed up-and-go test; 5STS: Five-repetition sit-to-stand test; 10MWT: 10-meter walking test. Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions). The p values were for within-group comparisons versus baseline; * $p<0.05$ and ** $p<0.01$.

	LG (n=20)		MG (n=20)		HG (n=20)		CG (n=20)	
	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up
TUG (s)	11.78(2.73)**	12.90(2.84)&&	11.90(1.53)**&&	12.02(1.79)**&&	11.54(2.07)	11.76(1.95)	12.00(2.87)	12.63(2.89)
5STS (s)	12.34(5.08)&	13.14(4.94)&&	11.03(2.15)**&	11.41(2.07)*&&	11.33(2.36)	11.54(2.10)&	11.15(3.13)	11.72(2.93)
10MWT at self-preferred speed (m/s)	1.01(0.14)**	0.99(0.13)*	1.04(0.14)*	1.02(0.15)	1.08(0.18)	1.03(0.16)	1.04(0.13)	1.00(0.14)*
10MWT at maximum speed (m/s)	1.43(0.24)&	1.42(0.25)&&	1.43(0.24)	1.40(0.25)&&	1.47(0.25)	1.44(0.22)	1.45(0.21)	1.40(0.23)

Table 8: The within-group changes on physical performance in the follow-up period (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; TUG: Timed up-and-go test; 5STS: Five-repetition sit-to-stand test; 10MWT: 10-meter walking test; Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * $p<0.05$ and ** $p<0.01$, the p values were for within-group comparisons versus baseline; & $p<0.05$ and && $p<0.01$, the p values were for within-group comparisons versus post-intervention assessment.

Between-group differences between MG and CG were found at mid-intervention (mean difference: 12.43, 95%CI: 0.40 to 24.46, p=0.039), post-intervention (mean difference: 15.76, 95%CI: 5.46 to 26.06, p=0.001) and follow-up assessments (mean difference: 13.23, 95%CI: 0.78 to 25.67, p=0.031). The differences between LG and CG at mid- and post-intervention were significant (mid-intervention: mean difference: 12.27, 95%CI: 0.24 to 24.30, p=0.043; post-intervention: mean difference: 12.66, 95%CI: 2.36 to 22.96, p=0.008). At the post-intervention assessment, MG also demonstrated better performance than HG (mean difference: 12.40, 95%CI: 2.10 to 22.70, p=0.010) (Figure 13).

4.4.2 5STS

There was a significant time effect ($F_{4, 304}$=11.799, p<0.001) but not a significant time × group interaction effect ($F_{12, 304}$=1.992, p=0.087) in 5STS. All training groups showed significant improvements in this outcome parameter after 36 training sessions (LG: $F_{1, 19}$=4.993, p=0.038; MG: $F_{1, 19}$=13.995, p=0.001; HG: $F_{1, 19}$=5.816, p=0.026). In MG and HG, significant decreases in time for 5STS were demonstrated in the first half of the training period (MG: $F_{1, 19}$=12.314, p=0.002; HG: $F_{1, 19}$=5.142, p=0.035). The change in LG was mainly in the second half of the training period (LG: $F_{1, 19}$=9.428, p=0.006) (Table 7). Only MG showed significantly better performance at the end of the follow-up period ($F_{1, 19}$=7.963, p=0.011). No improvement was found in CG during training and the follow-up assessment time points (Table 8).

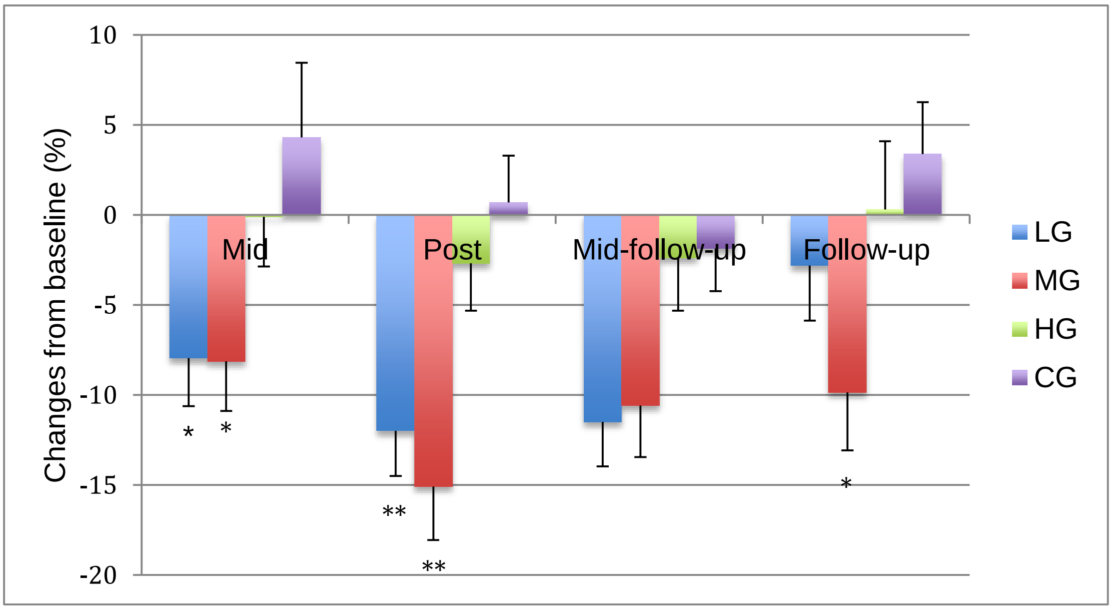

Figure 13: The group differences in percentage changes of Timed-up-and-go test. LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions); Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * p<0.05, ** p<0.01 vs. CG.

Between-group differences in 5STS were only found between MG and CG at mid-intervention (mean difference: 15.71, 95%CI: 3.21 to 28.21, p=0.006) and post-intervention (mean difference: 16.10, 95%CI: 3.04 to 29.16, p=0.008) (Figure 14).

4.4.3 Self-preferred walking speed

There was a significant time effect ($F_{4, 304}$=4.147, p=0.003) but not time × group interaction effect ($F_{12, 304}$=1.873 p=0.056) in self-preferred walking speed. Both LG and MG showed significant improvements in this outcome parameter after 36 training sessions (LG: $F_{1, 19}$=8.683, p=0.008; MG: $F_{1, 19}$=5.594, p=0.029) (Table 7). No significant decreases were found in the 12-week follow-up (Table 8). Between-group difference in self-preferred walking speed was only found in the MG and CG comparison at post-intervention time point (mean difference: 12.03, 95%CI: 0.35 to 23.71, p=0.012) (Figure 15).

4.4.4 Maximum walking speed

There was a significant time effect ($F_{4, 304}$=5.595, p<0.001) but not time × group interaction effect ($F_{12, 304}$=1.021 p=0.429) in maximum walking speed. Both LG and MG showed significant improvements after 18 training sessions (LG: $F_{1, 19}$=4.900, p=0.039; MG: $F_{1, 19}$=11.314, p=0.003) (Table 7). Significant decreases were found in both LG and MG during the 12-week follow-up period (LG: $F_{1, 19}$=9.478, p=0.006; MG: $F_{1, 19}$=8.797, p=0.008). There was 2.97% decrease in CG during the 12-week follow-up period ($F_{1, 19}$=4.849, p=0.040) (Table 8). Between-group difference in maximum walking speed was only found in the MG and CG comparison at mid-intervention (mean difference: 10.02, 95%CI: 0.20 to 19.83, p=0.043) (Figure 16).

4.5 BALANCE

4.5.1 Proprioception

There was neither a significant time effect ($F_{4, 304}$=0.564, p=0.689) nor a time × group interaction effect ($F_{12, 304}$=1.348, p=0.537) in the knee joint position test (Table 9 and 10). No between-group difference was found for this outcome measurement (p>0.05).

4.5.2 Tandem stance

There was not a significant time effect ($F_{4, 304}$=1.893, p=0.112) or a time × group interaction effect ($F_{12, 304}$=1.227, p=0.263) in the tandem stance test (Table 9 and 10). No between-group difference was found in all the group comparisons for this test (p>0.05).

4.5.3 One-leg stand (OLS) with eyes open

There was not a significant time effect ($F_{4, 304}$=2.022, p=0.091) or a time × group interaction effect ($F_{12, 304}$=0.733, p=0.719) in the OLS test with eyes open. Significant increase in time for OLS with eyes open was found in MG at mid- and post-intervention (Mid-intervention: $F_{1, 19}$=6.963, p=0.016; post-intervention: $F_{1, 19}$=5.851, p=0.026) (Table 9). The improvement in MG was preserved for 12 weeks ($F_{1, 19}$=5.282, p=0.033) (Table 10). No between-group difference was found in all the group comparisons for OLS with eyes open (p>0.05).

4.5.4 One-leg stand (OLS) with eyes closed

There were a significant time effect ($F_{4, 304}$=7.948, p=0.001) but not a time × group interaction effect ($F_{12, 304}$=1.466, p=0.136) in the OLS test with eyes closed. Both LG and HG had significant increases after 36 training sessions (LG: $F_{1, 19}$=13.742, p=0.001; HG: $F_{1, 19}$=6.640, p=0.018) (Table 9). However, no between-group difference was found in OLS with eyes closed (p>0.05).

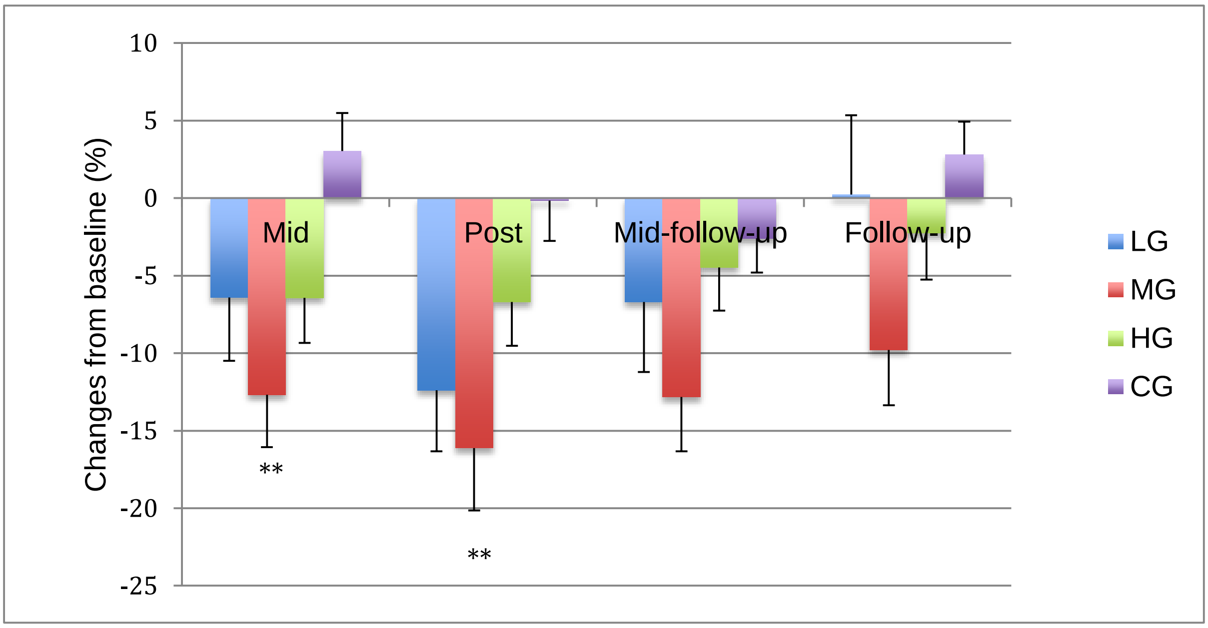

Figure 14: The group differences in percentage changes of Five-repetition sit-to-stand. LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions); Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. ** $p<0.01$ vs. CG

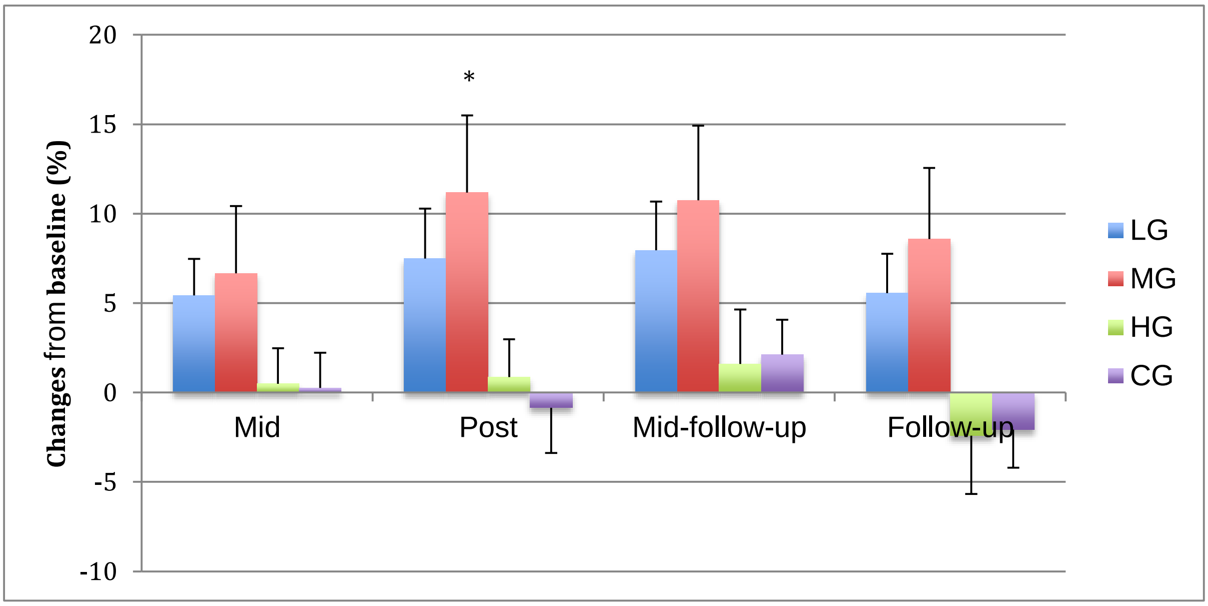

Figure 15: The group differences in percentage changes of self-preferred walking speed. LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions); Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * p<0.05 vs. CG

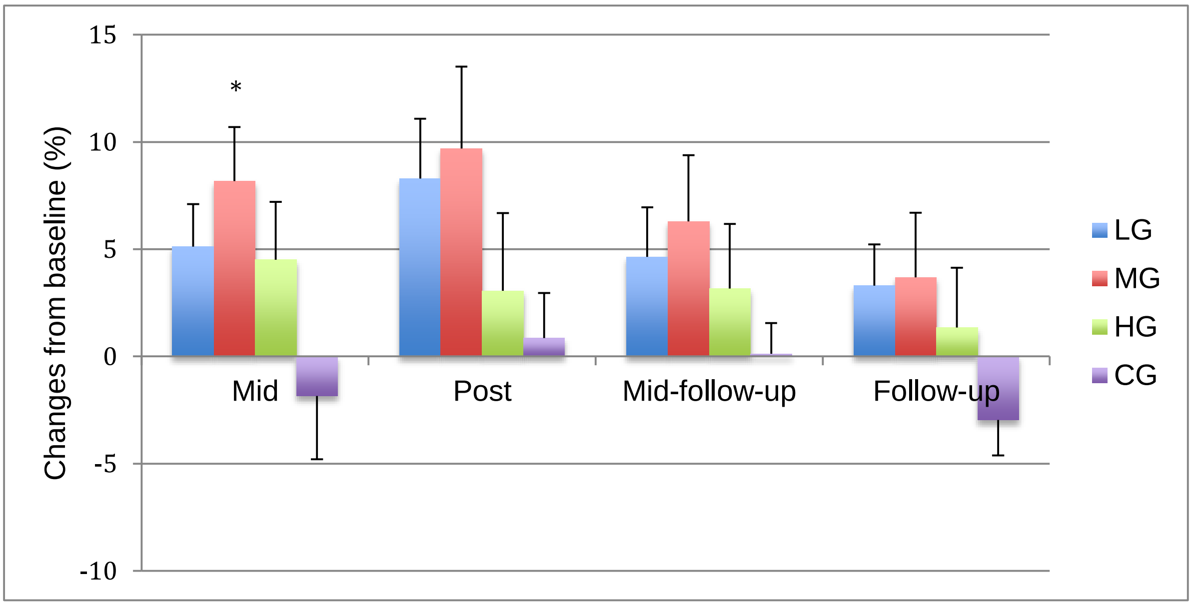

Figure 16: The group differences in percentage changes of maximum walking speed. LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions); Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * p<0.05 vs. CG.

	LG (n=20)		MG (n=20)		HG (n=20)		CG (n=20)	
	Mid	Post	Mid	Post	Mid	Post	Mid	Post
KJP (degree)	4.50(2.07)	4.45(2.31)	4.95(2.59)	5.10(2.14)	4.42(2.15)	4.53(2.53)	4.68(2.48)	4.42(2.38)
Tandem test (s)	20.59(11.40)	23.76(11.11)	23.35(10.23)	25.62(9.22)	24.66(9.98)	24.95(10.22)	22.76(11.70)	22.55(12.03)
OLS with eyes open (s)	12.90(10.85)	11.20(9.24)	18.01(11.52)*	18.13(11.38)*	15.48(11.46)	16.18(11.80)	17.66(13.29)	17.07(12.10)
OLS with eyes closed (s)	1.96(3.21)	2.46(1.85)**	4.89(4.07)	4.53(3.64)	3.77(3.80)	5.42(6.76)*	3.78(3.45)	5.55(5.41)

Table 9: The within-group changes on balance performance in the training period (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; KJP: knee joint position. OLS: one-leg stand; Mid: completion half training session (18 sessions); Post: completion all training session (36 sessions). The p values were for within-group comparisons versus baseline; * $p<0.05$ and ** $p<0.01$.

	LG (n=20)		MG (n=20)		HG (n=20)		CG (n=20)	
	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up	Mid-follow-up	Follow-up
KJP (degree)	5.00(1.95)	4.68(2.15)	5.12(2.56)	5.36(2.44)	4.40(2.50)	4.28(2.20)	4.29(2.22)	4.11(2.13)
Tandem test (s)	24.08(11.04)	19.88(11.63)	20.96(10.82)	22.56(10.83)	23.09(11.09)	23.98(11.13)	22.28(12.36)	21.56(12.28)
OLS with eyes open (s)	11.66(9.18)	10.69(9.56)	16.29(10.58)	17.99(11.86)*	14.67(11.64)	16.22(12.20)	17.73(13.37)	17.02(12.46)
OLS with eyes closed (s)	1.81(1.64)	2.23(2.13)	5.15(3.88)*	3.89(4.18)	6.05(6.69)**	5.47(5.36)**	4.82(5.07)	4.42(4.80)

Table 10: The within-group changes on balance performance in the follow-up period (Mean(SD)). LG: low-frequency group; MG: Medium-frequency group; HG: High-frequency group; CG: Control group; KJP: knee joint position. OLS: one-leg stand; Mid-follow-up: 6 weeks after training cessation; Follow-up: 12 weeks after training cessation. * $p<0.05$ and ** $p<0.01$, the p values were for within-group comparisons versus baseline.

CHAPTER 5 DISCUSSION OF MAIN STUDY

The aims of the present study were: 1) to examine the effect of WBV training for developing muscle performance and physical functions in elderly subjects with sarcopenia; 2) to determine the optimal combinations of frequency and exposure time on muscle performance and physical function in elderly subjects with sarcopenia and 3) to determine whether the changes associated with WBV training could be maintained for 3 months after cessation of training.

This is the first study of WBV training programme on muscle mass, strength, physical function and balance in people with sarcopenia. The present results suggested that WBV is beneficial for improving muscle strength, physical function and balance in older individuals with sarcopenia, but not for muscle mass and proprioception. Among the three training groups of LG, MG and HG, MG appeared to be optimal for improving muscle and physical performance with 36 sessions of training, followed by LG. Therefore, the medium frequency (40Hz) and medium exposure time (360 seconds) combination would be the most effective protocol for muscle and physical performance improvements in older people with sarcopenia. Most outcome variables had better performance than the values at baseline after 12-week cessation of WBV training programme. Compared with the values at post-intervention, the improvements in muscle strength and self-preferred walking speed could be maintained after training cessation.

5.1 MUSCLE MASS

In the previous studies (Bogaerts et al., 2007; Fjeldstad et al., 2009; von Stegel et al., 2012; Verschueren et al., 2004), muscle mass was assessed in different ways in the older adults to investigate the effect of WBV training. One study revealed the muscle volume of right upper leg increased by 3.4% after one year (144 sessions) of WBV training (Bogaerts et al., 2007). Also, the bone free lean tissue mass of the trunk was increased by 2.7% after 8 months (96 sessions) of training (Fjeldstad et al., 2009). Two studies reported that the fat mass had significantly decreased after WBV training (von Stegel et al., 2012; Verschueren et al., 2004). However, Verschueren et al. (2004) stated there was no change in lean body mass after 72 sessions of WBV training, which was consistent with the study conducted by Bautmans et al. (2005).

Few studies had measured the CSA of the lower extremity. Mikhael et al. (2010) reported the CSA of mid-calf was increased by more than 3cm^2 after 39 WBV training sessions, which was clinically meaningful but not statistically significant. Only Machado et al. (2010) examined the CSA of individual leg muscles and found a statistically significant increase of 8.7% for the CSA of VM and BF after 38 training sessions in healthy older women. In the present study, there was no significant increase in CSA of VM after 36 sessions of WBV training in elderly subjects with sarcopenia. Although without statistical significance, the CSA of VM had increased in the three training groups after the study (LG: 0.42%; MG: 1.53%; HG: 0.53%), while those in control group had decreased by 3.24% in the same period.

The main difference between the present study and that of Machado et al. (2010) was the nature of the exercise performed during WBV training. In the study of Machado et al. (2010), the older subjects needed to do dynamic exercise on the platform, such as deep squat, wide stance squat and heel rise, while the participants in the present study only had to maintain a static standing posture during the training, which was same as the study of Mikhael et al. (2010). It might be that the stimulation on the muscle with static standing on the platform was inadequate to induce any significant changes in muscle size in the seniors and dynamic exercise performed during WBV training would lead to additional benefits. Furthermore, as all subjects in this study were older people with sarcopenia who were inclined to lose their muscle mass, it would be difficult for CSA to have large increase with relatively short training duration. Considering the variety of WBV protocols, outcome variables and individual characteristics among these studies, it is too early to negate the potential beneficial effects of WBV training on muscle mass.

Meanwhile, despite the gains in CSA of VM in all training groups during the training period, the muscle size went down immediately after cessation of the training programme in these groups, which was in line with the findings of a previous study that indicated the improvements in muscle volume obtained from one year of WBV training could not be maintained after cessation of the training (Kennis et al., 2013). However, Kennis et al. (2013) was the only study that examined the changes of muscle volume after the training had stopped. More studies are needed to shed lights on the effect of WBV training on muscle mass.

5.2 MUSCLE STRENGTH

There was a significant within-group increase in isometric strength in MG after 36 training sessions with WBV. The present finding is comparable with the study of Machado et al. (2010), which reported isometric knee extension strength had increased after 36 WBV training sessions. Moreover, Roelants et al. (2004b) found significant increase in both isometric and isokinetic strength after 72 WBV training sessions.

In this study, subjects of the WBV group had a significant within-group improvement in isokinetic strength at 180 °/s and 60 °/s of contraction speed. The positive effects of WBV on isokinetic strength had been reported in some previous studies (Roelant et al., 2004b; Verschueren et al., 2004). The present study found group difference in isokinetic strength at 180 °/s was significant both at mid- and post-interventions. For the 60 °/s testing speed, the difference was only significant at mid-intervention. Furthermore, only the isokinetic strength at a testing speed of 180 °/s had significant improvement in the second half of training. Compared with the testing speed of 60 °/s, the improvement in 180 °/s was greater. It is speculated that the fast-twitch muscle fibers in the subjects might have been preferentially stimulated with WBV training, which was consistent with the study of Pollock et al. (2012b) which reported the recruitment threshold of fast-twitch muscle motor units had declined after a 5-minute WBV training programme. These findings suggested that WBV training could be effective for improving the muscle strength in the elderly under higher contraction speed.

5.3 PHYSICAL PERFORMANCE

Increased muscle strength leads to better physical functioning (Pisciottano et al., 2014). Subjects in the WBV groups had significant improvements in TUG, 5STS and 10MWT with self-preferred speed after 36 training sessions. The performance in TUG and 5STS had significantly improved after 18 training sessions, which were in agreement with the report of a very recent study on institutionalized older people, which revealed significant improvements in 5STS performance after 18 sessions of WBV training (Sitjà-Rabert et al., 2015). Another study has reported that the TUG was significantly improved after 24 training sessions (Pollock et al., 2012a).

5.3.1 5STS

All three training groups had shown improvements in 5STS after 36 WBV training sessions, which was consistent with the findings of some previous studies (Raimundo et al., 2009; Zhang et al., 2014), but contrary to some other studies that did not find any changes after WBV training (Bautmans et al., 2005; Mikhael et al., 2010). The reasons for this inconsistence might be the different training protocols. Bautmans et al. (2005) used a very short exposure time of 30-60 seconds for their training. Whereas for Mikhael et al. (2010), they asked their subjects to perform only static standing with a very low vibration frequency of 12Hz and small amplitude of 1mm. These two studies might therefore be considered as not having enough training stimuli to their subjects.

The improvements in 5STS in all three training groups disappeared at 3 months of follow-up. Only MG had significantly better performance than that at baseline. This is the first study to report the performance in 5STS in elderly people with a post-training follow-up period. It is therefore impossible to make comparisons with other studies. Further studies are needed to verify the effects of WBV training on 5STS.

5.3.2 Walking speed

Both LG and MG had significant increase in self-preferred walking speed after 36 WBV training sessions. Between-group difference was found between MG and CG at post-intervention. The present findings are in line with several previous studies that reported an increased speed in walking test after WBV training. Iwamoto et al. (2012) had found the time decreased by 13.3% in 10m walking test after 6 months of WBV training. Also, Bogaerts et al. (2011) reported a 10.08% increase in walking speed with 6 months of WBV training. However, a study comparing WBV training with a walking exercise programme has demonstrated that the walking programme was more efficient than the WBV training for improving walking speed (Raimundo et al., 2009). It is reasonable because the walking programme was particularly designed to improve walking performance thus the outcome measure has accurately reflected that.

In this study, both LG and MG showed significant increase in the first half of the training period (18 sessions), but not the second half. Between-group difference was only found between MG and CG at mid-intervention. In the past, only one study had investigated the influence of WBV training on maximum walking speed (Bogaerts et al., 2011). It revealed the maximum walking speed had increased by 3.15% after 72 sessions of WBV training. Previous studies had reported that increase in muscle strength could predict faster walking speed (Janssen et al., 2002; Roubenoff, 2001). In this study, the muscle strength in MG continually increased in the second half of training period, but the maximum walking speed did not improve in parallel, which echoed with a previous finding that the increase in muscle strength would not necessarily couple with an increase in walking speed when muscle strength was well above the minimum required level (Ferrucci et al., 1997).

5.3.3 TUG

The TUG test was the most common assessment for mobility in elderly population, especially in the frail older subjects. In the present study, significant improvement in TUG was found in both LG and MG, which revealed the effective training frequency was ranged from 20Hz to 40Hz for TUG. In fact, the positive effects of WBV training on TUG had been demonstrated in several other studies. Pollock et al. (2012a) reported a 25.5 % decrease in time of completing TUG after 24 sessions of WBV training. Machado et al. (2010) found a 9% improvement in TUG performance in the WBV training group after 38 training sessions, while the control group had worsened during the studied period. Recently, Zhang et al. (2013) examined the effectiveness of WBV training in the Chinese older people and found the time for completing TUG to have decreased from 40.47 to 21.34 seconds after 8 weeks of WBV training.

However, some studies found no change in TUG after long-term WBV training (Bautmans et al., 2005; Beaudart et al., 2013). With various training protocols, the response to WBV training would be different. For the two studies that indicated no effects of WBV training on TUG, it should be noted that the total exposure time of their training programme was shorter than those studies that found positive effects with WBV. As exposure time equals to the product of duration of each session and number of sessions, therefore the decrease in either one would reduce the exposure time. Beaudart et al. (2013) only had 75 seconds for one session and Bautmans et al. (2005) only had 18 training sessions, which were the shortest exposure time among the reported studies. Thus, it is advisable to conduct WBV training with adequate exposure time to reach the needed threshold level of stimulation for mobility improvements.

Although the time for completing TUG at follow-up assessment was significantly decreased than that at post-intervention assessment, it still had better performance than that at baseline, which indicated the training-induced improvements could partly maintained after 3 months of follow-up. Only one study had conducted follow-up assessment for the participants after cessation of training and found significant increases in time of completing TUG during a 6-month follow-up period, which was worse than that at baseline (Pollock et al., 2012a). The explanation for the disagreement on the comparison between pre-intervention and follow-up assessments might be the training duration and follow-up period. The participants in the study of Pollock et al. (2012a) had only received 24 training sessions but the follow-up period was 6 months, which was longer than the training period. It was probably that the training-induced improvements would totally disappeared after 6 months of follow-up. However, in this study, the follow-up period was 3 months, which was equal to the training period. According to the findings in this and the previous studies, WBV training could improve TUG in older people and the maintenance of improvements would depend on the duration of training and follow-up period.

In this study, MG also had significantly better performance than HG. According to a previous study, the high frequency stimulations should have greater improvements (Marín & Rhea, 2010). However, HG had poorer performance than MG, which might be attributed to the inadequate exposure time. As the same number of vibration was applied to all training groups, the larger frequency would lead to the shorter exposure time. HG only had 240 seconds for each session, while MG had 360 seconds and LG had 720 seconds. It is suggestive that adequate exposure time is essential to the effectiveness of WBV training on TUG. Also, those studies that reported the positive effects of WBV had applied the frequency ranged from 6-40Hz, which is inclusive of the frequencies used in LG and MG of this study, but not HG. The frequency applied in HG was 60Hz, which might be too high to elicit the improvements in physical performance.

In this study, the improvements were significant in TUG, 5STS and self-preferred walking speed in MG after 36 sessions of WBV training. However, in the first half of training period (after 18 training sessions), significant improvement was only found in TUG and 5STS, but not in self-preferred speed. It is well known that TUG contained several action components of standing up, walking, turning and sitting down. Therefore, it is speculated the improved completion time of TUG in the first half of training might be attributed to the less time spent in standing up. Also, the coordination and balance might play a role in TUG. A systematic review with meta-analysis by Lam et al. (2012) has reported that WBV could improve balance in the elderly. However, the effects of WBV on coordination of old people were still unclear. It is therefore necessary to examine the effects of WBV on this aspect.

5.4 BALANCE

5.4.1 Proprioception

Very few studies had investigated the effects of long-term WBV training on proprioception. Some researchers have demonstrated that there were no changes in joint position sense after WBV training (Bogaerts et al., 2011; Hiroshige et al., 2014). Hiroshige et al. (2014) reported no significant changes in joint proprioception for both young and elderly subjects after 8 weeks of WBV training. Prior to that report, Bogaerts et al. (2011) had demonstrated that even 6 months of WBV training could not improve the proprioception in the knee in older adults (Bogaerts et al., 2011). The present finding is in agreement with the previous reports that no changes in knee joint position were found in any of the training groups. Based on these findings, it is suggestive that WBV may not be a suitable method for training proprioceptive sense.

5.4.2 Tandem stance and one-leg stand (OLS)

Tandem stance test and OLS were used to evaluate the effects of WBV training on balance in older people with sarcopenia in this study. No significant increase in time of tandem standing was found after WBV training, which was in agreement with a previous investigation that also found no change in movement velocity of center of pressure during tandem stance after 108 sessions of WBV training (Stolzenberg et al., 2013a).

In this study, the OLS with eyes closed improved in LG and HG after WBV training, while the OLS with eyes open only improved in MG. This finding was in partial agreement with some previous studies. Gusi et al. (2006) reported the time for OLS with eyes closed increased after 96 sessions of training. Rees et al. (2009) also found the OLS steadiness improved after 24 WBV training sessions and they stated the improvements in OLS steadiness were dramatically influenced by the initial level of performance of the participants. The poorer initial scores would result in greater changes (Rees et al., 2009). A systematic review by Lam et al. (2012) revealed the WBV training had positive effects on balance in older people. In that review, the researcher used Tinetti test as the outcome measure to assess the effects of WBV training on balance. However, the increase in balance score might be attributed to the increases in sitting balance, turning balance, but not standing balance. Thus, according to the existing studies, it is difficult to draw a conclusion on the effect of WBV training on tandem and OLS tests.

5.5 OPTIMAL COMBINATION

To the best knowledge of the author, this is the first report to explore the optimal combination of frequency and exposure time of WBV training in people with sarcopenia. Since there has not been any study investigating the optimal combination of frequency and exposure time of WBV training, this following discussion would compare the present results with the previous studies on frequency and exposure time separately. In the present study, although both the participants trained with 20Hz and 40Hz have significant increases in muscle performance after 36 sessions of WBV training, only the medium vibration frequency (40Hz) had achieved an improvement level to reveal difference from the other groups on most muscle and physical performance. To synthesize the findings of this study, there is evidence to postulate the most effective frequency for muscle performance improvement in WBV training programme might range between 20Hz and 40Hz. When compared with 20Hz, the more efficient frequency might be 40Hz. There were few studies that had investigated the optimal frequency of long-term WBV training on muscle performance and no agreement was reached. One study had controlled the acceleration, the product of frequency and amplitude, and found no difference in muscle performance in young adults between low- (18Hz) and high-frequency (32Hz) of vibration (Chen et al., 2014). Another study only controlled the exposure time and revealed that 50Hz with 4mm was more effective than 30Hz with 2mm for improving muscle strength in active males after 6 weeks of WBV training (Petit et al., 2010). Considering the various training protocols, it is difficult to make comparisons among these studies.

Thus, more researches are needed to verify the optimal frequency of the WBV training.

Despite the optimal frequency of long-term WBV training has not been well investigated, the optimal frequency of acute WBV training in young people was reported in several studies. Turner et al. (2011) found the young participants trained with 40Hz had presented with better counter-movement jump performance than those trained with lower frequencies of 30Hz and 35Hz when the same amplitude and duration were applied. Lienhard et al. (2014) reported that young people trained with 40Hz had significantly higher muscle activity in the soleus muscle, while the training with 35Hz had led to higher muscle activity in vastus laterlis and vastus medialis muscle, and there was no change in muscle activity of rectus femoris when frequency increased from 25Hz to 40Hz. The finding of Lienhard et al. (2014) is suggestive that the optimal frequency should be determined for individual muscles. Only one study had investigated the optimal frequency of WBV training in older people and revealed that 35Hz was the most effective frequency for older people (Carlucci et al., 2015).

According to the literature, there were even fewer researchers who had investigated the optimal exposure time of WBV training than the optimal frequency. Different research groups suggested various exposure times. In this study, 90 seconds was the most effective exposure time for one set of WBV training. Since each training session consisted of 4 sets, the optimal exposure time for one session was 360 seconds, which was consistent with a previous study reporting that 360 seconds resulted in a higher jump height than the exposure times of 180 and 540 seconds (Da Silva-Grigoletto et al., 2011). However, for the optimal duration of one set, there was no consensus. Da Silva-Grigoletto et al. (2011) found the participants with 60 seconds per set increased the height of counter-movement and squat jumps, while those with 90 and 30 seconds showed decreases in jump height and power (Da Silva-Grigoletto et al., 2011). Adams et al. (2009) found no difference between the groups with set durations of 30, 45 and 60 seconds in muscle performance (Adams et al., 2009). Whereas, Stewart et al. (2009) advocated 120 seconds to be the optimal duration for one set, while longer durations of 240 and 360 seconds would lead to the decreases by 2.7% and 6% in knee extensor strength, respectively. In light of the insufficient evidence, it is impossible to determine the optimal exposure time of WBV.

Besides exposure time for one training session, the number of training sessions per week is also important when the total duration of the training programme (number of training week) is fixed. Only one study had investigated the optimal number of sessions per week for WBV training on physical performance and balance. Furness and Maschette (2009) found 3 sessions per week for 6 weeks was the most effective protocol for improving TUG, sit-to-stand test and Tinetti test score than one or two sessions per week. In the present study, both 20Hz with 720 seconds and 40Hz with 360 seconds had positive effects on TUG in the people with sarcopenia, while for 5STS and walking speed, only 40Hz with 360 seconds showed a positive outcome.

5.6 LIMITATIONS

There are a few limitations in this study. First, there was no blinding of the subjects or the researcher. However, since no study had investigated the optimal combination of frequency and time of WBV on muscle performance with identical number of vibration in the people with sarcopenia, there was not an expectation as to which was the optimal combination of frequency and time of WBV for combating sarcopenia. Therefore, the lack of blinding would not lead to a bias in the outcome. Furthermore, all assessments were objective, thus assessors could not influence the results.

Second, due to practical consideration, this study only included the frequencies of 20Hz, 40Hz and 60Hz for exploring the optimal frequency of WBV training. In this condition, it can be concluded that 40Hz combined with 360 seconds was more effective than 20Hz with 720 seconds and 60Hz with 240 seconds. Whether a gap of 20Hz between each training group can be further narrowed down to smaller ranges in future studies when adequate resources are available to study more groups.

Third, although the participants were seniors with sarcopenia, some of them were still in the early stage of sarcopenia, which means they were physically active. The subjects who had poorer conditions could not endure the 36 training sessions and had dropped out. Therefore, findings of this study may not be generalized to the people with poorer physical conditions.

Fourth, the tests and variables used for evaluating balance might not be sensitive to detect the small changes resulting from the training. However, considering the physical conditions and limited resources, tandem timing and OLS were used as they were the most reliable and valid in the clinical evaluation for balance. In future studies, changes in the area of center of pressure should be examined as undertaking tandem stance and OLS tests.

Finally, there were only control group without any intervention in this study. The differences between control group and the training groups may not only due to WBV, but also static squatting on WBV platform. It would have been better to have a placebo group that only received static squatting training without WBV. The effects of static squatting could then be examined with this design.

5.7 CONCLUSION

Both low frequency with long exposure time and medium frequency with medium exposure time could effectively improve isokinetic strength with high- and low-angular velocity after 36 training sessions. The improvements in the group with high frequency and short exposure time were not obvious. In conclusion, a 12-week WBV training programme could improve isokinetic muscle strength, TUG and 5STS in older individuals with sarcopenia.

As compared with other combinations, the medium frequency (40Hz) and medium exposure time (360 seconds) combination was the most efficient for improving muscle and physical performance. Most parameters tested at the follow-up assessment (24 weeks) had better performance than at baseline. It is essential to find out the optimal duration of training cessation that would not wash out the training effect so as to inform clinician on designing their exercise training regime and schedule.

5.8 FURTHER ISSUE TO ADDRESS

With the positive outcome of medium frequency and medium duration of WBV training protocol on muscle performance, it is necessary to explore the underlying mechanism of how this training protocol has worked. The next chapter reports on a pilot study that explored the neuromotor basis of this training protocol on the recruitment pattern of the quadriceps muscles as so to determine whether the effect is on the muscle or it has enhanced the motor unit activation that drives the muscle fibers.

CHAPTER 6 EXPLORING AN UNDERLYING MECHANISM OF WHOLE BODY VIBRATION TRAINING ON MUSCLE PERFORMANCE

6.1 INTRODUCTION

6.1.1 Age-related changes in motor units

As people age, the physiology of the motor units gradually change, which would lead to age-related loss of the muscle mass and impairment of force production (Keen et al., 1994). The age-related physiological changes of motor units include loss of motor neuron, increased nerve to muscle innervation ratio and remodeled motor units (Doherty & Brown, 1997; McComas et al., 1993). McComas et al. (1993) applied electrophysiological techniques to estimate the number of motor unit of extensor digitorum brevis muscle in the thenar eminence and reported the number of motor units was significantly less in older people than younger people, which provided a strong evidence for the loss of motor unit with aging. A few years later, Doherty and Brown (1997) examined the contractile properties of motor unit of thenar muscle and found the aged people had slower twitch contraction and larger twitch tensions than the young counterparts.

Some researchers had measured the motor unit discharge rate to examine the age-related changes of motor unit in different age groups. Connelly et al. (1999) used needle electrodes to record maximal motor unit discharge rate and found that older people had decreased motor unit discharge rate than the young ones. More recently, Kallio et al. (2012) also reported a similar finding that the motor unit discharge rate of soleus was lower in older people, which had led to decreased muscle strength and impaired balance control. The evidence suggested that motor unit discharge rate decreased in older people, which would lead to impaired motor performance.

6.1.2 The changes in motor neurons after training

It is known that suitable type and sufficient level of exercise training would benefit the muscle mass and strength in man (Machado et al., 2010; Scanlon et al., 2014; Sipilä & Suominen, 1995). However, many studies had reported that the increase in muscle strength was not in line with the changes in muscle mass (Goodpaster et al., 2006; Maughan et al., 1983; Mikhael et al., 2010). An early study by Moritani and DeVries (1979) found muscle strength improved very early in a training programme, which preceded the muscle size improvement. Actually, muscle hypertrophy would not be noticeable until after eight weeks of exercise training, which indicated there would be other reasons for improvement of muscle strength in the early phase of training.

Considering the non-parallel relationship between the training-induced changes in muscle mass and strength, neural adaptation would be a contributor to the increased muscle strength in the early phase of training. A strong evidence of neural adaptation after training is the increase in EMG amplitude, which indicates the neural drive to muscle fiber was increased (Aagaard et al., 2002; Häkkinen et al., 2000). However, EMG is a measurement that could only detect the changes of muscle activity, but not the motor unit firing patterns. The training-induced changes in motor unit firing rate were only investigated in very few studies (Kamen & Knight, 2004; Patten et al., 2001). Kamen and Knight (2004) used needle electrodes to record the maximal motor unit discharge rate of tibialis anterior on the dominant leg before and after 6 weeks of strength training and found the maximal motor unit discharge rate had increased after strength training in both older and younger people.

The use of needle electrodes involves an invasive technique thus it is not widely used. Compared to needle electrodes recording, twitch interpolation is relatively more safe and simple with the logistics. Twitch interpolation is a technique that involves electrical stimulation to the muscle nerve with a single pulse during a maximal voluntary contraction to elicit an increment of force (Herbert & Gandevia, 1999). The interpolated twitch ratio (%) was calculated to represent the level of excitation of motor neuron pool (Gandevia, 2001; Molley et al., 2006). The formula [1 – (Superimposed twitch / Control twitch)] x 100% was commonly used to calculate the interpolated twitch ratio (Allen et al., 1995). The superimposed twitch was the force increment produced during a maximal contraction at the time of stimulation and the control twitch was the force evoked by the stimulation with a resting muscle.

Twitch interpolation has been used to explore the neural adaptations after exercise training in human muscle (Herbert et al., 1998; Knight & Kamen, 2001; Petit et al., 2010; Scaglioni et al., 2002). Some studies reported the voluntary activation of muscles increased after several weeks of training (Knight & Kamen, 2001; Scaglioni et al., 2002), while some others had found no training-induced changes in the voluntary activation of muscles (Herbert et al., 1998; Petit et al., 2010). The reasons for the discrepancies might be due to the different original level of voluntary activation in the subjects. For subjects who could achieve high level of voluntary activation, there would be minimal increase in force output with the superimposed twitch, whereas people who achieve relatively low level of voluntary activation would have more room for the increase in force output with the superimposed twitch. Therefore, if a type of training facilitated motor recruitment as compared to another type that facilitated muscle contractile performance beyond the level of excitation-contraction coupling, the former might reveal a higher twitch-interpolation ratio after training than the latter one. Although there is no agreement in the previous studies, it is accepted that twitch interpolation is a relatively direct and accessible method for assessing the level of excitation of motor neuron pool in human beings (Shield & Zhou, 2004) thus this technique is deemed suitable to assess the change in motor neuron recruitment before and after an exercise training programme.

6.1.3 The possible mechanisms of WBV training

The mechanical movement of WBV causes a stimulus to the human body in standing or when one performs various movements on a platform that generates vibration at a frequency below 100Hz (Wilcock et al., 2009). This mechanical stimulus results in muscle contractions similar to the tonic vibration reflex (TVR) (Delecluse et al., 2003). The TVR has been suggested as a plausible underlying mechanism that explains the benefits of WBV training (Cardinale & Bosco, 2003). The vibration stimulates muscle spindle discharges, which activate the monosynaptic and polysynaptic reflex arcs through the afferent nerve fibers causing muscle contraction.

The evidence of TVR was found with local vibration in the early 1970's when

Burke et al. studied 10 subjects and found that the tonic contraction reached a plateau level between 20 and 60 seconds after applying the vibration to the muscle belly. They also reported that the increased muscle stretch would lead to the larger TVR, which implied that the primary endings of muscle spindle would be activated by vibration, while both the primary and secondary endings would be activated by the muscle strength during vibration (Burke et al., 1972).

Recently, TVR has also been found during WBV training. Zaidell et al. (2013) used EMG to record the muscle activity of soleus and tibialis anterior under two different situations of WBV training versus localized vibration. After comparing the EMG data of the two muscles, they found no difference between these two types of vibration training. They therefore concluded that TVR was present in WBV training as it did in local vibration training. In view of this finding, TVR is at least one mechanism that accounts for the effects of WBV training for the improvement of muscle performance.

Besides TVR, neural adaption was speculated as another possible underlying mechanism of WBV training (Cardinale & Bosco, 2003; Rittweger, 2010). As discussed in section 1.2.2 and 1.2.3, many studies had reported an increased EMG amplitude with WBV training in both young and old subjects (Giombini et al., 2013; Pollock et al., 2010; Rønnestad et al., 2012), but only one study had investigated the changes in voluntary activation of muscles after long-term WBV training with twitch interpolation technique and found there was no significant changes after 6 weeks of WBV training (Petit et al., 2010). However, it is worth noting that the subjects in the study of Petit et al. (2010) were physically active college students who were able to voluntarily activate their muscles at high level, which could have masked the change after training. Thus, their finding may not be generalized to older subjects suffering from sarcopenia. The aim of this experiment was to investigate the effect of 12 weeks of WBV training on the voluntary activation of quadriceps muscles in older people with sarcopenia.

6.2 OBJECTIVES AND HYPOTHESES

6.2.1 Objectives

1) To investigate the test-retest reliability of twitch interpolation in the elderly with sarcopenia.

2) To explore the effect of a 12-week WBV training programme on the voluntary activation of quadriceps in the elderly with sarcopenia.

6.2.2 Hypotheses

1) There would be high test-retest reliability of twitch interpolation in the studied population.

2) A 12-week of WBV training programme would increase the voluntary activation of quadriceps in the elderly with sarcopenia.

6.3 METHODS

6.3.1 Subjects and intervention

The diagnosis of sarcopenia for screening subjects was described in section 2.2.1.

Two sessions of measurements were conducted on two separate days to examine the test-retest reliability of twitch interpolation. The interval of the testing sessions was 7 days apart and in order to avoid the circadian effect, the tests were conducted in the same hour of the two days.

After establishing the test-retest reliability for the twitch interpolation technique, the recruited subjects were randomly allocated into WBV training group (WBV) and control group (CON). Each participating subject gave voluntary informed written consent before participating the study (Appendix I or II).

Considering the findings of the main study, the training protocol for the WBV was same as the one for the medium frequency group (MG), which was mentioned in section 3.2. The reason for using the WBV parameters of MG is because this training protocol has demonstrated the best training effect among the three WBV training protocols.

6.3.2 Neuromotor recruitment testing

The neuromotor recruitment of the quadriceps muscle was tested using the twitch interpolation technique. The test was conducted in each group before and after 12 weeks of training to measure the changes in motor unit activation in the quadriceps of the dominant leg (Molloy et al., 2006). Participants sat on an isokinetic testing chair with hip at 80° and knee at 90° of flexion and performed a maximal isometric knee extension. The knee extension force was simultaneously shown on a digital indicator (AD-4532A, A&D company, Tokyo, Japan) and converted to digital output by a

12-bit analog-to-digital converter (NI USB-6211, National Instruments, Austin, USA) with sampling frequency at 1 kHz. A custom-made stimulation electrode connected to an electrical stimulator (S88 Square Pulse Stimulator, Grass Technologies, Warwick, USA) was placed on the femoral nerve trunk after the skin was cleansed with exfoliating scrub (Figure 17). The location of femoral artery was firstly determined by palpation within the inguinal triangle. The pulse from the femoral artery was detected and this was used as the landmark to locate the femoral nerve, which sits immediately lateral to the femoral artery. Then several submaximal electrical stimulations were delivered along the course of the femoral nerve trunk to search the best location of applying the stimulation pulse and determine the supermaximal electrical stimulation that the subjects could tolerate.

Participants were asked to perform 3 maximum voluntary extensions (MVCs), which lasted for 2-3 seconds. When the peak force was obtained, a supramaximal electrical stimulation was delivered to the femoral nerve trunk to trigger a superimposed quadriceps muscle twitch. Afterwards, the participant would relax the quadriceps for 5 seconds and another supramaximal electrical stimulation was applied to the femoral nerve trunk to elicit a control muscle twitch of the quadriceps. The data were stored for calculating the interpolated twitch ratio.

6.3.3 Statistical analysis

Descriptive analyses were reported as means ± standard deviations. Test-retest reliability was evaluated by intraclass correlation coefficient (ICC) of model (3,1) to analyze the reliability of twitch interpolation. The 95% confidence interval was also reported. The interpretations of the ICC values were made according to the study of Pittenger (2003).

Kolmogorov-Smirnov test was used to examine whether the data followed the normal distribution. To compare the baseline characteristics of the two groups, independent-sample t-test was conducted. Paired t-test was used to investigate the within-group changes. The changes of interpolated twitch ratio were calculated as Post minus Pre in both groups. Independent-sample t-test was performed to compare the between-group difference in the changes of interpolated twitch ratio.

Figure 17: The participants undertaking twitch interpolation test. The stimulating electrode was placed over the femoral nerve trunk underneath the femoral triangle.

6.4 RESULTS

The $ICC_{(3,1)}$ value of twitch interpolation was 0.811. According to Pittenger (2003), ICCs between 0.81 and 1.0 were considered to be excellent, thus the test-retest reliability of twitch interpolation in older people with sarcopenia was excellent. The present finding suggested twitch interpolation was reliable to be used for examining the training-induced changes in the voluntary activation of quadriceps muscles.

Twelve subjects were recruited to this study. Two subjects withdrew due to the pain of twitch interpolation test. Finally ten subjects completed this study. There was no significant difference between the two groups at baseline (Table 11). After 12 weeks of WBV training, the interpolated twitch ratio increased in the WBV group and decreased in the control group. Although there was no significant difference between WBV and control groups on the absolute values of the interpolated twitch ratio after 12 weeks of training, the changed values of ratio were significantly different between the two groups (Table 12).

	WBV (n=5)	CON (n=5)	p value
Age (yrs)	73.8 (5)	74.8(7)	0.801
Height (cm)	151.6(7.9)	157.4(5.7)	0.221
Weight (kg)	51.6(6.1)	52.8(4.9)	0.737
BMI (kg/m^2)	22.63(3.72)	21.32(1.55)	0.487
SMI (kg/m^2)	6.51(1.26)	6.31(1.25)	0.805

Table 11: The characteristics of participants at baseline assessment (Mean(SD)). WBV: whole body vibration group; CON: control group; BMI: body mass index; SMI: skeletal mass index. The p values were for between group comparisons.

	WBV (n=5)	CON (n=5)	p value
Pre	71.90%(9.4%)	73.20%(5.3%)	0.649
Post	74.20%(9.6%)	72.10%(5.7%)	0.823
Delta	1.33%(2.7%)	-2.06%(-1.7%)	0.044

Table 12: The effects of a 12-week WBV training on interpolated twitch ratio (Mean(SD)). WBV: whole body vibration group; CON: control group; Pre: before training; Post: after completion of 36 training sessions; Delta: the changes of interpolated twitch ratio between before and after training; BMI: body mass index; SMI: skeletal mass index. The p values were for between group comparisons.

6.5 DISCUSSION

In this study, the rest-retest reliability of twitch interpolation in older people with sarcopenia was excellent, which indicated it is reliable to use the twitch interpolation technique to determine the voluntary activation of quadriceps muscles. A previous study examining the reliability of twitch interpolation on femoral nerve in 8 young people had found the test-retest reliability was 0.78, which was similar to the present finding (Behm et al., 1996). It is suggestive that twitch interpolation on the femoral nerve is a reliable technique for assessing the voluntary activation both in young and older people.

In the present study, the interpolated twitch ratio increased from 71.9% to 73.2% in the subjects with 12-week WBV training, while those in the control group showed a decrease by 2.1%. Since no previous study had investigated the interpolated twitch ratio after WBV training in older people with sarcopenia, this is the first study to explore the training-induced changes in the motor units activation levels in older people with sarcopenia.

According to the literature, only one study had applied the twitch interpolation technique to investigate the effect of a 6-week WBV training programme on voluntary activation of knee extensors (Petit et al., 2010). They found voluntary muscle activation did not change after 6 weeks of WBV training programme. However, the subjects participated in that study were active college students, who already had high level of voluntary activation before training. In the present study, the subjects were older people with sarcopenia, who had lower level of voluntary muscle activation than their young and healthy counterparts (McComas et al., 1993). Therefore, the different findings between the present study and that of Petit et al. (2010) are not surprising due to the different characteristics of subjects.

One possible mechanism of the WBV training effect is due to TVR. Some studies had proven the existence of TVR during WBV vibration (Shinohara et al., 2005; Zaidell et al., 2013). Zaidell et al. (2013) reported EMG amplitudes of soleus and tibialis anterior increased during WBV training. Shinohara et al. (2005) examined the maximal motor unit discharge rate of the first dorsal interosseous muscle in 32 young adults after 30 minutes of vibration training with 75Hz and reported the discharge rate to have increased after vibration training. Furthermore, they also found that the amplitude of the short-latency component of the stretch reflex increased after vibration. The WBV movements stimulate the sensory input of muscles with external vibration, which would increase the excitatory input to α motor neurons though Ia afferents in muscle spindle (Shinohara et al., 2005). Since Ia afferents from muscle spindle is sensitive to the changes of muscle length, vibration would activate the homonymous motor units, which induce the muscle strength increase (Eklund &

Hagbarth, 1966).

However, TVR might not be the only underlying mechanism of WBV training. Considering WBV training is a form of exercise training such that neural adaptations would also occur after long-term of WBV training. Roll et al. (1989) and Ushiyama et al. (2005) found the H-reflex amplitude would decrease after prolonged vibration. The H-reflex is usually used for assessing the excitability of motor neurons which in turn determines the motor unit activation (Schieppati, 1987). The changes in H-reflex after vibration hinted that there could be some other possible mechanisms underlying the effects of WBV.

In the present study, the increase of the twitch interpolation ratio in the quadriceps after 12 weeks of WBV training indicated WBV training could facilitate the central motor unit drive during voluntary muscle contraction. This study has provided the first piece of evidence that long-term WBV training is effective on facilitating central drive. Although there was no study examining the effect of long-term WBV training on central motor drive, there were two previous studies which reported the central drive of muscles was facilitated in both young and old subjects after long-term training (Scaglioni et al., 2002; Knight & Kamen, 2001). Scaglioni et al. (2002) examined the voluntary activation of plantar flexor of 14 healthy older adults and found the voluntary activation significantly increased after 16 weeks of strength training. Knight and Kamen (2001) reported the voluntary activation of knee extensors increased in both young and old subjects after 6 weeks of resistance training.

However, some studies applied the twitch interpolation technique and reported resistance training could not induce any increase in voluntary activation in healthy young and old subjects (Herbert et al., 1998; Sale et al., 1992). The explanations for the divergent findings might be due to the difference in the subjects and training protocols in the studies. Herbert et al. (1998) reported the voluntary activation of 44 college students had only marginally increased from 96.2% to 96.9% after 8 weeks of resistance training. Since those subjects were active young people, the voluntary activation of their muscles was already at a high level before training, thus they would have limited capacity for further improvement. Sale et al. (1992) trained their subjects with dynamic exercise and found no change in isometric strength and voluntary activation. Considering the principle of specificity with exercise training, it is unreasonable to expect large increase in isometric strength with dynamic training programme.

6.6 LIMITATIONS

There are some limitations in this pilot study. First, the sample size is relatively small. The twitch interpolation test was only conducted on 5 participants in each group. As discussed in the method session, the twitch interpolation test is uncomfortable for the participants thus it was difficult to recruit subjects to participate in this study. More subjects are needed to confirm the present finding. Second, the possible effect of antagonists and synergists on the peak force had not been taken into consideration. However, since the interpolated twitch ratio is a relative value, if there is a systemic effect between the antagonists and synergists, it should have happened in each trial thus the effect of which would be eliminated and not reflected in the value of the interpolated twitch ratio.

6.7 CONCLUSIONS

The voluntary activation of quadriceps muscles of older people with sarcopenia was facilitated after 36 sessions of WBV training with 40Hz x 4mm x 360 seconds of training dosage per session over a 12-week period. The present finding suggested the increased level of voluntary activation would be one of the underlying mechanisms of WBV training in older people with sarcopenia. This provides the first piece of evidence that WBV is effective for facilitating the central motor drive in seniors with sarcopenia. Based on the present findings, it is suggestive that the future study for investigating the possible mechanism of WBV training should target on the contractility and muscle synergies rather than the facilitation of the central motor drive.

CHAPTER 7 CONCLUSIONS AND CILINICAL APPLICATIONS

7.1 CONCLUSIONS

The present study is the first study to conduct WBV training on the people with sarcopenia. The objectives of this thesis were achieved after completing the experiments. A 12-week WBV training programme with 40Hz and 360 seconds is the most effective to improve muscle strength and physical activity of the elderly with sarcopenia. Although there was no statistically significant increase in cross-sectional area of vastus medialis, it is too early to negate the potential effect of WBV training on muscle mass since the effect of WBV training on other muscles is uncertain. For balance and proprioception, there was no significant improvement found after 12 weeks of WBV training in older people with sarcopenia. Furthermore, the training-induced improvements of muscle strength and self-preferred walking speed would be maintained after cessation of training for 12 weeks.

It is the first study to investigate the possible underlying mechanism of the elderly with sarcopenia. The finding revealed some WBV-induced changes of voluntary activation by twitch interpolation in this thesis. Voluntary activation of quadriceps muscles was facilitated after a 12-week WBV training programme with 40Hz and 360 seconds, which is the evidence for supporting the neural adaptation to WBV training in older people with sarcopenia.

Considering the literature and the present results of physical performance and balance, further studies are needed to investigate the effect of WBV training on coordination in older people with sarcopenia. Also, the other possible underlying mechanisms of WBV training should be explored extensively in the future.

7.2 CLINICAL IMPLICATIONS

- A 12-week WBV training programme is an effective exercise for improving isokinetic knee extension at 180 °/s, TUG and 5STS in elderly subjects with sarcopenia.
- The combination of 40Hz and 360 seconds is the optimal parameters of WBV training in elderly subjects with sarcopenia.
- The WBV-induced improvements of muscle strength and self-preferred walking speed would not persevered for 12 weeks after training cessation
- A 12-week WBV training programme with 40Hz and 360 seconds increased the voluntary activation of quadriceps muscles in elderly subjects with sarcopenia.

APPENDICES

Appendix I

香港特別行政區政府衞生署長者健康服務
香港理工大學康復治療科學系

全身震動治療法對患有肌肉無力的社區長者的療效
研究摘要

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研究內容：本項目旨在对患有肌肉無力的長者身体评价。凡自願參加的長者會被邀請參加一次身體脂肪分佈測試，情況符合研究的長者會被邀請作以下測試。

各測試內容如下：

身體脂肪分佈：長者只需站在身體脂肪分佈儀器上，有如量度體重。由研究員記錄身體脂肪數據。

肌力測試：長者坐在一台肌力測試機上，在研究員指導下進行膝部屈伸運動數次以測試下肢肌力。

量度肌肉大小：長者平卧在床上，由研究員用超聲波探測儀量度長者大腿四頭肌的大小。

關節本體感覺：長者閉上眼睛，坐在高椅上，由研究員作出特定的膝關節測試。

TUG 測試: 長者在研究員的指導下從座椅起身後步行 3 米, 再返回座椅坐下. 長者用自己平時的步行速度完成測試。長者可以使用步行輔助器。研究員將完成時間紀錄.

重複起身坐下測試：長者在研究員的指導下從座椅迅速起身再迅速坐下。研究員將記錄完成動作所需的時間。

Tandem 測試：長者在研究員的指導下任選一隻腳，將其腳跟擺放在另一隻腳的腳尖前方，使兩隻腳站成一直線，雙手擺放在身體兩側。研究員記錄下長者維持平衡站立的時間。

單腳站測試 （睜眼與閉眼)：長者在研究員的指導下任選一腳站立，另一腳量開地面，雙手擺放在身體兩側。研究員記錄下睜開雙眼和緊閉雙眼時維持平衡站立的時間。

步速測試：長者用日常和最快的步行速度走完 10 米的距離。長者可以使用步行輔助器。研究員記錄下分別所需要的時間。

肌肉收縮控制: 長者坐在一台肌力測試機上, 由研究員用電流刺激大腿肌肉收縮, 電流刺激只進行兩次，每次大約一秒鐘。長者會感到強電流和肌肉收縮及可能會有些微痛楚，但因為時間很短，所以這不舒服的感覺會很快消失，

亦不會對身體有任何不良反應。

在所有測試後，部分長者會被要求 7 天後再次接受所有測試。之後，部分長者會被安排到香港理工大學接受十二星期，每星期三次的全身震動治療訓練。長者站在震動機上，毋須特殊動作，維持同一站立姿勢兩至三分鐘。整個訓練包括三次震動治療，之間有五分鐘休息時間。

在研究過程中，研究員會為長者重覆四次以上的測試（除肌肉收縮控制測試）。部分長者會在開始階段和 12 周時進行肌肉收縮控制測試。在完成所有測試後，長者會獲得港幣伍佰圓作車馬費。

<u>參與研究長者的益處</u>: 長者參與治療會對肌肉無力的問題有所改善。而測試所得的數據會幫助我們認識有關全身震動治療對肌肉無力人士的療效，從而提升這種療法在臨床上的應用，以便更多長者能得益。

<u>安全性</u>: 我們會採取各種必要的預防措施，以確保安全。倘若長者在研究過程中有任何不適，請馬上通知研究人員。

如閣下對本研究有任何疑問可以致電 2766 與香港理工大學研究員位小姐查詢。

香港特別行政區政府衞生署長者健康服務
香港理工大學康復治療科學系研究

全身震動治療法對患有肌肉無力社區長者的療效研究

同意書

本人＿＿＿＿＿＿＿已了解此研究的具體情況。本人願意參加此研究，亦明白本人有權在任何時候，毋須解釋理由的情況下退出，而此舉不會影響我在衞生署長者健康中心正在接受的服務，更不會導致我受到任何不公平對待。本人明白參加此研究課題的潛在風險，本人的資料亦不會洩露予無關此研究的人員，我的名字和相片亦不會出現在任何出版物上。

簽名（參與者）：＿＿＿＿＿＿＿＿＿＿＿＿ 日期：＿＿＿＿＿＿＿＿＿＿＿

簽名（證人）： ＿＿＿＿＿＿＿＿＿＿＿＿ 日期：＿＿＿＿＿＿＿＿＿＿＿

如對此研究有任何疑問，可致電 2766 與香港理工大學康復治療科學系研究員位小姐查詢。若本人對研究人員有任何投訴，可以聯絡梁先生（香港理工大學部門科研委員會秘書），電話：2766 。

Appendix II

THE HONG KONG POLYTECHNIC UNIVERSITY

Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project title: Combating sarcopenia in community dwelling elderly with whole body vibration exercise

Investigator(s): Gabriel Ng, Chair Professor, Dept of RS, PolyU
Ruby Lee, Consultant of Family Medicine, Dept of Health
Mary Lau, Physiotherapist, Dept of Health

Project information:

This study aims to examine the effect of whole body vibration exercise for training muscle strength and balance and explore a possible mechinsm of WBV training in people with sarcopeniaVolunteers will be invited to undergo an initial screening of body fat measuring with a bioelectrical impedance measurement. Suitable subjects will be invited to join the study. The tests will be done as follow:

Bioelectric impedance measuring: You will need to rest supine on a plinth and skin electrodes will be attached to your arms and legs for a few minutes. During which, you will be ask to relax and the machine will measure your body resistance to electric current for estimating your body fat. During the test, you will not feel any pain or discomfort.

Muscle strength: You will be seated on a machine with your trunk and legs secured by straps. You will need to kick and bend your knee against the machine as hard as possible for a few times. There should not be any pain or discomfort with this test.

Muscle size: You will be positioned in supine lying on a plinth and an ultrasound machine will be used to measure the size of your thigh muscle. The researcher will place the ultrasound probe on your thigh, which will measure the size of your muscle and you will not feel any pain or discomfort.

Joint sense: You will be seated on a high chair, blind-folded and an air-splint will be applied to your foot. The researcher will move your leg to different positions and ask you to remember them, afterwards, you will need to reproduce the previous leg position.

TUG: You need stand up from an armchair, walk a distance of 3 meters, turn back to the chair, and sit down. You should finish this test by your normal pace. No physical assistance will be given. You can use your walking aid if you have. Time will be recorded.

Sit-to-stand test: You sit in a standard height chair (43-47cm) with back against chair, arms crossed on chest for entire test. You need stand up and sit down as quickly as possible. Time will be recorded.

Balance test:

(1) Tandem test: You will be asked to place the toes of the back foot touch the heel of the front foot. Timing started when a balanced and safe stance had been attained. Timing will stop when correcting a disturbance in balance by moving a foot or leg or reaching for support with hands. Researcher will record the balance time.

(2) One Leg Stand test (opened and closed eyes): The OLST is performed in the standing position with the your arms by your sides. Timing will start when you raise the appropriate foot off the ground. Researcher will record the balance time.

(3) 10-meter walk test: You use your usual and fastest speed to walk 10 meters. You can use your walking aid if you have. Researcher will record the time for only intermediate 6 meters.

Neuromotor recruitment pattern

You would sit on an isokinetic test chair with hip at 80° and knee at 90° of flexion. An active stimulation electrode would be placed over your groin and you will need to perform a maximal knee extension and during which, an electrical stimulation would be delivered to your groin region to trigger a maximal twitch of your thigh muscle. Afterwards, you need to relax and an electrical stimulation would be applied again to elicit another twitch of the muscle. The electrical stimulation is reasonably strong but with very short duration. You should feel a strong electrical shock to the groin during the test but the sensation will last only very momentarily and there is no known adverse effect with this procedure.

After the first testing session, you may retake all tests after 7 days. Then you may be assigned into a training group in which you will need to receive exercise at the Hong Kong Polytechnic University on alternate days for 12 weeks. The exercise will involve you standing on a machine that produces a whole body vibration force to you and you will need to maintain in the same standing position for 2-3 minutes. The exercise will be repeated 3 times and you will have 5 minutes break between each exercise session.

You will need to return to The Hong Polytechnic University at 6 weeks, 12 weeks, 18 weeks and 24 weeks for the above testing procedures, except neuromotor recruitment pattern. Neuromotor recruitment pattern will only be conducted on some volunteers at baseline and 12 weeks. Upon completion of all the training and testing sessions, you will be given $500 dollars to compensate for your transportation costs for the study.

Your participation in this study will help us understand the therapeutic effects of whole body vibration on improving strength and balance for people with weak muscles. The clinical protocol for training people with similar condition will therefore be improved. The risk of whole body vibration is muscle soreness and falling during the exercise but we have very stringent safety precautions to prevent these from happening. Should you feel any discomfort with the training, you should notify the researcher immediately during the study.

<u>Consent:</u>

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

I can contact the investigator, Ms Wei at telephone 2766 for any questions about this study. If I have complaints related to the investigator(s), I can contact Mr. Leung, secretary of Departmental Research Committee, at 2766 . I know I will be given a signed copy of this consent form.

Signature (subject): Date:

Signature (witness): Date:

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