EFFECTS OF WHOLE-BODY VIBRATION THERAPY IN INDIVIDUALS WITH CHRONIC STROKE

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CERTIFICATE OF ORIGINALITY

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

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ABSTRACT

Background: Whole-body vibration (WBV) has been shown to be effective in improving muscle strength and balance in older adults. Previous research on WBV in the stroke population has produced mixed results. No study has compared the effects of different WBV training protocols in persons with stroke.

Purposes: This project consists of seven inter-related studies, with each study having specific objectives. There are: **Study 1:** To conduct a systematic review to examine the available evidence related to the use of WBV therapy on influencing body functions and structures, activity and participation in individuals with stroke, and other relevant issues including the safety of WBV applications. **Study 2:** To establish the reliability of outcome measures of the main study of this thesis (e.g., reliability and validity of the Craig Hospital Inventory of Environmental Factors scale). **Study 3:** To examine the acute effects of different WBV protocols on the activity of the vastus lateralis and gastrocnemius muscles during the performance of different static exercises in people with chronic stroke. **Study 4:** To examine the acute effect of different WBV protocols on the activity of biceps femoris and tibialis anterior muscles activity during static exercises among individuals with chronic stroke and how the neuromuscular response is influenced by severity of leg motor impairment. **Study 5:** To investigate the immediate effect of WBV in neuromuscular activity of leg muscles during dynamic exercises in individuals with stroke. **Study 6:** To determine the acute effect of different WBV protocols on oxygen consumption, heart rate, blood pressure, and rate-pressure product during the performance of different exercises among people with chronic stroke. **Study 7 (main study):** A single-blinded randomized controlled study was conducted to investigate the effects of different whole-body vibration (WBV) intensities on body functions/structures, activity and participation in individuals with stroke.

Methods: Study 1: Electronic search were conducted on MEDLINE, CINAHL, PEDro, PubMed, PsycINFO, Science Citation Index. Randomized controlled trials (RCTs) that investigated the effects of WBV among individuals with stroke were identified by two independent researchers. Ten articles (nine studies) totaling 333 subjects satisfied the selection criteria and were included in this systematic review. The methodological quality was rated using the PEDro scale. The results were extracted by two independent researchers and confirmed with the principal investigator. **Study 2:** 107 individuals with chronic stroke and 56 age-matched healthy subjects participated in this study. The English version of the 25-item Craig Hospital Inventory of Environmental Factors was translated into Chinese using standardized procedures, and then administered to both the stroke and control groups. The same questionnaire was administered again to the stroke group at 1-2 weeks after the first session. The test-retest reliability, construct validity, and known-groups validity were assessed. **Study 3:** Forty-five chronic stroke patients were studied. Each subject was exposed to three WBV conditions of (1) no WBV, (2) low-intensity WBV protocol [peak acceleration: 0.96 unit of gravitational constant (g)], and (3) high-intensity WBV protocol (peak acceleration: 1.61g) while performing 8 different static exercises involving upright standing, semi squat, deep squat, weight-shifted-forward, weight-shifted-backward, weight-shifted-to-the-side, forward lunge and single-leg-standing. Bilateral VL and GS muscle activity was recorded with surface electromyography (EMG), and expressed as percentage of the EMG amplitude recorded during a maximal voluntary contraction of the respective muscles (%MVC). **Study 4:** Each of the 36 individuals with chronic stroke performed eight different static exercises under three WBV conditions: (1) no WBV, (2) low-intensity

WBV as used in Study 3, and (3) high-intensity WBV as used in Study 3. The levels of bilateral TA and BF muscle activity were recorded using surface EMG. **Study 5:** Thirty people with chronic stroke performed a series of dynamic exercises with and without WBV: (1) no WBV, (2) low-intensity WBV, and (3) high-intensity WBV. Neuromuscular activation was measured by surface EMG on bilateral VL, TA, BF, and GS muscles and was reported as EMG root mean square normalized to % MVC. **Study 6:** Each of the 48 participants experienced the same three WBV protocols in separate sessions: (1) no WBV, (2) low-intensity WBV, and (3) high-intensity WBV. The order in which they encountered the WBV protocols was randomized, as was the order of exercises performed during each session. VO2, HR and RPE were measured throughout. BP and RPP were measured before and after each session. **Study 7(main study):** Eighty four people with chronic stroke (mean age: 61.2 years, SD: 9.2) who had mild to moderate motor impairment (Chedoke McMaster Stroke Assessment lower limb motor score: median=9 out of 14, interquartile range=7-11.8) were randomly assigned to the low-intensity WBV, high-intensity WBV, or control groups. The former two groups performed various leg exercises while receiving low-intensity and high-intensity WBV respectively. The controls performed the same exercises without WBV. All individuals received 30 training sessions over an average period of 75.5 days (SD=5.2). Outcome measurements included knee muscle strength (isokinetic dynamometry), spasticity at the knee and ankle joints (Modified Ashworth Scale), balance (Mini Balance Evaluation Systems Test, Mini-BESTest), mobility (Timed-Up-and-Go test, TUG), walking endurance (6-Minute Walk Test, 6MWT), balance self-efficacy (Activities-specific Balance Confidence scale, ABC), participation in daily activities (Frenchay Activity Index), perceived environmental barriers to societal participation (Craig Hospital Inventory of Environmental Factors), and quality of life (Short-Form 12 Health Survey, SF-12). The assessments were performed at baseline and post-intervention.

Results: Study 1: Only two RCTs were considered as level 1 evidence (PEDro score ≥6 and sample size >50). Two RCTs examined the effects of a single WBV session whereas seven examined the effects of WBV programs spanning 3-12 weeks. No consistent benefits on bone turnover, leg motor function, balance, mobility, sensation, fall rate, activities of daily living, and societal participation were found, regardless of the nature of the comparison group. Adverse events were not uncommon but minor. **Study 2:** The Craig Hospital Inventory of Environmental Factors had good internal consistency (Cronbach's alpha = 0.916) and test-retest reliability (intra-class correlation coefficient = 0.845). It also had significant association with Personal Wellbeing Index ($r = -0.344$, $p < 0.001$) but not with Fugl-Meyer Assessment upper limb motor score ($r = -0.183$, $p = 0.088$) among stroke subjects, thus demonstrating convergent and discriminant validity, respectively. The mean Craig Hospital Inventory of Environmental Factors score in the stroke group was also significantly higher than that in controls ($p<0.05$), thus showing good known-groups validity. **Study 3:** Exposure to WBV (low- and high-intensity protocols) significantly increased VL and GS EMG amplitude (large effect size, partial $\eta^2 = 0.135-0.643$, $p<0.001$) on both the paretic and non-paretic sides in different exercise conditions, compared with no WBV. No significant difference in EMG magnitude was found between the high- and low-intensity WBV protocols ($p>0.05$). With a few exceptions, WBV enhanced EMG activity in the paretic and non-paretic leg muscles to a similar extent in different exercise conditions. **Study 4:** The main effect of intensity was significant. Exposure to the low-intensity and high-intensity protocols led to a significantly greater increase in BF and TA EMG magnitude in both legs compared with no WBV ($p<0.05$). The intensity × exercise interaction was also significant ($p<0.05$), suggesting that the WBV-induced increase in EMG activity was exercise-dependent. The EMG responses to WBV were similar between the paretic and non-paretic legs, and were not associated with level of lower extremity motor impairment and spasticity. **Study 5:** The neuromuscular activation of VL, BF, TA and GS muscles of both legs was significantly increased by adding WBV during dynamic exercise ($P<0.05$) and that EMG neuromuscular activation in the BF, TA and GS muscles during exposure to the high-intensity WBV protocol was significantly greater than the low intensity WBV protocol ($P<0.05$). The WBV induced an increase in EMG neuromuscular activation in the TA and GS muscles that was exercise-dependent ($P<0.05$). The EMG response to WBV in the GS and BF muscles, but not the VL and TA muscles, was greater on the paretic leg than the non-paretic leg. **Study 6:** Low-intensity and high-intensity WBV induced significantly higher VO_2 by an average of 0.69 and 0.79ml/kg/min respectively ($P\leq0.001$) than the control condition. These protocols also increased HR by an average of 4 beats per minute ($P\leq0.05$). The two WBV protocols induced higher RPE than the control condition during static standing exercise only ($P\leq0.001$). While the diastolic and systolic BP and RPP were increased at the end of each exercise session ($P\leq0.001$), the addition of WBV had no significant effect on these variables ($P>0.05$). **Study 7 (main study):** Intention-to-treat analysis revealed a significant time effect for muscle strength, TUG, distance and oxygen consumption rate achieved during 6MWT, Mini-BESTest, ABC, and SF-12 physical composite score domain ($P<0.05$). However, the time by group interactions effects were not significant for any of the outcome measures ($P>0.05$).

Conclusions: Study 1: The Chinese version of the Craig Hospital Inventory of Environmental Factors is a reliable and valid tool for evaluating the environmental barriers experienced by people with chronic stroke. **Study 2:** There is insufficient evidence to support or refute the clinical use of WBV in enhancing body functions and structures, activity and participation after stroke. **Study 3:** Neuromusular activity in VL and GS muscles was increased significantly with addition of WBV. Further clinical trials are needed to determine the effectiveness of different WBV protocols for strengthening leg muscles in chronic stroke patients. **Study 4:** Adding WBV during exercise significantly increased EMG activity in TA and BF. The EMG responses to WBV in the paretic and non-paretic legs were similar, and were not related to degree of motor impairment and spasticity. The findings are useful for guiding the design of WBV training protocols for people with stroke. **Study 5:** This study found a positive relationship between the neuromuscular activation (EMGrms) of the bilateral VL, BF, TA and GS muscles and WBV intensity (up to 1.61g) in individuals with stroke. The increase in neuromuscular activation in the TA and GS muscles evoked by WBV was also influenced by the specific dynamic exercise performed. The EMG response in the BF and GS muscles was greater in the paretic than non-paretic lower extremity. The choice of WBV intensity, dynamic exercise and muscle trained should be important factors to consider when prescribing WBV exercise. **Study 6:** Addition of high- and low-intensity WBV significantly increased the VO2 and HR, but the increase was modest. WBV thus should not pose any substantial cardiovascular hazard in people with chronic stroke. **Study 7 (main study):** The addition of the 30-session WBV paradigm to the leg exercise protocol was no more effective in enhancing body functions/structures, activity and participation than leg exercises alone in people with stroke who sustained mild to moderate motor impairments. Overall, this thesis showed that WBV is safe and feasible when applied in stroke patients and the cardiovascular stress induced is modest. The addition of WBV also significantly augments the neuromuscular activation of leg muscles during exercise. However, the 10-week WBV training program does not lead to any additional benefits on body functions and structures, activity and participation in people with chronic stroke. Further study is required to identify the

optimal WBV parameters for modifying different outcomes in stroke patients with various disability levels.

LIST OF RELATED CONFERENCE AND PUBLISHED JOURNAL PAPERS

A. *Peer review journal papers*

1. **Liao LR**, Ng GY, Jones AY, Huang MZ, Pang MY. Different whole-body vibration intensities in stroke: randomized controlled trial. Under the reviewing of the Med Sci Sports Exerc.
2. **Liao LR**, Ng GY, Jones AY, Pang MY. Effect of whole-body vibration on neuromuscular activation of leg muscles during dynamic exercises in individuals with stroke. Manuscript in preparation.
3. **Liao LR**, Ng GY, Jones AY, Chung RC, Pang MY. Effect of vibration intensity, exercise and motor impairment on leg muscle activity induced by whole-body vibration in people with stroke. Phys Ther. 2015;95(12):1617-27.
4. **Liao LR**, Ng GY, Jones AY, Pang MY. Cardiovascular stress induced by whole-body vibration exercise in individuals with chronic stroke. Phys Ther. 2015 2015;95(7):966-77.
5. **Liao LR**, Huang M, Lam FM, Pang MY. Effects of whole-body vibration therapy on body functions and structures, activity, and participation poststroke: a systematic review. Phys Ther. 2014;94(9):1232-51.
6. **Liao LR**, Lam FM, Pang MY, Jones AY, Ng GY. Leg muscle activity during whole-body vibration in individuals with chronic stroke. Med Sci Sports Exerc. 2014;46(3):537-45.
7. **Liao LR**, Lau RW, Pang MY. Measuring environmental barriers faced by individuals living with stroke: development and validation of the Chinese version of the Craig Hospital Inventory of Environmental Factors. J Rehabil Med. 2012;44(9):740-6.

B. Conference papers

1. **Liao LR**, Ng GY, Jones AY, Huang MZ, Pang MY. Effects of whole-body vibration therapy on body functions and structures, activity and participation in individuals with stroke: a randomized controlled trial. *World Confederation for Physical Therapy (WCPT) Congress 2015*; Singapore 1-4 May 2015 (Oral presentation).
2. **Liao LR**, Ng GYF, Jones AYM, Pang MYC. Leg flexor muscle activity induced by different whole-body vibration protocols in people with chronic stroke. 2nd Symposium of HEALED Research Group, Hong Kong, 2014. (Poster presentation: Best Poster Award).
3. **Liao LR**, Ng GY, Jones AY, Pang MY. Leg flexor muscle activity during whole body vibration in individuals with chronic stroke. *7th World Congress of the International Society of Physical and Rehabilitation Medicine (ISPRM 2013)*; Beijing, China 16-20 June 2013 (Poster presentation).
4. **Liao LR**, Huang MZ, Pang MY. The effects of whole body vibration therapy on body function, activity, and participation post-stroke: a systematic review. *7th World Congress of the International Society of Physical and Rehabilitation Medicine (ISPRM 2013)*; Beijing, China 16-20 June 2013. (Poster presentation).
5. **Liao LR**, Ng GY, Jones AY, Pang MY. Acute effect of whole body vibration on leg muscle activity, oxygen consumption and heart rate in individuals with chronic stroke. The 8th Pan-Pacific Conference on Rehabilitation; Manila, Philippines 17-18 November 2012. (Oral presentation).
6. **Liao LR**, Jones AY, Ng GY, Pang MY. The effects of whole body vibration on leg muscle activity and oxygen consumption in individuals with stroke. *The 21st European stroke conference;* Lisbon, Portugal 22-25 May 2012 (Poster presentation: Best Poster Award).

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TABLE OF CONTENTS

CERTIFICATE OF ORIGINALITY I

ABSTRACT II

LIST OF RELATED CONFERENCE AND PUBLISHED JOURNAL PAPERS IX

ACKNOWLEDGEMENTS XI

TABLE OF CONTENTS XIII

LIST OF TABLES XXVII

LIST OF FIGURES XXIX

LIST OF ABBREVIATIONS XXXI

CHAPTER ONE GENERAL INTRODUCTION 1

- 1.1 EPIDEMIOLOGY OF STROKE 2
- 1.2 COMMON IMPAIRMENTS IN BODY FUNCTIONS AND STRUCTURES AFTER STROKE 3
  - 1.2.1 Neuro-motor Deficits 4
    - 1.2.1.1 Spasticity 4
    - 1.2.1.2 Muscle Weakness 5
    - 1.2.1.3 Balance Deficits 7
  - 1.2.2 Cardiorespiratory Impairment 7
- 1.3 RESTRICTED ACTIVITY AFTER STROKE 9

1.3.1 Dysfunctions in Walking 9

1.3.2 Dysfunctions in Activities of Daily Living (ADL) 10

1.4 RESTRICTED PARTICIPATION AND HR-QOL AFTER STROKE 11

1.4.1 Restricted Participation after Stroke 11

1.4.2 Reduced QOL after Stroke 12

1.5 WHOLE BODY VIBRATION THERAPY 13

1.5.1 Whole Body Vibration and Animal Models 14

1.5.1 Acute Effects of Exposure to WBV in Animal Models 15

1.5.2 Effects of WBV in Human Applications 21

1.6 RATIONALE OF RESEARCH STUDIES 43

1.7 OBJECTIVES AND HYPOTHESES 47

1.7.1 Overall Aim 47

1.7.2 Objectives of Individual Chapters 47

1.7.2.1 Chapter 2: Effects of Whole-body Vibration Therapy on Body Functions and Structures, Activity and Participation Post-stroke: A Systematic Review. 47

1.7.2.2 Chapter 3: Measuring the Environmental Barriers Faced by Individuals Living with Stroke: Development and Validation of the Chinese version of the Craig Hospital Inventory of Environmental Factors 48

1.7.2.3 Chapter 4: Leg Muscle Activity during Whole-body Vibration in Individuals with Chronic Stroke 48

1.7.2.4 Chapter 5: Effect of Vibration Intensity, Exercise and Motor Impairment on Leg Muscle Activity Induced by Whole-Body Vibration in People with Stroke 48

1.7.2.5 Chapter 6: Effect of Whole-body Vibration on Neuromuscular Activation of Leg Muscles during Dynamic Exercises in Individuals with Stroke 49

1.7.2.6 Chapter 7: Cardiovascular Stress Induced by Whole-Body Vibration Exercise in Individuals with Chronic Stroke 49

1.7.2.7 Chapter 8: Different Whole-Body Vibration Intensities in Stroke: Randomized Controlled Trial.. 50

1.7.3 Hypotheses of each Individual Chapter.. 50

1.7.3.1 Chapter 3: Measuring the Environmental Barriers Faced by Individuals Living with Stroke: Development and Validation of the Chinese Version of the Craig Hospital Inventory of Environmental Factors 50

1.7.3.2 Chapter 4: Leg Muscle Activity during Whole-body Vibration in Individuals with Chronic Stroke 50

1.7.3.3 Chapter 5: Effect of Vibration Intensity, Exercise and Motor Impairment on Leg Muscle Activity Induced by Whole-Body Vibration in People with Stroke 51

1.7.3.4 Chapter 6: Effect of Whole-body Vibration on Neuromuscular Activation of Leg Muscles during Dynamic Exercises in Individuals with Stroke 51

1.7.3.5 Chapter 7: Cardiovascular Stress Induced by Whole-Body Vibration Exercise in Individuals with Chronic Stroke 52

1.7.3.6 Chapter 8: Different Whole-Body Vibration Intensities in Stroke: Randomized Controlled Trial.. 52

CHAPTER TWO EFFECTS OF WHOLE-BODY VIBRATION THERAPY ON BODY FUNCTIONS AND STRUCTURES, ACTIVITY AND PARTICIPATION POST-STROKE: A SYSTEMATIC REVIEW.. 54

2.1 ABSTRACT 55

2.2 INTRODUCTION.. 57

2.3 METHOD.. 59

2.3.1 Research question.. 59

2.3.2 Study selection.. 60

2.3.3 Data sources and searches 60

2.3.4 Methodological quality assessment.. 61

2.3.5 Data synthesis and analysis 63

2.4 RESULTS.. 63

2.4.1 Study selection.. 63

2.4.2 Quality of reviewed articles.. 65

2.4.3 Participants 65

2.4.4 Intervention protocol 70

2.4.5 Effects of a single session of WBV intervention.. 75

2.4.6 Effects of multiple sessions of WBV intervention.. 79

2.4.7 Adverse events.. 87

2.5 DISCUSSION 88

2.5.1 Does vibratory stimulation alone confer any benefits? 88

2.5.2 Is WBV exercise approach as a whole a viable alternative to other forms of physical exercise? 93

2.5.3 Relationship between treatment effect and characteristics of participants 96

2.5.4 Limitations of the Studies Reviewed 97

2.5.5 Limitations of the Systematic Review 97

2.5.6 Future research directions 98

2.5.7 Conclusion 99

CHAPTER THREE MEASURING ENVIRONMENTAL BARRIERS FACED BY INDIVIDUALS LIVING WITH STROKE: DEVELOPMENT AND VALIDATION OF THE CHINESE VERSION OF THE CRAIG HOSPITAL INVENTORY OF ENVIRONMENTAL FACTORS 100

3.1 ABSTRACT 101

3.2 INTRODUCTION 102

3.3 METHODS 105

3.3.1 Sample size calculation 105

3.3.2 Subjects 105

3.3.3 Cultural adaptation of CHIEF 106

3.3.4 Measurement procedures 108

3.3.5 Statistical analysis 109

3.4 RESULTS 110

3.4.1 Participant characteristics 110

3.4.2 Reliability 112

3.4.3 Validity 114

3.5 DISCUSSION 116

3.5.1 Environmental barriers faced by individuals with stroke 116

3.5.2 Reliability 118

3.5.3 Validity 118

3.5.4 Long form Vs short form 120

3.5.5 Limitations and future research directions 120

3.5.6 Conclusion 121

CHAPTER FOUR LEG MUSCLE ACTIVITY DURING WHOLE-BODY VIBRATION IN INDIVIDUALS WITH CHRONIC STROKE 122

4.1 ABSTRACT 123

4.2 INTRODUCTION 125

4.3 METHODS 127

4.3.1 Study Design 127

4.3.2 Subjects and sample size estimation 127

4.3.3 Basic demographics and spasticity 129

4.3.4 WBV Protocol 129

4.3.5 Exercise protocol 130

4.3.6 Measurement of leg muscle activity responses 132

4.3.7 Statistical analysis 133

4.4 RESULTS 134

4.4.1 Demographic characteristics of subjects 134

4.4.2 EMG activity of Paretic leg VL 138

4.4.3 EMG activity of Paretic leg GS 141

4.4.4 EMG activity of Non-Paretic leg VL 141
4.4.5 EMG activity of Non-Paretic leg GS... 143
4.4.6 Paretic to non-paretic EMG amplitude ratio... 143
4.4.7 Relationship between spasticity and EMG data 146
4.5 DISCUSSION 146
4.5.1 Effect of WBV intensity 146
4.5.2 Interaction between exercise and WBV intensity.. 148
4.5.3 Analysis of paretic to non-paretic EMG amplitude ratio 150
4.5.4 Limitations and future research directions 151
4.5.5 Conclusion 153

CHAPTER FIVE EFFECT OF VIBRATION INTENSITY, EXERCISE AND MOTOR IMPAIRMENT ON LEG MUSCLE ACTIVITY INDUCED BY WHOLE-BODY VIBRATION IN PEOPLE WITH STROKE 154

5.1 ABSTRACT 155
5.2 INTRODUCTION... 156
5.3 METHODS.. 158
5.3.1 Study Design 158
5.3.2 Participants 158
5.3.3 Ethics Statement 159
5.3.4 WBV Protocols... 159
5.3.5 Exercise Protocols 160
5.3.6 Measurements.. 163

5.3.7 Statistical analysis 165

5.4 RESULTS 167

5.4.1 Characteristics of the Participants 167

5.4.2 Three-way ANOVA 170

5.4.3 Main effect of intensity 170

5.4.4 Intensity by exercise interaction 174

5.4.5 Intensity by side interaction 177

5.4.6 Association with leg motor impairment and spasticity 177

5.5 DISCUSSION 177

5.5.1 Influence of WBV intensity 177

5.5.2 Interaction effect between WBV intensity and exercise 179

5.5.3 Comparison of EMG responses between paretic and non-paretic legs 180

5.5.4 Relationship with motor impairment and spasticity 180

5.5.5 Clinical Implications 181

5.5.6 Methodological considerations 183

5.5.7 Limitations and Future Research Directions 183

5.5.8 Conclusions 184

CHAPTER SIX EFFECT OF WHOLE-BODY VIBRATION ON NEUROMUSCULAR ACTIVATION OF LEG MUSCLES DURING DYNAMIC EXERCISES IN INDIVIDUALS WITH STROKE 186

6.1 ABSTRACT 187

6.2 INTRODUCTION 189

6.3 METHODS 194
  6.3.1 Experimental Design 194
  6.3.2 Subjects 194
  6.3.3 Sample Size Calculation 194
  6.3.4 WBV Conditions 195
  6.3.5 Exercise Conditions 195
  6.3.6 Measurement of neuromuscular activation 196
  6.3.7 EMG data analysis 197
  6.3.8 Statistical Analyses 198
6.4 RESULTS 199
  6.4.1 Characteristics of Participants 199
  6.4.2 Three-way ANOVA 202
  6.4.3 Main Effect of Intensity 202
  6.4.4 Intensity by Exercise Interaction 204
  6.4.5 Intensity by Side Interaction 206
6.5 DISSCUSSION 206
  6.5.1 Influence of WBV Intensity 206
  6.5.2 Interaction Effect between WBV Intensity and Exercise 208
  6.5.3 Comparison of EMG responses between paretic and non-paretic legs 208
  6.5.4 Clinical Implications 209
  6.5.5 Limitations and Future Research Directions 209
  6.5.6 Conclusions 210

CHAPTER SEVEN CARDIOVASCULAR STRESS INDUCED BY WHOLE-BODY VIBRATION EXERCISE IN INDIVIDUALS WITH CHRONIC STROKE 211

7.1 ABSTRACT 212

7.2 INTRODUCTION 214

7.3 METHODS 216

  7.3.1 Study design 216

  7.3.2 Participants and sample size calculation 216

  7.3.3 WBV Protocol 217

  7.3.4 Exercise protocol 218

  7.3.5 Measurement of cardiovascular response 225

  7.3.6 Statistical Analysis 226

7.4 RESULTS 227

  7.4.1 Characteristics of participants 227

  7.4.2 Washout period 230

  7.4.3 DBP, SBP, RPP and RPE changes 230

  7.4.4 VO_2 changes 237

  7.4.5 HR changes 237

  7.4.6 Association with baseline values 238

7.5 DISCUSSION 239

  7.5.1 Is WBV exercise training safe for individuals with stroke? 239

  7.5.2 Do WBV exercises have potential to provide a positive cardiovascular training effect? 240

  7.5.3 Limitations and future directions 243

7.5.4 Conclusions 244

CHAPTER EIGHT DIFFERENT WHOLE-BODY VIBRATION INTENSITIES IN STROKE: RANDOMIZED CONTROLLED TRIAL 245

8.1 ABSTRACT 246

8.2 INTRODUCTION 248

8.3 METHODS 250

8.3.1 Design 250

8.3.2 Participants and sample size 250

8.3.3 Recruitment and randomization 252

8.3.4 Interventions 252

8.3.5 Outcome measures 257

8.3.6 Test-retest reliability of the SF-12, ABC, FAI, and isometric contraction at 30º of knee flexion 261

8.3.7 Statistical analysis 262

8.4 RESULTS 263

8.4.1 Subjects 263

8.4.2 Demographic data 266

8.4.3 Test-retest reliability of the SF-12, ABC, FAI, and knee isometric muscle strength at 30º of knee flexion 272

8.4.4 Training duration 274

8.4.5 Adverse events 274

8.4.6 Outcome measures 274

8.5 DISCUSSION 283

8.5.1 Does WBV stimulation alone confer any additional benefits?.................................. 283

8.5.2 Limitations 286

8.5.2 Future directions... 287

8.5.4 Conclusion 287

CHAPTER NINE SUMMARY AND CONCLUSION **289**

9.1 CHAPTER 2 ENTITLED: EFFECTS OF WHOLE-BODY VIBRATION THERAPY ON BODY FUNCTIONS AND STRUCTURES, ACTIVITY AND PARTICIPATION POST-STROKE: A SYSTEMATIC REVIEW 290

9.2 CHAPTER 3 ENTITLED: MEASURING THE ENVIRONMENTAL BARRIERS FACED BY INDIVIDUALS LIVING WITH STROKE: DEVELOPMENT AND VALIDATION OF THE CHINESE VERSION OF THE CRAIG HOSPITAL INVENTORY OF ENVIRONMENTAL FACTORS 290

9.3 CHAPTER 4 ENTITLED: LEG MUSCLE ACTIVITY DURING WHOLE-BODY VIBRATION IN INDIVIDUALS WITH CHRONIC STROKE 290

9.4 CHAPTER 5 ENTITLED: EFFECT OF VIBRATION INTENSITY, EXERCISE AND MOTOR IMPAIRMENT ON LEG MUSCLE ACTIVITY INDUCED BY WHOLE-BODY VIBRATION IN PEOPLE WITH STROKE 291

9.5 CHAPTER 6 ENTITLED: EFFECT OF WHOLE-BODY VIBRATION ON NEUROMUSCULAR ACTIVATION OF LEG MUSCLES DURING DYNAMIC EXERCISES IN INDIVIDUALS WITH STROKE 291

9.6 CHAPTER 7 ENTITLED: CARDIOVASCULAR STRESS INDUCED BY WHOLE-BODY VIBRATION EXERCISE IN INDIVIDUALS WITH CHRONIC STROKE 292

9.7 CHAPTER 8 ENTITLED: DIFFERENT WHOLE-BODY VIBRATION INTENSITIES IN STROKE: RANDOMIZED CONTROLLED TRIAL 292

APPENDICES 293

APPENDIX I CONSENT FORM FOR CHAPTER 3 294

APPENDIX II APPROVAL LETTER FOR CHAPTER 3 300

APPENDIX III CONSENT FORM FOR CHAPTER 4, 5, 6, AND 7 301

APPENDIX IV APPROVAL LETTER FOR CHAPTER 4, 5, 6, AND 7 307

APPENDIX V CONSENT FORM FOR CHAPTER 8 308

APPENDIX VI APPROVAL LETTER FOR CHAPTER 8 315

APPENDIX VII ABBREVIATED MENTAL TEST (HONG KONG VERSION) 316

APPENDIX VIII CHEDOKE MCMASTER STROKE ASSESSMENT FORM (LEG AND FOOT) 317

APPENDIX IX FUNCTIONAL AMBULATORY CATEGORY 318

APPENDIX X MINI BALANCE EVALUATION SYSTEMS TEST 319

APPENDIX XI MODIFIED ASHWORTH SCALE 321

APPENDIX XII ACTIVITIES-SPECIFIC BALANCE CONFIDENCE (CHINESE VERSION) 322

APPENDIX XIII FRENCHAY ACTIVITY INDEX 323

APPENDIX XIV CRAIG HOSPITAL INVENTORY OF ENVIRONMENTAL FACTORS 324

APPENDIX XV SHORT-FORM 12 HEALTH SURVEY, VERSION 2 330

APPENDIX XVI PERMISSION FOR CHAPTER 2 EFFECTS OF WHOLE-BODY VIBRATION THERAPY ON BODY FUNCTIONS AND STRUCTURES, ACTIVITY AND PARTICIPATION POST-STROKE: A SYSTEMATIC REVIEW 332

APPENDIX XVII Permission for Chapter 3 Measuring environmental barriers faced by individuals living with stroke: development and validation of the Chinese version of the Craig Hospital Inventory of Environmental Factors 334

APPENDIX XVIII Chapter 4 Leg Muscle Activity during Whole-body Vibration in Individuals with Chronic Stroke 335

APPENDIX XIX Permission for Chapter 5 Effect of Vibration Intensity, Exercise and Motor Impairment on Leg Muscle Activity Induced by Whole-Body Vibration in People with Stroke ……………………..…………………………..……………… 337

APPENDIX XX Permission for Chapter 7 Cardiovascular Stress Induced by Whole-Body Vibration Exercise in Individuals with Chronic Stroke 339

REFERENCES... 341

LIST OF TABLES

Table 2.1 ....Rating of the PEDro scale and level of evidence

Table 2.2 ....Subjects characteristics of studies

Table 2.3 ....Training protocols for WBV group and comparison group

Table 2.4 ....Summary of immediate effects of a single session of WBV on body functions and structures, and activity in people with stroke

Table 2.5 ....Summary of effects of multiple WBV sessions on body functions and structures, activity and participation in people with stroke

Table 3.1 ....Items in the CHIEF questionnaire

Table 3.2 ....Subject characteristics

Table 3.3 ....Test-retest reliability of CHIEF-C scores in the stroke group (n=71)

Table 3.4 ....Comparison of the CHIEF-C scores between the stroke and control groups

TABLE 4.1.......Static exercises performed while standing on the vibration platform

TABLE 4.2.......Characteristics of subjects (N=45)

Table 5.1 ....Characteristics of the Participants (n=36)

Table 5.2 ....The effect of whole-body vibration (WBV) intensity on normalized EMGrms values

Table 6.1 ....WBV protocols

Table 6.2 ....Characteristics of Participants (n=30)

Table 6.3 ....The effect of whole-body vibration (WBV) intensity on neuromuscular activation

Table 7.1 ....Characteristics of study participants (n=48)

Table 7.2 ....The effect of whole-body vibration (WBV) intensity on outcome measurements

Table 8.1 ....Parameters of WBV and exercise protocols

Table 8.2 ....Intention-to-treat analysis: Characteristics of participants

Table 8.3 ....Intention-to-treat analysis (primary outcomes): muscle strength

Table 8.4 ....On-protocol analysis: characteristics of participants

Table 8.5 ....Test-retest reliability of SF-12, ABC, FAI, and isometric muscle strength at 30º of knee flexion (n=37)

Table 8.6 ....Intention-to-treat analysis: secondary outcomes

Table 8.7 ....On-protocol analysis (primary outcomes): muscle strength

Table 8.8 ....On-protocol analysis: secondary outcomes

LIST OF FIGURES

Figure 1.1 ....A plot of displacement against time in vertical vibration

Figure 2.1 ....Flow diagram

Figure 4.1 ....Study flow chart

Figure 4.2 ....Effect of WBV on EMG amplitude in the paretic leg

Figure 4.3 ....Effect of WBV on EMG amplitude in the non-paretic leg

Figure 4.4 ....Ratio of EMG amplitude of the paretic leg to the non-paretic leg

Figure. 5.1 ....Exercise Protocol

Figure 5.2 ....Study flow chart

Figure 5.3 ....Trend analysis: illustration of the effect of WBV intensity

Figure 5.4 ....Normalized EMG magnitude under different WBV exercise conditions

Figure 6.1 ....Exercise Protocol

Figure 6.2 ....Study Flow Chart

Figure 6.3 ....Normalized EMG Magnitude Under Different WBV Exercise Conditions

Figure 7.1 ....Exercise protocol

Figure 7.2 ....Study flow chart

Figure 7.3 ....Effect of whole-body vibration on blood pressure and rate-pressure product

Figure 7.4 ....Effect of whole-body vibration on rate of perceived exertion, oxygen consumption and heart rate

Figure 8.1 ....CONSORT Flow Chat

LIST OF ABBREVIATIONS

%MVC .... Percentage of the peak EMG amplitude

10 MWT..........10-meter walk test

6MWT............. Six-minute walk test

A.......................Amplitude

ABC ....Activities specific balance confidence

ACL .... Anterior cruciate ligament injury

ADL ....Activities of daily living

AFO .... Ankle-foot-orthosis

AMM ....Apparent Mass Magnitude

AMT................Abbreviated mental test

ANOVA .... Analysis of variance

a_{peak}...................Peak acceleration

BADL..............Basic ADL

BAP.................. bone-specific alkaline phosphatase

BBS..................Berg Balance Scale

BF..................... Biceps femoris

BI ....Barthel Index

BMC................ Bone mineral content

BMD .... Bone mineral density

BOS.................Base of support

BP.................... Blood pressure

CF.................... Cystic fibrosis

CGS.................Comfortable gait speed

CHIEF .... Craig Hospital Inventory of Environmental Factors

CI ....Confidence interval

CMSA ....Chedoke-McMaster Stroke Assessment

CNS.................Central nervous system

CON................ Control group

COPD.............. Chronic obstructive pulmonary disease

CP.................... Cerebral palsy

CTx ....Serum C-telopeptide of type I collagen cross-links

CVA................ Cerebrovascular accident

DBP................. Diastolic blood pressure;

DBWS............. Dynamic backward weight shift

DCL ....Directional control

DDS ....Dynamic deep squat

df......................Degrees of freedom,

DFL..................Dynamic forward lunge

DFWS ....Dynamic forward weight shift

DS ....Deep squat

DSS..................Dynamic semi-squat

DWSSTS.........Dynamic weight shift side to side

EMG................ Electromyography

EMGrms.......... Root mean square electromyography

EPE .... End point excursions

f........................ Frequency

FAC..................Functional Ambulation Categories

FAI.................. Franchay Activity Index

FGS ....Fast gait speed

FIM ....Functional Independence Measure

FL.....................Forward lunge

FMA.................Fugl-Meyer Motor Assessment

GS ....Gastrocnemius

H-reflex...........Hoffmann reflex

Hmax/Mmax ratio Maximum Hoffmann reflex/maximum M response ratio

HR.................... Heart rate

HR-QOL .... Health-related quality of life

HWBV ....High intensity WBV

Hz..................... Hertz

IADL................ Instrumental ADL

ICC...................Intraclass correlation coefficient

ICF .... International Classification of Functioning, Disability and Health

IQR...................Interquartile range

ITT .... Intention-to-treat

IVD ....Intervertebral disc

LBP .... Low back pain

LOCF ....Last observation carried forward

LWBV.............. Low intensity WBV

MANOVA ....Multivariate analysis of variance

MAS................. Modified Ashworth Scale

MCS................. Mental health composite score

MDD ....Minimal detectable difference

MG	Medial gastrocnemius
MI	Motricity Index
min	Minute
mm	Millimeters
MMSE	Mini-mental State Examination
MQE	Measure of the Quality of the Environment
MS	Multiple Sclerosis
MVC	Maximal voluntary contraction
MVL	Movement velocity
MXE	Maximum excursion
NIHSS	National Institutes of Health Stroke Scale
NP/P	Non-paretic to paretic
NR	Not reported
NWBV	No WBV
PWI	Personal Wellbeing Index
P	Significant level
P-P	Peak-to-peak
PAP	Post-activation potentiation

PASE	Physical activity scale for individuals with physical disabilities
PCS	Physical composite score
PD	Parkinson’s disease
RCT	Randomized controlled trial
RES	Resistance exercise training
RF	Rectus femoris
RMI	Rivermead Mobility Index
RMS	Root mean square
RPE	Rate of perceived exertion
RPP	Rate-pressure product
s	Seconds(s)
SBP	Systolic blood pressure;
SCI	Spinal Cord Injury
SD	Standard deviation
SENIAM	Surface EMG for a Non-invasive Assessment of Muscles
SES	Standardized effect size
SF-12	Short-Form 12 Health Survey
SIS	Stroke Impact Scale
SLS	Single-leg-standing

SOT.................. Sensory Organization Test

SS.....................Semi squat

ST.....................Upright standing

TA .... Tibialis anterior

TBW%.............Percentage of total body weight

TUG..................Timed Up & Go test

UANOVA....... Univariate analysis of variance

VAS................... Visual analogue scale

VL....................Vastus Lateralis

VO2.................. Oxygen consumption

VO_{2max}.............. Maximal Oxygen consumption

WBV................ Whole body vibration

WBVT............. Whole body vibration training

WHO................ World Health Organization

WSB.................Weight-shifted-backward

WSF ....Weight-shifted-forward

WSTS............... Weight-shifted-to-the-side

CHAPTER ONE

General Introduction

Liao Lin Rong

1.1 EPIDEMIOLOGY OF STROKE

The definition of stroke (cerebrovascular accident, CVA) is "rapidly developing clinical signs of focal or global disturbance of cerebral function lasting more than 24 hours with no apparent non-vascular cause, unless interrupted by surgery or death" (WHO MONICA Project, 1988). Stroke can be classified into three main categories according to the nature of the cerebral lesion: ischemic stroke (80% of cases), intracerebral hemorrhage (16%) and subarachnoid hemorrhage (4%) (WHO, 1989). According to the World Health Report from WHO, stroke is the second most common cause of mortality and disease burden all over the world (WHO, 2003; Venna & McCullough, 2014) and is expected to rise due to aging of the population. Moreover, most of the stroke survivors are presented with the long-term disability post a stroke (Desalu et al., 2011). There are enormous emotional and potentially socioeconomic consequences for stroke survivors, their family members, and public health systems (Feigin et al., 2003; Mackay et al., 2004; Pompili et al., 2015). According to the model of International Classification of Functioning, Disability and Health (ICF), stroke may affect various dimensions of health and functioning, including body functions and structures, activity and social participation, depending on the location of the brain damage and the severity (WHO, 2001).

Stroke is the most common life-threatening neurological disease (Foulkes et al., 1988; Desalu et al., 2011). The prevalence of stroke was approximately 2.8% during the period of 2007-2010 in America (Heart Disease and Stroke Statistics, 2014). A study conducted by Li (1998) reported that the incidence of stroke is approximately 159.9/100,000 person/years. More recently, the incidence of stroke in rural China has increased rapidly along with a concurrent increase in risk factor prevalence, particularly among middle-aged adults (Wang et al., 2014b). It is projected that stroke will become one of the most prevalent conditions affecting women in coming years in China (Wang et al., 2015). Locally, Chau et al. (2011) reported that the overall age-adjusted incidence of stroke in Hong Kong was higher than that in other developed countries. According to statistics from the Hospital Authority (Hospital Authority Statistical Report, 2012-2013) in Hong Kong, 25,730 people were diagnosed with stroke in 2012. Among these people, 11,981 had a cerebral infarction (I63, ICD10), 6,509 had an intracranial hemorrhage (I60-62, ICD10), 3,712 had other cerebrovascular diseases (I65-69, ICD10), and 3,528 had a stroke not specified as a hemorrhage or infarction (I64, ICD10). In summary, stroke has been and will continue to be a serious health threat to the public.

1.2 COMMON IMPAIRMENTS IN BODY FUNCTIONS AND STRUCTURES AFTER STROKE

Stroke is a heterogeneous condition, and the signs and symptoms are highly dependent on the location and extent of the lesion in the central nerve system (CNS) (Hubli et al., 2012). The cluster of symptoms after stroke is often complex but typically involves muscle spasticity, muscle weakness, sensory impairments, balance deficits, and cognitive problems (Mayer et al., 1997). Motor dysfunction is recognized as the most common problem caused by stroke (Langhorne et al., 2009), involving a limitation or loss of function in muscle strength, muscle control, coordination, movement or mobility (Wade, 1992). Motor impairment after stroke typically involves one side of the body (leg, arm, trunk, and face) and affects about 80% of stroke survivors (Warlow et al., 2008). The next section provides a summary of the neuro-motor deficits commonly encountered after a stroke.

1.2.1 Neuro-motor Deficits

Some of the most prevalent neuro-motor deficits observed after stroke are spasticity, muscle weakness, and balance impairments.

1.2.1.1 Spasticity

Lance (1980) defined spasticity as a “velocity-dependent increase in tonic stretch reflex (i.e. muscle tone) with exaggerated tendon jerks.” Its main feature is the hyper-excitability of the muscle-stretch reflexes. The pathophysiology and clinical interpretations of spasticity are complex. It is believed that the lesion involving the cortico-reticulo-spinal fibers (i.e. the CNS) leads to decreased inhibition or increased facilitation of the spinal reflex arc (Hubli et al., 2012), resulting in post-stroke spasticity (Priori et al., 2006).

The overall pattern of spasticity may manifest itself as focal or multifocal, and the resulting problems may vary. The prevalence of spasticity post-stroke has been estimated to range from 19% to 43% (Urban et al., 2010; Wissel et al., 2010; Zorowitz et al., 2013; Sommerfeld et al., 2004). Spasticity is considered as an important contributing factor to the substantial debilitation of stroke survivors (Bhakta et al., 2000). Spasticity may result in muscle shortening, fibrosis, calcification, and fixed contractures (Bai et al., 2014). Additionally, it is positively correlated with disturbance in motor functions. For example, Eng et al. (2002) demonstrated that spasticity of the leg and foot (as measured by the Ashworth scale) was moderately associated with gait velocity measured in the comfortable walking speed test ($r = -0.452$) and the distance achieved in the 6-minute walk test (6MWT) ($r = -0.534$) in a sample of 25 individuals with stroke. Hsu et al. (2003) showed that among the various stroke-related impairments, spasticity of the plantar flexors in the paretic leg was the single most important determinant of spatial and temporal gait asymmetry during both the fast-speed and comfortable-speed walking tests. Spasticity has also been related to upper limb functioning post-stroke. Spasticity, as assessed by the Modified Ashworth Scale (MAS), was strongly correlated with Chedoke Arm and Hand Activity Inventory score, a measure of the ability of the affected upper limb to perform functional activities (r = -0.80) (Harris et al., 2007). Moreover, the MAS score was significantly associated with the Reintegration to Normal Index (RNI), a measure of community-reintegration (r = -0.23) (Harris et al., 2007). Overall, due to the disturbance of the motor function, spasticity may lead to difficulties in performing activities of daily living (ADL) (Bai et al., 2014), such as grooming, dressing, mobility, and transportation, thereby compromising stroke survivors' health-related quality of life (HR-QOL) (Cerniauskaite et al., 2012; Doan et al., 2012; Schinwelski et al., 2010).

1.2.1.2 Muscle Weakness

Muscle weakness (i.e. paresis) is the most common motor impairment post-stroke, involving the inability to voluntarily generate a normal amount of force (i.e. maximum voluntary force or torque) (Suresh et al., 2014). Several studies that used electromyography (EMG) to assess neuromuscular activation in individuals with stroke had found that the EMG magnitude recorded during maximal voluntary contraction (MVC) of the muscles in the paretic leg was considerably lower than that in the non-paretic leg (Andersen et al., 2011; Olney & Richards, 1996; Lee et al., 2013; Lee et al., 2015). In addition to reduced ability to generate muscle force, the time required to develop peak tension is also prolonged in people with stroke (McCrea et al., 2003). The extent of muscle weakness in patients with stroke is not uniform within the same limb. More severe weakness is often observed in the distal muscles than the more proximal muscles (Colebatch & Gandevia, 1989). The degree of muscle weakness is also not uniform across the range of motion. Muscle weakness in both the paretic upper limb (Ada et al., 2003) and lower limb (Lomaglio & Eng, 2008) is more prominent at shorter muscle length. The extent of muscle weakness post-stroke is also influenced by the type of muscle contraction, with eccentric muscle strength being better preserved than concentric muscle strength (Eng et al., 2009).

Apart from the impaired muscle activation by the CNS (Knuttson & Richards, 1979; Knarr et al., 2014), local changes in the muscle contribute to the compromised ability to generate force among people with stroke. Electrophysiological studies have found a reduction in the number of functional motor units, and lower motor unit firing rates in the paretic muscles among individuals with stroke (McComas et al., 1973; Brown & Snow, 1990; Spaans & Wilts, 1982; Dattola et al., 1993; Gemperline et al., 1995; Suresh et al., 2014). Muscle atrophy (Pang et al., 2005a & b; Ryan et al., 2002), which is a common result of reduced physical activity levels and disuse (Pang et al., 2007 & 2013a; Michael et al., 2005; Michael & Macko, 2007; Manns et al., 2009), may also play a role in muscle weakness after stroke. In addition to the reduction in muscle mass/density, connective and fat tissue infiltration (MacIntyre et al., 2010; Ryan et al., 2002), and metabolic changes in the muscles may contribute to post-stroke paresis (Hubli et al., 2012).

Loss of muscle strength is strongly associated with limitations in functional activities after stroke (Nascimento et al., 2014; Kim & Eng, 2003; Bohannon & Andrews, 1990; Dorsch et al., 2012; Bohannon & Walsh, 1991; Chae et al., 2002; Boissy et al., 1999). Among the various stroke impairments, muscle weakness is often the most important determinant of the ability to perform functional activities (Bohannon et al., 1991, Lin et al., 2006; Canning et al., 2004; Hsu et al., 2003; Lin, 2005; Nadeau et al., 1999). Hsu et al. (2003) identified the strength of the paretic knee flexors and hip extensors as the most important determinants of the fast and comfortable gait velocities, explaining 72% and 57% of the variance, respectively. Lin et al. (2006) showed that the ankle dorsiflexors strength was the single most important determinant of gait temporal symmetry and velocity, accounting for 36% and 30% of the variance, respectively.

1.2.1.3 Balance Deficits

Balance deficits are common after stroke and are one of the leading causes of long-term disability (Lamb et al., 2003). Previous studies have consistently demonstrated that people with stroke have greater postural sway than healthy age-matched adults (Lamontagne et al., 2003; Corriveau et al., 2004; Ikai et al., 2003; De Haart et al., 2004). The patterns of weight distribution are altered in stroke patients, as less weight is taken through the paretic lower limb and smaller movements are made when moving their weight around the base of support (BOS) (i.e. dynamic balance), or in response to external perturbations (Eng & Chu, 2002; Au-Yeung et al., 2003). Physical impairments such as muscle weakness (Eng et al., 2002; Ng & Hui, 2005) of the lower extremities and spasticity in the knee and ankle (Eng et al., 2002), and psychological factors may contribute to balance deficits in individuals with stroke. Impaired balance increases the risk of falls (Eng et al., 2008; Lam et al., 2003), and reduces the ability to perform ADL and mobility tasks. This may trigger a vicious cycle of physical deconditioning, sedentary lifestyle, and reduced participation in community activities.

1.2.2 Cardiorespiratory Impairment

Cardiorespiratory impairment is well-documented in patients with chronic stroke (Pang et al., 2005a,b,c&d; Salbach et al., 2014; Kelly et al., 2003; Tseng et al., 2009;Tang et al., 2006;

Marsden et al., 2013; Brogårdh et al., 2012a&b; Carvalho et al., 2008;Smith et al., 2012; Courbon et al., 2006). Cardiorespiratory fitness represents the ability to carry out moderate-to-high intensity, large-muscle dynamic exercise over an extended period of time (Whaley et al., 2006). Shephard (2009) suggested that loss of independence is likely if maximum oxygen consumption (VO_{2max}) levels (an indicator of cardiorespiratory fitness) fall below 15 ml/kg/min in women and 18 ml/kg/min in men. Depending on the severity of the deficit, poor cardiorespiratory fitness may limit basic activities. For example, walking at 3 miles/hour, cooking and food shopping for groceries required a VO_2 rate of 11.55 ml/kg/min, 8.25 ml/kg/min, and 8.05 ml/kg/min respectively (Ainsworth et al., 2000). Cardiorespiratory fitness in stroke survivors is often poor. The peak oxygen consumption rate (VO_2peak) has been reported to be only at 50-80% of the values obtained from the sex- and age-matched physically inactive people (Pang et al., 2005a), and is far below the threshold for independent living (around 20 ml/kg/min) (Letombe et al., 2010). There are two reasons for the low cardiorespiratory fitness levels observed in people with stroke. First, their poor cardiorespiratory health may predate the stroke event, as cardiovascular disease and poor cardiorespiratory fitness are known risk factors for stroke (Agabiti-Rosei et al., 2007). Second, the sedentary lifestyle (Michael et al., 2005) following a stroke may result in further physical deconditioning and compromise cardiorespiratory fitness.

Previous studies have reported that the endurance exercise program can significantly improve cardiovascular health outcomes in people with stroke (Pang et al., 2013b; Pang et al., 2005a,b,c&d; Pang et al., 2006; Pang & Eng, 2008). A recent meta-analysis by Pang et al. (2013) provided convincing evidence that endurance training at 60-80% of the heart rate reserve (HRR) for 20-40 minutes/day for 3-5 days/week, improves cardiovascular fitness and walking endurance and is thus recommended for patients with mild to moderate stroke.

1.3 RESTRICTED ACTIVITY AFTER STROKE

1.3.1 Dysfunctions in Walking

Dysfunctions in walking are a major contributor to long-term disability in people with stroke (Mauritz, 2002). Eng & Tang (2007) reported that regaining walking ability in the community is the most important goal of stroke survivors, making the rehabilitation of walking function a top priority. Although up to 88% of those discharged from hospital recover their walking function after stroke (Jorgensen et al., 1995). However, many of the stroke patients lose the ability to walk independently, and a large proportion of them patients do not regain their normal walking speed (Jorgensen et al., 1995; Wade et al., 1987).

Typical walking deficits in post-stroke individuals involve a combination of impaired muscle strength, coordination and proprioception, and often excessive muscle tone (i.e. spasticity) in the paretic lower limb. The two most immediate biomechanical effects of these impairments are instability of the paretic leg during the stance phase of gait, and insufficient foot clearance on the paretic side during the swing phase of the gait cycle (Hutin et al., 2012). Individuals with history of stroke often develop compensatory actions to mitigate these deficits. For instance, they may use asymmetric spatial and temporal step lengths and develop a substantial frontal plane lean toward the non-paretic leg, both of which bias the individual away from loading the paretic leg in stance (MacLellan et al., 2013; Chow et al., 2015). Additionally, hip circumduction of the paretic leg during the swing phase, and non-paretic ankle plantar flexion during the stance phase (i.e., vaulting on the non-paretic lower extremity), both facilitate foot clearance of the paretic lower extremity during the swing phase (Hak et al., 2013). The primary features of dysfunctions in walking post-stroke vary, depending upon the location of lesions, stroke severity, type of rehabilitation received, stroke duration, and other individual factors (Olney et al., 1996; Patterson et al., 2010).

The inability to walk obviously affects one's independence and ability to live in the community, and thus their QOL and continued health. Similarly, compromised walking ability increases the incidence of falls and fragility fractures (Forster & Young, 1995; Harris et al., 2005; Batchelor et al., 2010; Mackintosh et al., 2005; Pouwels et al., 2009; Weerdesteyn et al., 2008; Michael et al., 2005).

1.3.2 Dysfunctions in Activities of Daily Living (ADL)

Stroke is the most common cause of dependence in ADL among the elderly (Stineman et al., 1997; Lee et al., 2014; Lu et al., 2012; Hsueh et al., 2004). The ADL can be categorized into basic ADL (BADL) (e.g., dressing, grooming, etc.) and instrumental ADL (IADL) (e.g., using a telephone, housekeeping, recreation, hobbies, social outings), which are necessary for independent functioning in the community (Hsueh et al., 2013). Most patients with stroke experience role changes as a result of the impaired autonomy caused by difficulties in performing the ADL. Sturm et al. (2002) reported that about 75% of patients with stroke experience difficulties with ADL.

Gialanella et al. (2012) investigated various ADL as possible predictors of functional outcome, and found that social interaction, problem solving, grooming and upper body dressing on admission to hospital were the most important predictors of functional outcome at discharge. More recently, a study by De Wit et al. (2014) found that assessing patients' ability to dress and bathe themselves when discharged from a rehabilitation center were useful in making the prognosis for long-term independence in personal ADL after stroke. Dependence in ADL can influence the QOL of individuals with stroke (Kim et al., 2014; Clarke et al., 2000). Therefore, reducing the degree of dependence in performing ADL is often a central goal of rehabilitation programs for people who have sustained a stroke (Gialanella et al., 2013).

1.4 RESTRICTED PARTICIPATION AND HR-QOL AFTER STROKE

1.4.1 Restricted Participation after Stroke

According to the ICF model (WHO, 2001), participation is defined as involvement in a life situation, participation restrictions are problems that an individual may experience with involvement in life situations, such as employment, education, spirituality, leisure and cultural activities (Bickenbach et al., 1999). Participation is not limited to a specific environment, such as the hospital or home environment, but also involves the wider physical and social environment encompassing all possible life circumstances. Participation also implies that the individual manages to control his or her own life in every situation, in spite of the fact that he/she cannot complete the activities by himself/herself (Perenboom et al., 2003). Participation is therefore the result of a complex and dynamic interaction between the individual and their physical and social environment (Fougeyrollas, 1995).

Many individuals with stroke report that they have experienced difficulty with community reintegration following a stroke (Pang et al., 2007; Walsh et al., 2014; Eriksson et al., 2013). Limitations in the ability to perform IADL may affect the social participation of patients with chronic stroke who live in the community (Gadidi et al., 2011; Hsueh et al., 2000; Bouffioulx et al., 2010; Schuling et al., 1993). Thus, optimizing stroke survivor’s participation in community has become an important goal of rehabilitation. Only a few studies have examined the determinants of post-stroke restrictions in participation (Rochette et al., 2001; Sturm et al., 2002; Andrenelli et al., 2015; Mackenzie et al., 2002; Gadidi et al., 2011; Carod-Artal et al., 2000). Previous studies reported that the age, level of post-stroke functional motor ability (e.g., gait dysfunction), and psychological functions (such as depression, low self-esteem, and balance self-efficacy) are the main factors underlying restriction in participation among people with chronic stroke (Mackenzie et al., 2002; Andrenelli et al., 2015). It was suggested that improving both psychosocial functioning (e.g. balance self-efficacy) and physical (functional ability) functioning may be the key to facilitating community reintegration in individuals with stroke (Chau et al., 2009; Pang et al., 2007).

1.4.2 Reduced QOL after Stroke

Health-related quality of life (HR-QOL) refers to the effects that health has on the individuals' ability to function and their perceived well-being in the different domains (e.g. physical, mental, and social) of life (Coons et al., 2000). Studies have demonstrated that stroke survivors have lower HR-QOL than healthy adults (Golomb et al., 2001; Gunaydin et al., 2011; Teixeira-Salmela et al., 2009; Geyh et al., 2007). Restrictions in mobility and physical functioning have been found to be associated with lower QOL in individuals with stroke (Ahtsio et al., 1984; Gunaydin et al., 2011; Astrom et al., 1992; Teixeira-Salmela et al., 2009; de Haan et al., 1995; Geyh et al., 2007; King, 1996; Robinson-Smith et al., 2000; Kim et al., 1999; Golomb et al., 2001; Clarke et al., 2000). However, there is increasing awareness that psychosocial status also plays a role in determining QOL (Ones et al., 2005). Even patients who sustain only minimal or no physical impairments experience a substantial reduction in their QOL, thus it has been suggested that other factors might contribute (Ones et al., 2005), such as depression (Ahtsio et al., 1984; Angeleri et al., 1993; Astrom et al., 1992; Kim et al., 1999; King, 1996), age (Darlington et al., 2007), pain (Kong et al., 2004), amount of social support (King, 1996), and individual personality traits (Johansson et al., 1992).

In summary, individuals with stroke often encounter problems with functioning at different levels (i.e., body functions & structures, activity and participation), leading researchers to search for effective intervention strategies to tackle these problems. Recently, whole body vibration (WBV) training has garnered increasing attention in research field and gained popularity in clinical practice settings. WBV therapy has been used to improve muscle strength, flexibility, power, and coordination among elderly (Rogan et al., 2011; Lau et al., 2011; Lam et al., 2012), athletes (Jones, 2014; Wang et al., 2014a), and people with neurological disorders, including spinal cord injury (Herrero et al., 2011), Parkinson’s disease (King et al., 2009; Ebersbach et al., 2008), cerebral palsy (El-Shamy, 2014) and multiple sclerosis (Hilgers et al., 2013). WBV therapy may have potential applications in individuals with stroke (Lau et al., 2012; Liao et al., 2014a,b&2015; Pang et al., 2013b).

1.5 WHOLE BODY VIBRATION THERAPY

The WBV therapy is also known as WBV training (Gloeckl R et al., 2015), vibration training (Park et al., 2015), and vibration therapy (Thompson et al., 2014). There are two major types of vibrations in WBV: vertical (synchronous), in which the whole platform oscillates uniformly up and down and thus the force produced is mainly in the vertical direction; and side-alternating, in which the platform rotates about an anteroposterior horizontal axis and thus the force is applied alternately between the two sides and contains a mediolateral component

(Cardinale & Wakeling 2005; Abercromby et al., 2007). The peak acceleration (a_{peak}) represented as the WBV intensity, is calculated by the formula:

$$a_{peak} = (2\pi f)^2 A$$

where f is the frequency, which represents the number of oscillations (cycles of motion) per second expressed in Hertz (Hz) and A is the amplitude (i.e., the size of each deflection expressed in millimeters, mm) (Kiiski et al., 2009; Rauch et al., 2010) (Figure 1). Physically, WBV exercise represents a forced oscillation in which vibration energy is transferred from a WBV device (i.e. an actuator) to the person, and is represented as a unit of the Earth's gravitational constant (1 g = 9.81 m/s^2).

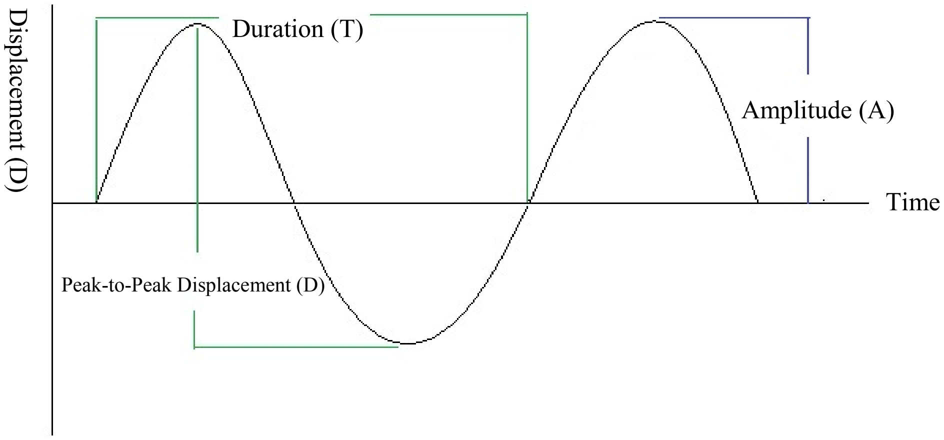

Figure 1. A plot of displacement against time in vertical vibration.

1.5.1 Whole Body Vibration and Animal Models

The effects of WBV (low magnitude, high-frequency vibrations) have been investigated in ovariectomized rats and mice (Komrakova et al., 2013; Huang et al., 2014; Wehrle et al., 2014), sheep (Rubin et al., 2001 & 2002a), rabbits (Weinstein et al., 1988), and horses (Carstanjen et al., 2013). WBV has been shown to induce anabolic bone changes (Rubin et al., 2001a; Omar et al., 2008), stimulate the neuromuscular system (Murfee et al., 2005), affect the cardiovascular system (Edwards et al., 1972), and reduce fat accumulation and suppress abiogenesis (Maddalozzo et al., 2008; Rubin et al., 2007). Rubin et al. (2001) proposed that WBV may have a secondary stimulatory effect on bone tissue as well, due to the mechanical strain generated from the WBV-induced muscle dynamic contractions. Although the mechanism behind the correlation has not yet been established, cellular mechanics and extracellular fluid dynamics are considered to be important.

1.5.1 Acute Effects of Exposure to WBV in Animal Models

Acute effects of WBV may be defined as physiological changes that occur during WBV stimulation and/or immediately subsequent to a short period of WBV stimulation. Research studies on the acute effects of WBV in animal models are relatively scarce. Edwards et al. (1972) investigated the short-term (less than 30 seconds) effect of mechanical vibration (2 - 12 Hz, 1-3 g) on the cardiovascular system. They monitored the regional and central blood pressures (BP) and blood flow velocities during WBV in 4 dogs and 1 pig. Their results showed that the frequency range from 3 to 9Hz contained the smallest minimum and largest maximum peak blood flow rates for all acceleration amplitudes. Their findings indicate the potential effects of WBV on the cardiovascular system in animals (dog and pig).

More recently, Carstanjen et al. (2013) analyzed the acute effect of WBV exercise on seven healthy adult horses (4 geldings, 3 mares). The horses stood on four separate WBV platforms for 10 minutes each, with horizontal and vertical vibrations at a frequency of 15-21 Hz. The results showed that acute short-term WBV exercise induced a significant decrease in creatine-kinase and serum cortisol values (Carstanjen et al., 2013). The WBV exercise did not cause any sign of discomfort in the horses. Matthew et al. (2013) used *ex vivo* and *in vivo* mouse models to examine the acute effects of WBV (15-90 Hz, 0.3g, 30-min) on the catabolic and anabolic pathways in the intervertebral disc (IVD), and characterized the changes in terms of time and frequency. Their findings showed that a single WBV episode induced anabolic gene expression with *in vivo* models. In addition, the changes in gene expression were significantly increased in extracellular matrix content, including increased levels of biglycan, type I collagen, decorin, and aggrecan. This study also found that the greatest changes occurred at 6 hours post-WBV. However, the effects of WBV were frequency dependent. No significant changes in gene expression were detected between the WBV and sham controls if WBV frequencies of 45 Hz or greater were used (Matthew et al., 2013).

1.5.1.2 Effects of Long-term WBV Training in Animal Models

1.5.1.2.1 Neuromuscular System

There is evidence that WBV increases the activation of the motor units, thereby increasing the contractile activity of skeletal muscles (Wakeling et al., 2006; Wakeling et al., 2002). Xie et al. (2008) showed that a 6-week low-intensity WBV (vertical, 45 Hz, 0.3 g, 15 minutes per day) program increased the total cross sectional area of the soleus in mice. Stuermer et al. (2010) investigated the effect of WBV (vertical, 90 Hz, 0.5 mm, 4 g, 15 minutes/session, 2 times/day, 30 days) on muscle healing in ovariectomized and intact rats. The finding suggested that WBV increased the fiber size in the medial gastrocnemius and medial longissimus muscles of all rats, and also improved the blood supply and oxidative metabolism of these muscles in ovariectomized rats only. A study by Prior et al. (2003) reported that the type and magnitude of WBV were correlated with vascular adaptations at the capillary level, leading to rarefaction or network growth. Additionally, Murfee et al. (2005) demonstrated that WBV (vertical, 45 Hz, 0.3 g, 15 minutes/day, 6 weeks) could significantly reduce the total number of blood vessels per muscle fiber in the medial soleus of adult male mice. Łochyński et al. (2013) reported that specific functional adaptations occurred in the fast fatigable and fast fatigue-resistant motor units of the medial gastrocnemius muscle in rats following a 5-week WBV intervention (vertical, 2.5 mm for the platform, 0.98 mm for the bedding of a cage, 4.9 g, 30 seconds, 4 repetitions separated by 60-second rest intervals), principally manifested by an increase in the maximum tetanus force and a shortening of the twitch contractile characteristics, respectively. However, the mechanisms by which muscle tissue senses and responds to the WBV are yet to be elucidated.

1.5.1.2.2 Bone

The effects of WBV on bone tissue have been studied extensively (Judex et al., 2007; Oxlund et al., 2003; Omar et al., 2008; Rubin & McLeod, 1994; Rubin et al., 2001 & 2002a,b; Castillo et al., 2006). Animal studies can demonstrate the efficacy of WBV on bones while avoiding the limitations of human studies such as comorbidity, age, sex, and hormonal status, etc. For instance, Rubin et al. (2002b) exposed sheep to WBV (30 Hz, 0.3 g, 20-min per day, 5-day per week, 1-year). Their results revealed a 34.2% increase in the bone mineral density (BMD) of the proximal femur, and the distal femur also presented a 10.6% increase in the bone mineral content (BMC) (Rubin et al., 2002b).

The positive effect of WBV on bone growth has also been examined in other animal models. Judex et al. (2007) showed that in ovariectomized mature rats, a 28-day WBV intervention (45 Hz or 90 Hz, 0.15 g, 10-min per day) significantly increased trabecular bone formation by 159% (Judex et al., 2007). Using the same animal model, Oxlund et al. (2003)

found that WBV (45 Hz with 3.0 g, 30 Hz with 1.5g, 17 Hz with 0.5 g, 30-min per day, 90 days) increased the formation rate of periosteal bone and decreased endocortical bone resorption, thereby improving the overall biomechanical strength (Oxlund et al., 2003). A recent study found that 5 weeks of WBV treatment (45 Hz, 0.3g, 15-min per day, 5-day per week) significantly increased the femoral and tibial thickness and cortical area in wild type osteogenesis imperfecta mice compared with a sham control group (Vanleene & Shefelbine, 2013). Taken together, these studies emphasize that low magnitude vibrations (< 1 g or < 10 microstrains) at high frequencies (20-50 Hz) provide sufficient stimuli for bone regeneration in animal models.

1.5.1.2.3 Body Composition

Previous studies demonstrated that WBV can increase energy metabolism by increasing oxygen consumption (VO_2) (Rubin et al., 2007; Maddalozzo et al., 2008; Rittweger et al., 2001, 2002a). For example, Rubin et al. (2007) reported that a short period of WBV in young mice reduced the differentiation of precursor cells to adipocytes, indicating a plausible mechanism by which WBV may prevent fat accumulation. Additionally, Maddalozzo et al. (2008) evaluated the effects of WBV (30-50 Hz, 6 mm, 30-min per day, 5-day per week, 12 weeks) on muscle mass, fat, leptin, and bone. After the intervention period, the WBV group weighed approximately 10% less, and had a lower serum leptin level and lower percentage of body fat than the age-matched non-WBV control group (Maddalozzo et al., 2008).

1.5.1.3 Effects of Long-term WBV Training in Animal Models with Clinical Conditions

1.5.1.3.1 Spinal Cord Injury (SCI)

WBV has been suggested to affect spinal reflex modulation and reduce muscle spasticity

(Ness et al., 2009a; Manthou et al., 2015; Sayenko et al., 2010), walking function (Ness et al., 2009b), and BMD in humans with SCI (Davis et al., 2010). However, few basic experimental studies have investigated WBV in an animal model of SCI. In a recent study by Bramlett et al. (2014) using female rats with mid-thoracic SCI, they demonstrated that WBV (40 Hz, 0.3 g, 15 minutes/time, 2 times/day, 5 days/week, 35 days) increased serum osteocalcin and Runx2 expression in cultured osteoblasts, accompanied by reduced SOST expression. WBV also reduced the osteoclastogenic potential of marrow precursors by 70%. However, despite these highly encouraging biochemical and cell culture findings, after 35 days of WBV there was no significant increase in BMD and no improvements in trabecular bone or serum CTX levels, indicating that there was no reduction in bone resorptive activity. Wirth et al. (2013) used a low-thoracic SCI Wistar rat model to investigate the effect of WBV (1.5 mm, 15 and 30 Hz, 1.45 g and 5.8g, 3-min per trial, 5 trials/session, 5 days/week, 12 weeks) post-SCI. Their findings showed that WBV significantly improved walking function between 6 and 12 weeks. The density of synaptic terminals in the lumbar spinal cord was also restored at 12 weeks (Wirth et al., 2013).

1.5.1.3.2 Parkinson's disease (PD)

A recent study, Zhao et al. (2014) used a PD mouse model to examine the long-term effects of WBV (10 or 30 Hz, 5 mm, 1 min/repeat, 15 repeats/session, 1 session/day, 4 weeks) on the number of dopaminergic neurons in the substantia nigra, the brain-derived neurotrophic factor, and the levels of dopamine. Their results showed that WBV significantly increased the number of nigrostriatal dopamine neurons, the levels of brain-derived neurotrophic factor and the levels of striatal dopamine (Zhao et al., 2014).

1.5.1.3.3 Bone Fracture

Bone fractures may lead to severe functional limitations and impose substantial economic burden on the health care system, especially in older adults (Hoy et al., 2014). Judex et al. (2009) reported that bone metabolism is partly regulated by mechanical factors, and proposed that suitable mechanical stimuli (e.g. WBV) can facilitate bone repair. Moreover, WBV therapy is a non-invasive intervention, so it may be a viable way of providing mechanical stimulation to bone tissue, thereby enhancing bone remodeling. However, few studies have examined the effect of WBV on fracture healing, and have yielded contradictory results.

Goodship et al. (2009) used a sheep (fractured tibia) model to investigate the effect of local vibration (30 Hz, 25 microm, 17 min) via a dynamic fixator and demonstrated that vibration significantly increased the mechanical properties and BMC of the fracture callus. Studies in ovariectomized rats (Shi et al., 2010) and healthy rats (Leung et al., 2009) demonstrated that WBV (35 Hz, 0.3 g) led to accelerated fracture healing, mineralization, and callus formation. Other researchers found that WBV stimulated callus angiogenesis (Cheung et al., 2012) and, in the late healing phase, bone resorption (Chow et al., 2011). Komrakova et al. (2013) examined the effects of WBV (vertical, 0.5 mm, 35 Hz, 50 Hz, 70 Hz, or 90 Hz, 15 minutes/day, 30 days) on fracture repair in ovariectomized rats, and found that WBV significantly upregulated osteocalcin expression, improved the callus density, suppressed osteoclast activity, accelerated osteotomy bridging, enlarged the callus area and width.

Other studies have reported different findings. Wolf et al. (2001) found that WBV (20 Hz, 20 mm) did not significantly improve the fracture healing in a sheep model. Wehrle et al. (2014) examined the frequency-dependent effects of low-magnitude WBV (35 or 45 Hz, 0.3 g, 20 minutes/day) on fracture healing in female mice. The finding revealed that WBV at 45 Hz significantly impaired bone healing (flexural rigidity of the callus and reduced bone formation) after 10 and 21 days. The results of this study indicated that changes in WBV parameters may induce very different effects on bone repair and bone remodeling (Wehrle et al., 2014). In summary, the optimum WBV protocols (type of vibration, frequency, amplitude, duration) for fracture healing are yet to be identified.

1.5.2 Effects of WBV in Human Applications

WBV has become a popular adjunct to exercise training over the past two decades. Usually, WBV training involves intermittent exposure to vibratory stimulation while performing traditional exercises such as semi-squats, weight shifting (forward and backward, left and right) and single-leg standing on a WBV platform (Pang et al., 2013b; Liao et al., 2015; Lienhard et al., 2015; Sá-Caputo et al., 2015). The vibratory signals are delivered to the person's body from the oscillating platform via the feet, and the resulting mechanical loading may elicit various physiological responses (Dolny & Reyes, 2008; Klefter & Feldt-Rasmussen, 2009; Rittweger et al., 2010). WBV has been used with different client populations, ranging from elite athletes (Bosco et al., 1999; Jones, 2014) to elderly people (Bautmans et al., 2005; Roelants et al., 2004a&b; Kawanabe et al., 2007; Bruyere et al., 2005) and individuals with chronic diseases (Tankisheva et al., 2013). Previous studies suggested that WBV therapy may be an effective intervention for improving muscle strength, power, balance, flexibility, and mobility in humans (Bautmans et al., 2005; Lau et al., 2011; Bogaerts et al., 2007a&b, 2009; Rogan et al., 2011; Bruyere et al., 2005; von Stengel et al., 2010 & 2011; Cheung et al., 2007, 2008, 2009; Verschueren et al., 2004; Furness & Maschette, 2009; Russo et al., 2003; Furness et al., 2010; Raimundo et al., 2009; Iwamoto et al., 2005; Gusi et al., 2006; Rubin et al., 2004; Machado et al., 2009; Roelants et al., 2004a&b; Rees et al., 2007; Lam et al., 2012). However, the therapeutic effects may depend on the interactions between various factors, including the WBV parameters (type of WBV, frequency, amplitude), exercise protocol (duration and frequency of exercise, body position during exercise), and the participants' characteristics (i.e. age, gender, impairment severity) (Luo et al., 2005; Chanou et al., 2012). The following sections provide a summary of the acute and long-term effects of WBV exposure in humans.

1.5.2.1 Acute Effects of Exposure to WBV in Able-bodied Humans

Acute effect of WBV may be defined as physiological changes that occur during and/or immediately subsequent to a single session of WBV training. There is no commonly accepted period of time following WBV after which effects are no longer considered to be acute. Previous studies, however, have shown that neuromuscular responses to short periods of WBV tend to diminish within 60 minutes (Torvinen et al., 2002a) to 180 minutes (de Ruiter et al., 2003). WBV training has significant acute effects on neuromuscular activation, which are often measured by surface electromyography (EMG) (Cardinale & Lim, 2003; McBride et al., 2010; Cormie et al., 2006; Hazell et al., 2007; Marin et al., 2009; Roelants et al., 2006), muscle force (Rønnestad et al., 2009a&b), power (Bosco et al., 1999b; Bedient et al., 2009; Cochrane & Stannard, 2005), flexibility (Jacobs & Burns, 2009; Tsuji et al., 2014; Cochrane & Stannard, 2005; Sands et al., 2006, 2008; Gerodimos et al., 2010; Kinser et al., 2008; Di Giminiani et al., 2010; Cochrane, 2013; Dallas et al., 2014a&b; Wirth et al., 2011), oxygen consumption (VO_2) (Rittweger et al., 2001), diastolic blood pressure (DBP), heart rate (HR), skin blood flow (Kerschan-Schindl et al., 2001; Rittweger et al., 2000; Maloney-Hinds et al., 2008; Lohman et al., 2007), tissue oxygenation (Yamada et al., 2005), sensory function (Pollock et al., 2011; Hannah et al., 2013; Games et al., 2013; Dickin et al., 2012), and functional performance (Armstrong et al., 2008, 2010; Iodice et al., 2011; Lamont et al., 2010; Padulo et al., 2014; Torvinen et al., 2002b; Bazett-Jones et al., 2008; Wilcock et al., 2009; Nordlund et al., 2007; Rehn et al., 2007; Cormie et al., 2006).

1.5.2.1.1 Neuromuscular function

A good number of studies have investigated the effects of WBV on neuromuscular performance in young and older adults (Cardinale & Lim, 2003; Marín et al., 2014; Cormie et al., 2006; Bedient et al., 2009; McBride et al., 2010; Rønnestad et al., 2009a&b; Bosco et al., 1999b; Roelants et al., 2006; Marin et al., 2009; Hazell et al., 2007; Cochrane & Stannard, 2005). Cardinale & Lim (2003) investigated the surface EMG response of the vastus lateralis (VL) muscle to different WBV protocols (no-WBV and 30-50 Hz, 10 mm, 60 seconds/exercise, 4 exercises) in a group of 16 professional female volleyball players. In all vibration conditions, the average EMG root mean square (EMGrms) activity of the VL muscle recorded was higher than that in the no-WBV condition (Cardinale & Lim, 2003). Roelants et al. (2006) investigated leg muscle activation during WBV exercise (vertical, 35 Hz, 2.5 mm, 30 seconds/exercise) in 15 male physical education students and found WBV to be associated with significantly higher EMGrms values in all four leg muscles across all exercise conditions, when compared with the control group. Moreover, Cormie et al. (2006) demonstrated that a single bout of WBV (30 Hz, 2.5 mm, 30 seconds) significantly increased the jump height during the countermovement performance in young adults, compared with the sham WBV condition. However, no significant difference was observed in the countermovement jump peak force and peak power during isometric squat between the WBV and sham conditions (Cormie et al., 2006). Wirth et al. (2011)

investigated the acute effect of WBV (30 Hz, 4 mm, 40 seconds/exercise, 8 exercises) on back and abdominal muscle activity in 25 young healthy participants. WBV significantly increased the activity of these muscles compared with the same exercises without WBV (Wirth et al., 2011).

Some studies have attempted to identify the optimal WBV protocol for increasing neuromuscular activity or muscle force generation. For example, Hazell et al. (2007) endeavored to identify the optimal WBV conditions to enhance the EMG magnitude in lower limb and upper limb muscles when performing dynamic leg squats, isometric semi-squats, and dynamic and isometric bilateral bicep curls in 10 recreationally active male university students. Their results showed that WBV (25-45 Hz, 2-4 mm, 45 seconds/session, 15 seconds with no WBV followed by 30 seconds with WBV) significantly increased muscle activity during static semi-squats and dynamic squats, with higher WBV frequencies resulting in the greatest increase in EMG activity. Bedient et al. (2009) found that a single bout of WBV (30-50 Hz, 2-5 mm, 30 seconds/exercise, 8 combinations) significantly increased power output at 1 minute across all frequencies and displacements in young healthy adults. The greatest effect was found at 50 Hz, and 30 Hz appeared to have a greater effect than either 35 or 40 Hz at all post-treatment time points (Bedient et al., 2009). Taken together, the findings of the above studies indicate that WBV could be an effective training method for improving neuromuscular performance in able-bodied populations.

1.5.2.1.2 Cardiovascular function

Cardiorespiratory responses to WBV have also been studied in young healthy adults (Rittweger et al., 2000, 2001, 2002a, 2010; Cochrane et al., 2008; Hazell et al., 2008, 2012; Maikala et al., 2009) and the elderly (Avelar et al., 2011). Among young healthy adults, the addition of WBV (26 Hz, 6 mm, 3 exercises) during exercise induced a significant increase in oxygen consumption (VO_2) compared with a mild resistance exercise group without WBV (Rittweger et al., 2001). As aforementioned, the m uscle activity levels were higher when WBV was added to exercise (Abercromby et al., 2007; Ritzmann et al., 2010; Cardinale & Lim, 2003; Marin et al., 2009; Hazell et al., 2007, 2010; Roelants et al., 2006). The increase in muscle work necessitates an increase in blood flow and supply of oxygen to the muscles. Therefore, the increase in VO_2 and HR during WBV exercises may be explained by the increased intensity of exercise resulting from the WBV-induced increase in neuromuscular activation. Hazell and Lemon (2012) demonstrated that VO_2 and HR increased by 23% and 71%, respectively, during WBV exercise (vertical, 45 Hz, 2 mm, 30 seconds/exercise, 6 exercises/set, 5 sets) compared with no-WBV. In contrast, Hazell et al. (2008) reported minimal effects on HR and mean arterial pressure, with the addition of WBV (vertical, 45 Hz, 2 mm, 1 minute /bout, 15 bouts) to a static semi-squat exercise. Differences in the WBV protocols and exercises performed may account for the different results reported in these studies.

Rittweger et al. (2002a) provided evidence that the intensity of WBV influences the cardiorespiratory response. They investigated the effect of WBV on metabolic power in healthy subjects, and found that the specific oxygen uptake showed a linear increase as the WBV (5 mm) frequency increased from 18 to 34 Hz. Moreover, the specific VO_2 increased significantly when an additional load of 40% of the lean body mass was attached to the waist of subjects. When the load was applied to the shoulders, the VO_2 further increased. This increase in VO_2 and HR responses during WBV led Rittweger et al. (2002a) to suggest that it could be used as an alternative intervention in cardiovascular exercise training. In contrast, Avelar et al. (2011) reported that adding WBV (40 Hz, 4 mm, 40 seconds/exercise, 8 exercises) to a squatting exercise increased VO_2 by 20% and HR by 7.5% in 18 healthy elderly participants. However, during the WBV exercise, the mean HR was around 56% of the age-match predicted maximum HR, and the increase in VO_2 was limited to around 2 metabolic equivalents. This finding indicated that the WBV exercise intensity did not meet the recommended threshold for cardiovascular training in this study (Avelar et al., 2011). Overall, although there is some evidence that exposure to WBV during both dynamic and static exercises may successfully increase VO_2 when compared to preforming the same exercises without WBV, the changes observed were only modest (Rittweger et al., 2000, 2001 & 2002a; Da Silva et al., 2007).

5.2.1.3 Flexibility

A number of studies have investigated the acute effects of WBV on muscle flexibility in the general population (Jacobs & Burns, 2009; Cochrane & Stannard, 2005; Gerodimos et al., 2010; Tsuji et al., 2014; Di Giminiani et al., 2010; Sands et al., 2006, 2008;Dallas et al., 2014a&b; Kinser et al., 2008; Cochrane, 2013), some of which reported positive treatment effects. Cochrane and Stannard (2005) reported enhanced arm countermovement vertical jump and flexibility performance following WBV (vertical, 6 mm, 26 Hz, 30-60 seconds/exercise, 6 exercises) compared with the control group (no WBV). Gerodimos et al. (2010) investigated the effects of WBV (a single session, all protocols: side-to-side alternating vibration; amplitude study: 25 Hz, 4-8 mm, 6 min; frequency study: 15-30 Hz) on flexibility in young females. Their main findings showed that a single session of WBV improved flexibility, which persisted for at least 15 minutes (Gerodimos et al., 2010).

Other studies have reported different results. Dallas et al. (2014a) assessed the effects of a single bout of WBV during eccentric and concentric squatting movements (30 Hz, 2 mm, 2 minutes) in young gymnasts. Their results revealed no significant effect on flexibility (Dallas et al., 2014a). Similarly, a randomized crossover study by Tsuji et al. (2014) reported that short-term WBV training (vertical, 40 Hz, 2-4 mm, 30 seconds/set, 3 sets) had no effect on flexibility (measured by the functional-reach and sit-and-reach tests). A meta-analysis conducted by Osawa et al. (2013a) revealed WBV had significant additive effects on flexibility compared with compared with the same condition without WBV.

1.5.2.1.4 Sensory

Research on the somatosensory effects of WBV in the general population is scarce (Pollock et al., 2011; Games et al., 2013; Dickin et al., 2012; Hannah et al., 2013). Pollock et al. (2011) investigated the effects of WBV (side-alternation vibration, 30 Hz, 1 min/bout, 5 bouts, 4 and 8 mm amplitude) on joint position sense (knee and ankle), cutaneous sensations in the leg and balance performance among young healthy participants. Their results showed that low amplitude (4 mm) WBV significantly decreased sensation in the ankle and foot immediately post-WBV, whereas high amplitude (8 mm) WBV reduced sensation in the foot, posterior shank, and ankle for the whole measure period. However, the joint position sense of the knee and ankle were not significantly influenced (Pollock et al., 2011). Hannah et al. (2013) also reported that a single session of unilateral WBV (vertical, 30 Hz, 4 mm, 1 minute of unilateral idometric squat exercise, 5 repetitions) did not influence knee joint proprioception in healthy males compared with the control group (the same exercise without WBV). Dickin et al. (2012), in contrast, demonstrated that when visual and somatosensory information was altered, WBV (10-50 Hz, 2 and 5 mm, 4 minutes) had an acute effect on the postural sway complexity and sway frequency in young healthy adults. Games et al. (2013) examined the acute effects of WBV (50 Hz, 2 mm, 5 minutes) on the sural nerve conduction velocity in young healthy adults and found no significant effects. To summarize, the effects of WBV on sensory system remain somewhat inconclusive, and warrant further study.

1.5.2.1.5 Functional Performance

A number of studies have examined the acute effects of WBV on functional performance in healthy older and young adults (Iodice et al., 2011; Armstrong et al., 2008; Lamont et al., 2010; Rehn et al., 2007; Padulo et al., 2014; Nordlund et al., 2007; Torvinen et al., 2002b; Wilcock et al., 2009; Bazett-Jones et al., 2008; Cormie et al., 2006).

Padulo et al. (2014) studied the effects of a short period of WBV (25 Hz, 10 minutes) on running gait in 16 male marathon runners. During the first minute following exposure to WBV, the step length and flight time were decreased, while the step frequency was increased compared to the sham control group, suggesting that WBV produced a significant alteration of the running kinematics (Padulo et al., 2014). Tunner et al. (2009) compared the acute effects of four different WBV frequencies (vertical, 0-40 Hz, 8 mm, 30 seconds) on countermovement jump performance in recreationally trained men. Their results revealed that a single bout of 30-second WBV (40 Hz, 8 mm) significantly improved jumping height in comparison to other frequencies (Tunner et al., 2009). In contrast, Armstrong et al. (2010) reported that after WBV (30-50 Hz, 2-6 mm, 1 minute/exercise, 8 exercises), the young healthy subjects made similar countermovement vertical jumps regardless of the WBV frequencies and amplitudes. In summary, research on the effects of WBV on functional performance in able-bodied individuals has produced mixed results. The effects may be highly dependent on the characteristics of the subjects, the WBV parameters, and the outcome measures used.

1.5.2.2 Effects of Long-term WBV Training in Able-bodied Humans

Apart from the acute effects, longer-term WBV training may induce physiological changes in human subjects (Bosco et al., 1998). Indeed, investigations into the effects of long-term WBV seem to provide more supportive evidence in various populations including athletes, active people, sedentary people, and the elderly. WBV therapy over a period of time appears to have the potential to elicit training effects on the neuromuscular (Wyon et al., 2010; Bautmans et al., 2005; von Stengel et al., 2010; Delecluse et al., 2003; Russo et al., 2003; Kvorning et al., 2006; Rees et al., 2007; Mahieu et al., 2006; Perchthaler et al., 2015; Osowa et al., 2011, 2013; Mikhael et al., 2010a; Petit et al., 2010), cardiovascular (Bogaerts et al., 2009; van Duijnhoven et al., 2010; Weber et al., 2013), and skeletal systems (Verschueren et al., 2011; Verschueren et al., 2004; Beck et al., 2010; Russo et al., 2003; Gusi et al., 2006; Rubin et al., 2004; Iwamoto et al., 2005; Slatkovska et al., 2011) in able-bodied individuals.

1.5.2.2.1 Neuromuscular Function

A number of randomized control trials (RCTs) have investigated the effects of WBV on various neuromuscular outcomes in able-bodied human subjects (Wyon et al., 2010; Petit et al., 2010; von Stengel et al., 2010; Delecluse et al., 2003; Russo et al., 2003; Kvorning et al., 2006; Rees et al., 2007; Mahieu et al., 2006; Perchthaler et al., 2015; Osowa et al., 2011, 2013; Mikhael et al., 2010b; Bautmans et al., 2005). The majority of these studies reported that WBV induced beneficial effects on leg muscle strength. Most recently, a meta-analysis by Osawa et al. (2013a) showed significant additional beneficial effects of WBV on countermovement jump performance and knee extension muscle strength compared with identical conditions without

WBV. However, there is limited evidence to conclude that WBV is better than conventional muscle strength training in improving leg muscle strength (Rehn et al., 2007; Sitjà-Rabert et al., 2012; Lau et al., 2011; Osawa et al., 2013b; Marin et al., 2010a,b). For example, a meta-analysis by Lau et al. (2011) concluded that WBV was not superior to other types of exercise program in modifying knee isometric muscle strength, knee dynamic muscle strength, and sit-to-stand performance among older adults.

1.5.2.2.2 Cardiovascular Function

Research on the long-term effects of WBV on the cardiovascular system in healthy participants is scarce (van Duijnhoven et al., 2010; Bogaerts et al., 2009; Weber et al., 2013). van Duijnhoven et al. (2010) examined whether resistive vibration exercise (16-26 Hz, 5-7 minutes/session) was effective in counteracting the detrimental vascular changes associated with prolonged bedrest in young healthy men. Their results showed that the resistive vibration exercise significantly attenuated the bedrest-induced reduction in dilatory capacity and diameter of the superficial femoral artery. These effects were not evident in the control group (resistive exercise without WBV) (van Duijnhoven et al., 2010). In contrast, Weber et al. (2013) reported that a 6-week resistive exercise training with superimposed WBV (side alternating, 20-40 Hz, 6 mm, 9 minutes/session) induced a significant increase in the resting diameter of the superficial femoral artery in a group of young healthy men, but the effect was similar to that observed after resistive exercise without WBV. Their study also found that the flow-mediated dilation of the same artery was not affected after either form of exercise training. Most recently, a study by Beiger et al. (2014) compared the effects of resistive exercise with and without superimposed vibrations on the microcirculation of the skeletal muscles in the lower extremities. Six weeks of resistive exercise with vibrations (20 Hz, 6 mm peak-to-peak amplitude) significantly increased the blood volume by 27% and the vasodilator response by 14% in the gastrocnemius muscle. These effects were not observed after resistive exercise without vibrations, although the number of capillaries around fibers increased similarly in both groups. The authors concluded that resistive exercise with WBV enhanced the microcirculation of muscles through the vasodilation of small arterioles.

Only one study has assessed the effect of WBV therapy on VO_{2peak}, which is considered an important indicator of cardiorespiratory fitness. In an RCT involving 220 older adults, Bogaerts et al. (2009) found that both the WBV training program (40 minutes/session, 3 sessions/week, 1 year) and the fitness exercise program (cardiovascular, resistance, balance, and flexibility exercises) resulted in similar gains in VO_{2peak}, and the improvement in both groups was significantly better than in the no-intervention control group. However, clinical recommendations on the use of WBV to improve cardiorespiratory fitness cannot be made on the basis of only one study, thus more research is required in this area.

1.5.2.2.3 Bone

A number of RCTs (Verschueren et al., 2011; Verschueren et al., 2004; Beck et al., 2010; Russo et al., 2003; Gusi et al., 2006; Rubin et al., 2004; Iwamoto et al., 2005; Slatkovska et al., 2011) have examined the effects of WBV on bone tissue in healthy young and elderly adults. For example, Gusi et al. (2011) demonstrated that 8 months of WBV (vertical, 12.6 Hz, 3 mm, 1 min/bout, 6 bouts/session, 3 sessions/week) increased BMD in the femoral neck by 4.3% compared to the walking-only group (55 minutes of walking, 5 minutes of stretching) among post-menopausal women. In contrast, a study involving 202 healthy post-menopausal women by Slatkovska et al. (2011) reported that 12 months of WBV therapy (vertical, 90 or 30 Hz, 0.3 g, 20 minutes/day) had no significant effect on tibial trabecular areal BMD or volumetric BMD at the femoral neck, lumbar spine, and total hip compared with the control group (no-WBV). The mixed results could be due to differences in the characteristics of subjects, WBV intervention protocols, and methodological quality (e.g., the sites of BMD measurement). A meta-analysis by Slatkovska et al. (2010) showed that WBV induced a modest but significant increase in the areal BMD of the hip, but not the volumetric BMD of the spine or the areal BMD of the tibial trabecular in post-menopausal women. In young adults, WBV had no significant effect on the volumetric BMD of the tibial trabecular, or the BMC of the spine or hip joint. However, this meta-analysis did not differentiate between those studies that used an active exercise comparison group and those that used a control group (no-WBV intervention). A meta-analysis by Lau et al. (2011) concluded that WBV has no significant effect on lumbar spine or hip BMD in female elderly compared with no-WBV intervention or without active exercise training.

1.5.2.3 Effects of Long-term WBV Training in Human with Chronic Conditions

The specific physiological effects induced by WBV in able-bodied individuals could potentially be exploited for treatment purposes in various chronic conditions (Ahlborg et al., 2006; van Nes et al., 2004, 2006; Arias et al., 2009; Turbanski et al., 2005; Baum et al., 2007; Trans et al., 2009; Ebersbach et al., 2008; Tihanyi et al., 2007 & 2010; Haas et al., 2006a&b; Schuhfried et al., 2005; King et al., 2009; Roth et al., 2008; Rietschel et al., 2008; Wunderer et al., 2010). The following paragraphs provide a brief overview of the current, up-to-date evidence for such applications.

1.5.2.3.1 Musculoskeletal Diseases

WBV is an increasingly common alternative intervention approach for musculoskeletal conditions such as knee osteoarthritis (Park et al., 2013), low back pain (Iwamoto et al., 2005), fibromyalgia syndrome (Alentorn-Geli et al., 2008), and anterior cruciate ligament injury (ACL) (Fu et al., 2013). Research has shown that WBV increases neuromuscular EMG activation (Cardinale & Lim, 2003; Roelants et al., 2006; Hazell et al., 2007), suggesting that WBV training may be a potentially useful therapeutic modality for improving muscle strength/power in people suffering from muscle weakness as a result of musculoskeletal disorders. Several studies have demonstrated that the improvement in muscle strength from WBV training is similar to that derived from more traditional muscle strength training (e.g., resistance training) (Roelants et al., 2004a&b; Delecluse et al., 2003; Torvinen et al., 2002a), while other studies (Delecluse et al., 2005; Cochrane et al., 2004; Kvorning et al., 2006) have reported limit therapeutic benefit. In general, WBV exercise is not recommended as an intervention for individuals with acute musculoskeletal conditions (Cardinale et al., 2006).

1.5.2.3.1.1 Knee Osteoarthritis

WBV training is recommended as an effective and safe non-pharmacological tool for improving self-perceived muscle weakness, pain, gait deficits, poor balance and proprioception in individuals with knee osteoarthritis (Trans et al., 2009; Zafar et al., 2015; Wang et al., 2014c; Park et al., 2013; Simão et al., 2012). Trans et al. (2009) examined the effects of WBV intervention program (8-week) in women suffering from knee osteoarthritis (6-9 bouts, 30-70 seconds/bout, 25-30 Hz, 2 days/week, 8 weeks) with the participants were randomly allocated to

3 groups: WBV exercise on a stable platform, WBV exercise on an unstable platform, and a no-intervention control group. Their results indicated that WBV training on a stable platform significantly improved isokinetic knee extensor strength, and those who exercised on an unstable WBV platform was significantly improved with the proprioceptive function (i.e. the threshold for the detection of passive movement). Simão et al. (2012) found that a 12-week WBV training program (6-8 bouts, 20-40 seconds/ bout, 35-40 Hz, 4 mm, 3 days/week) improved the balance, self-perception of pain, gait quality, and reduced the levels of inflammatory markers in older participants with knee osteoarthritis. More recently, Park et al. (2013) demonstrated that WBV (12-14 Hz, 2.5-5 mm, 10 minutes/bout, 2 bouts, 3 days/week, 8 weeks) was superior in reducing pain compared with a home-based exercise program (i.e. control group), but the gain in quadriceps muscle strength and balance were not significantly different between the two groups of individuals with chronic knee osteoarthritis. In contrast, Avelar et al. (2011) reported that a WBV exercise regime (35-40 Hz, 4 mm, 6-8 bouts, 20-40 seconds/bout, 1 day/week, 12 weeks) did not reduce knee pain compared with the control group that engaged in the same exercises without the WBV stimulation. Similarly, Segal et al. (2013) reported that middle-aged women with risk factors for knee osteoarthritis who participated in a 12-week WBV (35 Hz, 2 mm, 2 times/week) exercise program did not show greater improvements in lower limb strength or power than the control group.

The discrepancies in results may be attributable to the difference in the nature of the comparison groups. The studies that showed significant effects of WBV used a comparison group that received no-WBV intervention, whereas those that reported non-significant effects involved a comparison group that performed the same exercises without WBV stimulation. It can be argued, therefore, that the therapeutic effects reported for WBV may be due to the exercises themselves rather than the added WBV stimulation.

1.5.2.3.1.2 Low Back Pain

Evidence related to the long-term adaptation effects of WBV therapy in individuals with low back pain (LBP) is limited. Iwamoto et al. (2005) demonstrated that a WBV intervention (20 Hz, 4-min per exercise, 1 session per week, 12 months) successfully reduced chronic back pain in post-menopausal women with low bone mass. Rittweger et al. (2002b) demonstrated that WBV training (18Hz, 6 mm, 4-7 minutes/exercise, 12 weeks) significantly increased lumber extension torque (30.1 Nm/kg) compared with the control group (lumbar extension). These findings suggest that WBV exercise may be helpful for nonspecific chronic LBP. Moreover, del Pozo-Cruz et al. (2011) examined the effects of a low-frequency WBV therapy (20 Hz, 60 second/exercise, 6 repetitions, 24 sessions, 2 times/week, 12-week) in people with LPB. Their results found that WBV resulted in significantly higher scores on the postural stability index, Oswestry Index, Roland Morris Index, and the progressive isoinertial lifting evaluation test compared with the control group. They suggested that WBV therapy is feasible and may be a novel therapeutic modality for treating non-specific LBP.

1.5.2.3.1.3 Fibromyalgia

Fibromyalgia is a condition characterized by exaggerated pain sensation and unusual fatigue. Studies on the application of WBV in people with fibromyalgia has emerged in the past few years, including its effects on serum insulin-like growth factor (Alentorn-Geli et al., 2009), pain and fatigue (Alentorn-Geli et al., 2008), strength and quality of life (Olivares et al., 2011;

Sañudo et al., 2010), balance (Gusi et al., 2010; Sañudo et al., 2012; Adsuar et al., 2012; Sañudo et al., 2013), and functional performance (Sañudo et al., 2013).

Adsuar et al. (2012) showed that WBV therapy (12.5 Hz, 3 mm, 12 weeks) significantly improved scores on the postural stability indices for single leg stance (dominant limb), compared with the control group. Sañudo et al. (2013) investigated the effects of WBV (30 Hz, 4 mm, 30-seconds/exercise, 2 times/week, 8 weeks) on body balance and dynamic strength in women with fibromyalgia and found WBV had significantly improved scores on the medio-lateral stability index and medio-lateral mean deflection (with eyes opened) compared with the control group. The results suggested that traditional exercise training, supplemented with WBV stimulation, could improve balance in females with fibromyalgia.

Alentorn-Geli et al. (2008) reported that WBV (30 Hz, 2 mm, 2 sessions/week, 6 weeks, 4.5-min per session for the first 2-session, 18-minutes for 10-session) significantly reduced fatigue and pain in females with fibromyalgia compared with the no-exercise control group. However, the WBV group and the comparison group that performed the same exercises without WBV demonstrated no significant between-group difference (Alentorn-Geli et al., 2008), indicating that WBV did not confer any additional treatment effects over exercise alone. Gusi et al. (2010) showed that WBV training (12.5 Hz, 3 mm, 30-60 seconds/repetition, 6 repetitions, 3 times/week, 12 weeks) did not improve scores on the dynamic balance index compared with the no-exercise group (Gusi et al., 2010). Taken together, the effects of WBV in individuals with fibromyalgia remain inconclusive.

1.5.2.3.1.4 Post Anterior Cruciate Ligament Reconstruction Surgery

There are few RCTs that investigated the effects of WBV therapy on neuromuscular control post-anterior cruciate ligament (ACL) reconstruction (Moezy et al., 2008; Berschin et al., 2014; Fu et al., 2013). For example, Moezy et al. (2008) reported the effects of WBV (30-50 Hz, 2.5-5 mm, 4-16 minutes/session, 12-week) on athletes who had undergone ACL reconstruction surgery. The WBV group shows significantly improved postural stability and proprioception compared with the control group (i.e., conventional strengthening exercises, flexibility training, and proprioceptive training of the lower limbs). Fu et al. (2013) found that conventional rehabilitation combined with WBV training (20-60 Hz, 2 mm and 4 mm, 2 sessions/week, 8 weeks) starting 1 month postoperatively successfully improved isokinetic performance, postural control, shuttle run, and single-legged hop performance. Berschin et al. (2014) demonstrated that WBV exercise (10-15 Hz, 1 min/exercise, 2-6 repetitions) yielded significantly better results in the stability test. However, WBV did not significantly improve the clinical parameters (range of motion, anterior posterior knee laxity), isometric and isokinetic muscle strength, and Lysholm score compared with the standard exercise group (stretching, balance exercise, and muscle strength exercise). These findings indicated that WBV therapy may be an alternative intervention to traditional standard exercise training in the second week after surgery (Berschin et al., 2014). Overall, these studies suggested that WBV training may offer a practical alternative form of rehabilitation post-ACL surgery by enhancing the accuracy of knee joint proprioception during the stance phase of walking, and thereby improving postural stability (Moezy et al., 2008; Berschin et al., 2014; Fu et al., 2013).

1.5.2.3.2 Cardiorespiratory Conditions

1.5.2.3.2.1 Chronic Obstructive Pulmonary Disease

Although few studies have examined the effects of WBV training in patients with chronic obstructive pulmonary disease (COPD) (Furness et al., 2014; Pleguezuelos et al., 2013; Greulich et al., 2014; Braz Júnior et al., 2015; Gloechl et al., 2012), some positive findings have been reported. Gloechl et al. (2012) demonstrated that WBV (side alternating, 24-26 Hz, 3 minutes/exercise, 3 repetitions/session, 3 sessions/week, 3 weeks) significantly improved functional performance on the six-minute walking test (6MWT), and decreased the time required for a sit-to-stand test than the control group without WBV among individuals with COPD. Pleguezuelos et al. (2013) reported that the WBV group (35 Hz, 2 mm, 30 seconds/series, 6 series/session, 3 sessions/week, 6 weeks) walked longer distances and had lower oxygen desaturation during the 6MWT than the control group. The maximum inspiratory pressure and maximum expiratory pressure was also higher in the intervention group after the WBV training period. However, no significant differences in maximum moment of concentric knee flexor/extensor force between the two groups were found (Pleguezuelos et al., 2013). Overall, few WBV trials have been conducted in patients with COPD and its efficacy in the rehabilitation of this population remains inconclusive and requires further investigation.

1.5.2.3.2.2 Cystic Fibrosis

Cystic fibrosis (CF) is an autosomal recessive disease (Orenstein et al., 2004) that causes reduced muscle mass and decreased muscle strength (Hussey et al., 2002; Pinet et al., 2003). WBV may thus have treatment implications for this patient population.

Only three quasi-experimental studies have examined the effects of WBV on muscle function in individuals with CF (Roth et al., 2008; O’Keefe et al., 2013; Rietschel et al., 2008). In a study involving 11 young adults with CF, Roth et al. (2008) reported that six months of WBV training (side alternating, 12-26 Hz, 7.8 mm, 6-12 minutes, 5 days/week) resulted in no significant improvements in muscle velocity and power, as evaluated by one- and two-legged jumps on a Leonardo platform (Novotec Medical, Pforzheim, Germany). Rietschel et al. (2008) showed that three months of WBV training (vertical, 20-25Hz, 0.6 mm, 3 minutes/session, 3 sessions twice/day, 5 days/week) significantly improved the power and force of leg muscles among 10 young adults with CF. However, O'Keefe et al. (2013) found that 12 weeks of WBV (20-22 Hz, 1 mm, 3 days/week) did not induce significant changes in leg extension and leg press strength and power in 7 children with CF. In summary, the results are mixed and no conclusion can be drawn yet. Further studies in this area are warranted.

1.5.2.3.3 Neurological Disorders

The application of WBV in patients with neurological conditions has aroused much interest in recent years, including SCI (Herrero et al., 2011), Parkinson's disease (PD) (Zhao et al., 2014; Ebersbach et al., 2008; Gaßner et al., 2014; King et al., 2009), multiple sclerosis (MS) (Hilgers et al., 2013), and cerebral palsy (CP) (El-Shamy, 2014). Additionally, several systematic reviews have examined the effects of WBV in individuals with neurological conditions (Lau et al., 2011; Sadeghi & Sawatzky, 2014; Madou & Cronin, 2008; Sharififar et al., 2014; del Pozo-Cruz et al., 2012; Rigau Comas et al., 2012).

1.5.2.3.3.1 Spinal Cord Injury

Evidence on the long-term effects of WBV in people with SCI is limited. Some studies support the use of WBV for evoking reflex-induced standing in patients with SCI, some of whom progressed to walking (Gianutsos et al., 2000; Ness & Field-Fote, 2009b), spasticity management

(Ness & Field-Fote, 2009a; Murillo et al., 2011), and enhancing EMG muscle activity and blood flow in the legs (Herrero et al., 2011).

In a pilot study conducted by Ness and Field-Fote (2009b), 17 individuals with chronic (onset 1 year or more), motor-incomplete SCI received 12 sessions of WBV intervention (3 days/week, 4 weeks). WBV significantly increased the patients' walking parameters (e.g., step length, walking speed, and cadence) and improved the consistency of intra-limb coordination, suggesting that WBV may be useful for improving walking ability in individuals with SCI. The same authors (Ness & Field-Fote, 2009a) found that WBV (3 days/week, 4 weeks) significantly reduced spasticity in individuals with chronic SCI (> 1 year). Herrero et al. (2011) demonstrated that WBV (10-30 Hz, 1 min/cycle, 3 cycles/session, 8 sessions) alone significantly increased the EMG neuromuscular activity and blood flow velocity in individuals with complete SCI (classified as A type by the American Spinal Injury Association). Their results also showed that higher frequencies (30 and 20 Hz) were more effective in increasing blood flow velocity of the lower extremity (Herrero et al., 2011).

In summary, research on long-term WBV training in patients with SCI is scarce. More studies are needed before WBV can be adopted into clinical practice guidelines for the management of SCI (Sadeghi & Sawatzky, 2014).

1.5.2.3.3.2 Cerebral Palsy

There is some evidence that WBV therapy can improve functional performance in individuals with CP (Ahlborg et al., 2006; El-Shamy, 2014; Semler et al., 2007; Marwa et al., 2014; Ruck et al., 2010; Lee et al., 2013; Unger et al., 2013; Stark et al., 2010). In adults with spastic diplegic CP, WBV training (25-40 Hz, 6 minutes, 3 times/week, 8 weeks) led to improved muscle strength of the lower-extremity, and reduced spasticity in the quadriceps muscles, but no additional effect on ambulatory and motor function, compared with the resistance training group (Ahlborg et al., 2006). Runck et al. (2010) conducted an RCT to examine the effects of WBV (side-to-side alternating vertical sinusoidal vibration, 12-18 Hz, 4 mm, 2.6 g, 9 minutes/session, 5 sessions/week, 6 months) in children with CP. The WBV group showed an increase in the average walking speed in the 10-minute walk test and reduced areal BMD in the femur diaphysis compared with the group who received individualized physiotherapy. Lee et al. (2013) demonstrated that WBV training (side-to-side alternating, 5-25 Hz, 1-9 mm, 18 minutes/session, 3 sessions/week, 8 weeks) resulted in significantly better walking speed, step length, cycle time ankle angle, and tibialis anterior thickness compared with the control group that underwent conventional physical therapy training. Notwithstanding the encouraging results reported in the literature, the number of studies and their sample sizes are small.

1.5.2.3.3.3 Parkinson's Disease

Neuromotor deficits are common in individuals with PD, and although they may benefit from WBV (Lau et al., 2011), previous studies have shown mixed results. A single session of WBV (6 Hz, 3 mm, 1 minute/bout, 5 bouts) resulted in significant improvement in waling ability as evaluated by the Timed-up-and-go (TUG) test, when compared with the standing exercises (King et al., 2009; Haas et al., 2006). However, WBV for a longer duration (3-5 weeks) did not result in better outcomes (body balance or signs and symptoms measured by the Unified Parkinson's Disease Rating Scale) than physical therapy alone (Ebersbach et al., 2008; Gaßner et al., 2014; Arias et al., 2009). Two systematic reviews (Sharififar et al., 2014; Lau et al., 2011) concluded that WBV applied in individuals with PD may have some positive effects, but there is still insufficient evidence to refute or prove its effectiveness in the PD population. More high-quality trials are needed.

1.5.2.3.3.4 Multiple Sclerosis (MS)

A number of studies have examined whether the use of WBV in people with MS improves functional outcomes such as balance (Alguacil et al., 2012), muscle strength (Jackson et al., 2008; Claerbout et al., 2012; Schyns et al., 2009), and walking (Mason et al., 2012; Hilgers et al., 2013), but the findings remain inconclusive (Schuhfried et al., 2005; Jackson et al., 2008; Wolfsegger et al., 2014). Wolfsegger et al. (2014) reported that a 3-week WBV training program (2.5-4.0 Hz, 45-60 seconds/set, 5-7 sets) for MS patients produced no significant differences in walking function (walking velocity, step length, stride length, and double support phase) compared to the no-WBV group. In a 4-week randomized cross-over study, 16 individuals with MS were equally allocated to two groups. The first group received 4 weeks of WBV exercises (vertical, 40 Hz, 2 mm, 30 seconds/exercise, 10 exercises/session, 3 sessions/week), followed by 2 weeks of no intervention and then 4 weeks of exercise alone without WBV. Group 2 received the same interventions, but in the reverse order. No significant difference in muscle strength and functional performance was detected between the two groups (Schyns et al., 2009). Broekamns et al. (2010) used a longer WBV intervention period (vertical, 25-45 Hz, 2.5 mm, 2.5-16.5 minutes/session, 20 weeks, but found no change in the maximal isometric or dynamic strength, and endurance of the leg muscles. There was also no change in patients' functional capacity, including the Berg balance scale, 2-minute walk test, TUG test, and timed 25-foot walk test.

In contrast, Algucil et al. (2012) found that WBV training (6 Hz, 3 mm amplitude, 1 minute/exercise, 5-mins/session for 5 consecutive days) led to a greater improvement in reaction times in the Motor Control Test than the control group without WBV, indicating that WBV is a possible therapeutic tool for maintaining balance and posture in MS patients. Similarly, Claerbout et al. (2012) found that three weeks of WBV training program (vertical, 30-40 Hz, 1.6 mm, 30-60 seconds/exercise, 7-13 minutes/session, 10 sessions) significantly improved maximal knee extensors and flexors muscle strength in those in the WBV-full group, who performed exercises on a vibration platform. However, no improvement was found for those in the WBV-light group, who performed exercise on the vibration platform covered by a damping mat, or the conventional therapy control group.

In summary, studies on WBV in MS patients have used small samples (3 to 25) and one study did not include a control group (Jackson et al., 2008; Sitja-Rabert et al., 2012). There is insufficient evidence of the effects of WBV training on muscle strength, balance, cardiovascular function, sensory function, and functional performance among people with neurological disorders. More studies assessing other functional tests and optimal WBV parameters are needed before a definitive recommendation can be made (Sitjà Rabert et al., 2012; del Pozo-Cruz et al., 2012).

1.6 RATIONALE OF RESEARCH STUDIES

The review of recent research presented in this chapter indicates that WBV has aroused much interest in both animal and human research. While the results are far from conclusive, the positive findings on neuromuscular and cardiovascular function reported in various patient populations suggest that WBV may also have potential applications in people with stroke, who often sustain considerable deficits in muscle strength, balance, mobility, and cardiovascular function. Indeed, an increasing number of studies on WBV applications in stroke have emerged in the past decade (Pang et al., 2013b; Silva et al., 2014; van Nes et al., 2004; Marı´n et al., 2013; van Nes et al., 2006; Chan et al., 2012; Tihanyi et al., 2007& 2010; Merket et al., 2011; Brogardh et al., 2012; Lau et al., 2012; Tankisheva et al., 2014). Therefore, it is of utmost importance to first review the scientific evidence related to the use of WBV in the stroke population. Chapter 2 of this thesis presents a systematic review of the effects of WBV therapy on body structure/function, activity, and participation in individuals with stroke (Liao et al., 2014a). The review adopts the WHO's International Classification of Functioning (WHO, 2001) as the theoretical framework.

The manual of International Classification of Functioning, Disability and Health provides the following definitions (WHO, 2001, 212-213).

Functioning is an umbrella term for body functions and structures, activities and participation. It denotes the positive aspects of the interaction between an individual (with a health condition) and contextual (environmental and personal) factors.

Disability is an umbrella term for impairments, activity limitations, and participation restrictions. It denotes the negative aspects of the interaction between an individual (with a health condition) and contextual (environmental and personal) factors.

Body functions - The physiological functions of the body systems (including psychological functions).

Body structures - Anatomical parts of the body such as organs, limbs, and their components.

Impairments - Problems in body functions and structures, such as significant deviation or loss.

Activity - The execution of a task or action by an individual.

Activity limitations - Difficulties an individual may experience in executing activities.

Participation - Involvement in a life situation.

Participation restrictions - Problems an individual may experience in involvement in life situations.

Environmental factors - The physical, social, and attitudinal environment in which people a person lives and conduct their lives. These are either facilitators to or barriers of the person's functioning.

This framework provided a more systematic approach and facilitated the development of a comprehensive picture of the effects of WBV on all aspects of health and functioning. The systematic review clearly highlighted several gaps of knowledge in the field (Liao et al., 2014a). First, few fundamental studies have explored the influence of different WBV parameters on different outcomes. None of the studies compared different WBV protocols. Further studies are required to compare the effects of different WBV protocols so that the optimal protocol can be identified. Second, many studies were limited by poor methodological quality and small sample sizes. Randomized controlled studies with larger sample sizes are required to further investigate the effects of WBV therapy in stroke. Third, safety issues need to be further explored, as quite a number of studies did not explicitly report the incidence of adverse events related to WBV and their severity. In particular, the cardiovascular stress induced by WBV is highly relevant to the stroke population considering that many stroke patients have a positive history of cardiovascular conditions (Roth et al., 1993). While some studies have examined the cardiovascular responses in young healthy individuals (Hazell et al., 2008; Hazell & Lemon, 2012; Rittweger et al., 2000, 2001, 2002a, 2010), none has studied the same in people with stroke. This topic merits further attention. Finally, very few WBV studies have adopted a holistic approach in the selection of outcome measures. In particular, there is a noticeable lack of evidence on outcomes at the participation level. While it is important to address stroke-related impairments, it is equally, if not more, important to determine whether the alleviation of these impairments leads to changes in functional activities and societal participation. It is essential to adopt a more holistic approach by incorporating outcomes that encompass all three domains of functioning (i.e., body structures/functions, activity, and participation) together with other contextual factors (i.e., perceived environmental barriers).

In light of the knowledge gaps identified in the systematic review of the literature, several studies were conducted to add knowledge to the field. The study reported in Chapter 3 developed a Chinese version of the Craig Hospital Inventory of Environmental Barriers (CHIEF-C) and established its validity and reliability for use with people after stroke. This instrument measures the perceived environmental barriers that may affect daily functioning, and it was subsequently used in the RCT as an outcome measure. The study presented in Chapter 4 aimed to compare the neuromuscular activity of the gastrocnemius and vastus lateralis during exposure to different WBV intensities while performing various static leg exercises in individuals with chronic stroke. Chapter 5 describes a study that investigated how the leg muscle activity in the tibialis anterior and biceps femoris varied with different WBV intensities, the static exercises performed, and their relationships with leg motor impairment and spasticity. Chapter 6 examines the neuromuscular response to WBV during different dynamic exercises. The study reported in

Chapter 7 assessed cardiovascular system responses (e.g., heart rate, blood pressure, oxygen consumption rate) during exposure to different WBV intensities and static/dynamic exercises. Finally, Chapter 8 presents the results of a RCT that examined the effects of a 10-week WBV exercise program on body functions and structures, activity, and participation in individuals with chronic stroke.

Overall, the studies contained in this thesis were designed to systematically evaluate the effects of WBV in individuals with stroke. The findings gained will be valuable in guiding the design of optimal WBV protocols to improve functional performance among people with stroke in a safe manner.

1.7 OBJECTIVES AND HYPOTHESES

1.7.1 Overall Aim

The overall aim of the thesis was to examine the acute and long-term effects of WBV in people with chronic stroke.

1.7.2 Objectives of Individual Chapters

1.7.2.1 Chapter 2: Effects of Whole-body Vibration Therapy on Body Functions and Structures, Activity and Participation Post-stroke: A Systematic Review.

Objective (1): To conduct a systematic review of the available scientific evidence to evaluate the effects of WBV therapy on body functions and structures, activity and participation in individuals with stroke.

Objective (2): To conduct a systematic review of the available evidence to assess the safety of WBV in people with stroke.

1.7.2.2 Chapter 3: Measuring the Environmental Barriers Faced by Individuals Living with Stroke: Development and Validation of the Chinese version of the Craig Hospital Inventory of Environmental Factors

Objective: To perform a cultural adaptation of the Craig Hospital Inventory of Environmental Factors (CHIEF), and to establish its validity and reliability for use with individuals with stroke.

1.7.2.3 Chapter 4: Leg Muscle Activity during Whole-body Vibration in Individuals with Chronic Stroke

Objective (1): To assess the activation of the vastus lateralis (VL) and gastrocnemius (GS) muscles during exposure to varying WBV intensities while performing different static exercises in people with chronic stroke.

Objective (2): To assess the interaction between static exercise and WBV intensity on neuromuscular activation of the VL and GS muscles.

Objective (3): To compare the neuromuscular responses of the VL and GS muscles to WBV between the paretic and the non-paretic leg during static exercises.

1.7.2.4 Chapter 5: Effect of Vibration Intensity, Exercise and Motor Impairment on Leg Muscle Activity Induced by Whole-Body Vibration in People with Stroke

Objective (1): To examine the neuromuscular activation of the biceps femoris (BF) and tibialis anterior (TA) muscles during exposure to different WBV intensities when performing static exercises among individuals with chronic stroke.

Objective (2): To assess the interaction between static exercises and WBV intensity on neuromuscular activation of the BF and TA muscles.

Objective (3): To compare the neuromuscular responses of the BF and TA muscles to WBV between the paretic and the non-paretic leg during static exercises.

Objective (4): To assess the relationship between WBV-induced muscle activity and leg motor impairment and spasticity.

1.7.2.5 Chapter 6: Effect of Whole-body Vibration on Neuromuscular Activation of Leg Muscles during Dynamic Exercises in Individuals with Stroke

Objective (1): To investigate the immediate effect of different WBV intensities on neuromuscular activity in the VL, GS, BF, and TA muscles during dynamic exercises in individuals with chronic stroke.

Objective (2): To assess the interaction between dynamic exercise and WBV intensity on neuromuscular activation of the VL, GS, BF, and TA muscles.

Objective (3): To compare the neuromuscular responses of the VL, GS, BF, and TA muscles to WBV between the paretic and the non-paretic leg during dynamic exercises.

1.7.2.6 Chapter 7: Cardiovascular Stress Induced by Whole-Body Vibration Exercise in Individuals with Chronic Stroke

Objective: To determine the acute effect of different WBV protocols on VO_2, HR, blood pressure (BP), and rate-pressure product (RPP) during the performance of various static and dynamic exercises among people with chronic stroke.

1.7.2.7 Chapter 8: Different Whole-Body Vibration Intensities in Stroke: Randomized Controlled Trial

Objective (1): A single-blinded randomized controlled study was conducted to investigate the effects of different whole-body vibration (WBV) intensities on body functions/structures, activity and participation in individuals with stroke.

1.7.3 Hypotheses of each Individual Chapter

1.7.3.1 Chapter 3: Measuring the Environmental Barriers Faced by Individuals Living with Stroke: Development and Validation of the Chinese Version of the Craig Hospital Inventory of Environmental Factors

It was hypothesized that:

(1) The Chinese version of the CHIEF would have good reliability and validity for evaluating the perceived environmental barriers experienced by people with chronic stroke.

1.7.3.2 Chapter 4: Leg Muscle Activity during Whole-body Vibration in Individuals with Chronic Stroke

It was hypothesized that:

(1) The amplitude of the EMG activity of the bilateral VL and GS muscles would increase significantly with increasing WBV intensity;

(2) The intensity of the WBV-induced increase in leg muscle EMG activity would be exercise-dependent (i.e., WBV intensity × exercise interaction effect); and

(3) The WBV would exert greater effects on the EMG amplitude on the paretic side than on the non-paretic side.

1.7.3.3 Chapter 5: Effect of Vibration Intensity, Exercise and Motor Impairment on Leg Muscle Activity Induced by Whole-Body Vibration in People with Stroke

It was hypothesized that:

(1) The magnitude of the EMG activity of the bilateral BF and TA muscles would increase significantly with increasing WBV intensity;

(2) The magnitude of the WBV-induced increase in leg muscle EMG activity would be exercise-dependent (i.e., WBV intensity × exercise interaction effect);

(3) The WBV would exert similar effects on the EMG magnitude on the paretic side than on the non-paretic side (i.e., no WBV intensity × side interaction effect); and

(4) The WBV-induced EMG activity in the BF and TA muscles on the paretic side would not be significantly associated with the severity of leg motor impairment and spasticity.

1.7.3.4 Chapter 6: Effect of Whole-body Vibration on Neuromuscular Activation of Leg Muscles during Dynamic Exercises in Individuals with Stroke

It was hypothesized that:

(1) Increasing the WBV intensity would significantly increase the EMG magnitude in the bilateral VL, GS, BF, and TA muscles during different dynamic exercises in individuals with stroke;

(2) There would be a significant WBV intensity × dynamic exercise interaction effect on leg muscle EMG magnitude (i.e., dynamic exercise-dependent); and

(3) WBV would have similar effects on the EMG magnitude on the paretic side and the non-paretic side (i.e., no WBV intensity × side interaction effect).

1.7.3.5 Chapter 7: Cardiovascular Stress Induced by Whole-Body Vibration Exercise in Individuals with Chronic Stroke

It was hypothesized that:

(1) The WBV intensity, exercises performed, and their interactions would significantly influence VO_2 and HR; and

(2) The WBV intensity would significantly influence BP and RPP.

1.7.3.6 Chapter 8: Different Whole-Body Vibration Intensities in Stroke: Randomized Controlled Trial

It was hypothesized that:

(1) Adding WBV to exercise training would lead to significantly more improvements in body functions and structures, activity and perceived participation compared with the same exercise training without WBV;

(2) The high-intensity protocol would induce significantly more gain in the same outcomes compared with the low-intensity protocol; and

(3) The change score (post-test score minus pre-test score) of each outcome (i.e., body functions and structures, activity, and perceived participation) would be significantly correlated with the impairment level.

CHAPTER TWO

Effects of Whole-body Vibration Therapy on Body Functions and Structures, Activity and Participation Post-stroke: A Systematic Review

Liao Lin Rong

2.1 ABSTRACT

Background: Whole body vibration (WBV) has gained increasing popularity in rehabilitation. Recent studies have seen the application of WBV in individuals with chronic illnesses, including stroke.

Purpose: To compare WBV exercise with (1) the same exercise condition without WBV, (2) other types of physical exercise in enhancing body functions and structures, activity and participation in individuals with stroke, and examine its safety.

Data source: Electronic search were conducted on MEDLINE, CINAHL, PEDro, PubMed, PsycINFO, Science Citation Index.

Study Selection: Randomized controlled trials (RCTs) that investigated the effects of WBV among individuals with stroke were identified by two independent researchers. Ten articles (nine studies) totaling 333 subjects satisfied the selection criteria and were included in this review.

Data extraction: The methodological quality was rated using the PEDro scale. The results were extracted by two independent researchers and confirmed with the principal investigator.

Data Synthesis: Only two RCTs were considered as level 1 evidence (PEDro score ≥6 and sample size >50). Two RCTs examined the effects of a single WBV session whereas seven examined the effects of WBV programs spanning 3-12 weeks. No consistent benefits on bone turnover, leg motor function, balance, mobility, sensation, fall rate, activities of daily living, and societal participation were found, regardless of the nature of the comparison group. Adverse events were not uncommon but minor.

Limitations: A broad approach was used, with stroke as an inclusion criterion for review. No solid evidence was found concerning the effects of WBV on sub-groups of people with specific stroke-related deficits due to the heterogeneity of patient groups.

Conclusions: Clinical use of WBV in enhancing body functions/ structures, activity and participation after stroke is not supported.

2.2 INTRODUCTION

In the past decade, whole body vibration (WBV) therapy has gained increasing popularity in rehabilitation of different patient populations. The use of local muscle vibration has long been used in physical therapy to stimulate muscle activity (Eklund & Hagbarth, 1966). In the 1990s, muscle vibration was used during weight training to enhance muscle strength and power (Issurin et al., 1994; Issurin & Tenenbaum, 1999). Later, WBV platforms, which are capable of generating mechanical vibrations at different frequencies and magnitude, were developed, and have been widely used to enhance muscle performance in athletes (Martínez et al., 2013), young adults (Bosco et al., 1999; Torvinen et al., 2002a) and older adults (Lau et al., 2011). Typically, individuals are asked to perform both static and dynamic exercises while receiving WBV, in order to train up muscle strength in both types of contraction (Jordan et al., 2005; Luo et al., 2005; Cardinale et al., 2006; Rehn et al., 2007). Numerous studies have shown that muscle activation level, as measured by electromyography (EMG), is substantially enhanced when WBV is added during exercise (Hazell et al., 2010; Pollock et al., 2010; Cardinale & Jim, 2003). In addition to inducing reflex muscle activity (Eklund & Hagbarth, 1966; Cardinale et al., 2006; Ritzmann et al., 2010), there is also evidence that WBV can modulate the excitability of the spinal motorneuronal pool and corticomotor neurons (Kipp et al., 2011; Sayenko et al., 2010; Mileva et al., 2009). These physiological phenomena may be some of the mechanisms underlying the WBV-induced improvement in neuromuscular functions reported in previous studies.

The rapid development of WBV applications in humans in recent years also stems from animal research in the 1990s and 2000s, which found that high-frequency dynamic mechanical loading is a potent stimulus for bone formation (Umemura et al., 1997; Robling et al., 2001;

Hsieh & Turner, 2001). Since then, different WBV protocols have been developed in various animal models, with promising results (Flieger et al., 1998; Rubin et al., 2001; Ozcivici et al., 2007). These findings had led to a surge of research efforts in exploring the use of WBV to enhance bone mass in people at risk of developing osteoporosis, such as individuals during prolonged bed rest (Belavý et al., 2011), postmenopausal women and older adults (Lau et al., 2011).

Recent meta-analyses have suggested that WBV has beneficial effects on some aspects of muscular strength, balance and mobility function in older adults while its effect on bone tissue is rather inconclusive (Lau et al., 2011; Lam et al., 2012; Rogan et al., 2011; Satlpvsla et al., 2010). WBV research incorporating outcomes related to societal participation and quality of life is scarce (Bruyere et al., 2005). Additionally, it is uncertain which combinations of WBV frequencies and amplitudes are most effective in improving various outcomes (Lau et al., 2011; Lam et al., 2012).

In the past few years, researchers have begun to explore the application of WBV in individuals with chronic illnesses (Ebersbach et al., 2008; Broekmans et al., 2010; Ness & Field-Fote, 2009). The potential use of WBV in stroke has also aroused great research interest. A systematic review was thus undertaken to examine the effect of WBV in people with stroke. In this review, we adopted a framework based on the International Classification of Functioning, Disability and Health (ICF) model endorsed by the World Health Organization (Jette, 2006). It is known that the deficits in functioning at the level of body functions and structures post-stroke (e.g., muscle weakness, spasticity, cognitive deficits, etc.) may not only interact with each other to produce problems with execution of tasks such as walking and other activities of daily living (i.e. activity), but also impose restrictions on the ability to partake fully in various life situations (i.e., participation) (Nadeau et al., 1999; WHO, 2001). When evaluating a rehabilitative intervention, it is important to assess its effects on all 3 different levels of functioning, as a holistic approach in patient care is essential (Teasell, 2011).

This systematic review aimed to examine the effects of WBV therapy on body functions and structures, activity and participation in individuals with stroke (van Nes et al., 2006; Tihanyi et al., 2007, 2010; Merket et al., 2011; Lau et al., 2012; Pang et al., 2013b; Brogardh et al., 2012; Chan et al., 2012; Marı´n et al., 2013; Tankisheva et al., 2014). To examine the safety of WBV applications in people with stroke, adverse events associated with WBV training were also reviewed.

2.3 METHOD

2.3.1 Research question

The objective of this systematic review was defined using the PICO method (University of Oxford, 2013). *PATIENTS (P)*: individuals with stroke; *INTERVENTION (I)*: WBV therapy; *COMPARISON (C)*: (1) WBV compared to no WBV under the same exercise condition, (2) WBV compared to other types of physical activity or training; *OUTCOMES (O)*: body functions and structures, activity and participation. Two comparisons were used, because WBV training has two components, namely, vibratory stimulation, and exercises while standing on the platform. Using comparison (1) would allow the delineation of effects of the vibratory stimulation alone, while comparison (2) would enable us to determine whether the WBV exercise approach as a whole would be a viable alternative to common practice or other types of exercise. Thus, this systematic review aimed to answer the following question: does WBV therapy lead to better outcomes in body functions and structures, activity and participation when compared with no vibration under the same exercise condition or other forms of exercise among individuals with stroke?

2.3.2 Study selection

The inclusion criteria were randomized controlled trials (RCTs) that investigated the effects of WBV among individuals with stroke; included body functions and structures, activity, or participation as one of the outcome measures; were published in English. Articles were excluded if they were research studies on the effects of WBV in individuals with a primary diagnosis other than stroke (e.g. arthritis, etc.); reports in books or conference proceedings.

2.3.3 Data sources and searches

An extensive literature search of electronic databases, including MEDLINE (1950–7 May 2013), Cumulative Index to Nursing and Allied Health Literature (CINAHL) (1982–7 May 2013), PubMed and PsycINFO (1806+) were performed. The specific search strategy for the MEDLINE database is described in Appendix 1 (supplementary material). A similar search strategy was used for other databases. In addition, the Physiotherapy Evidence Database was searched using the keyword “vibration” (Centre for Evidence-Based Physiotherapy, 2013). The review protocol can be obtained by contacting the principal investigator (MYCP).

The titles and abstracts of the articles generated from the above search were screened to eliminate irrelevant studies. The full text of the remaining articles was then reviewed in detail to determine their eligibility. For each article that fulfilled the eligibility criteria, the reference list was also examined to identify other potentially relevant papers. Additionally, a forward search using the Web of Science was conducted on 5 October 2013 to indentify all relevant articles that referenced the selected articles. The article screening and selection was performed by two independent researchers (LRL, MZH) and any disagreement was resolved by discussion with the principal investigator (MYCP).

2.3.4 Methodological quality assessment

The PEDro scale was used to assess the scientific rigor of the selected studies (9–10: excellent; 6–8: good; 4–5: fair; <4: poor) (Table 2.1) (Bhogal et al., 2005). The PEDro score was obtained by searching the PEDro database (Centre for Evidence-Based Physiotherapy, 2013). Studies rated as good or excellent by PEDro and having a sample size >50 were considered as level 1 evidence while those of lower quality were considered as level 2 evidence (rated as fair or poor by PEDro, or sample size ≤50) (Pang et al., 2013b).

Table 2.1 Rating of the PEDro scale and level of evidence

Criterion	**Study**								
	Comparison 1 (5 studies)[a]					**Comparison 2 (4 studies)[b]**			
	Tihanyi et al., 2007	**Lau et al., 2012 & Pang et al., 2013b**	**Brogardh et al., 2012**	**Chan et al., 2012**	**Marin et al., 2013**	**van Nes et al., 2006**	**Tihanyi et al., 2010**	**Merkert et al., 2011**	**Tankisheva et al., 2013**
PEDro Scale									
Eligibility Criteria	Yes	Yes	Yes	Yes	**No**	Yes	Yes	Yes	**Yes**
Random Allocation	1	1	1	1	1	1	1	1	**1**
Concealed Allocation	1	1	1	1	1	1	0	0	**1**
Baseline Comparability	1	1	0	1	1	1	1	1	**1**
Blind Subjects	0	0	1	1	0	0	0	0	**0**
Blind Therapists	0	0	1	0	0	0	0	0	**0**
Blind Assessors	0	1	1	1	1	1	0	0	**1**
Adequate follow-up	1	1	1	1	1	1	0	0	**1**
Intention-to-treat analysis	0	1	1	0	1	1	1	0	**1**
Between group comparisons	1	1	1	1	1	1	1	1	**1**
Point estimates and variability	1	1	1	1	1	1	1	1	**1**
TOTAL PEDro score	**6**	**8**	**9**	**8**	**8**	**8**	**5**	**4**	**8**
Sample size ≥50	**No**	**Yes**	**No**	**No**	**No**	**Yes**	**No**	**Yes**	**No**
Level of evidence	**2**	**1**	**2**	**2**	**2**	**1**	**2**	**2**	**2**

[a] **Comparison** 1: exercise under the same condition as the WBV group, but without WBV or with sham vibration.

[b] **Comparison** 2: other forms of exercise/physical activity

2.3.5 Data synthesis and analysis

The effects of WBV on outcomes of interest were initially summarized by the first author (LRL). Next, two co-authors (MZH and FMHL) checked the accuracy of the data. Disagreements were settled by discussion with the principal investigator (MYCP) until a consensus was reached. After reviewing the results of the selected studies, it was decided that meta-analysis was not appropriate because only a few studies (<5) used the same outcome measures, and the treatment protocols also varied substantially across the different studies (i.e., heterogeneity). To estimate the size of the treatment effect for those outcomes that yielded significant results, the standardized effect size (SES) with Hedges' correction was computed using the mean and standard deviation (SD) of the change scores of the experimental and control groups (small SES = 0.2, medium = 0.5, large = 0.8) (Hedges & Olkin, 1985). If the mean or SD values of the change scores were not reported, the mean and SD values measured at post-test for the two groups were used to compute the SES.

2.4 RESULTS

2.4.1 Study selection

The flow of information through the different phases of the systematic review is described in Figure 2.1. The inter-rater agreement for article selection was excellent (Kappa=0.88). The reports by Lau et al. (2012) and Pang et al. (2013b) were derived from the same trial. Overall, ten articles (9 studies) were selected for this systematic review (Table 2.1).

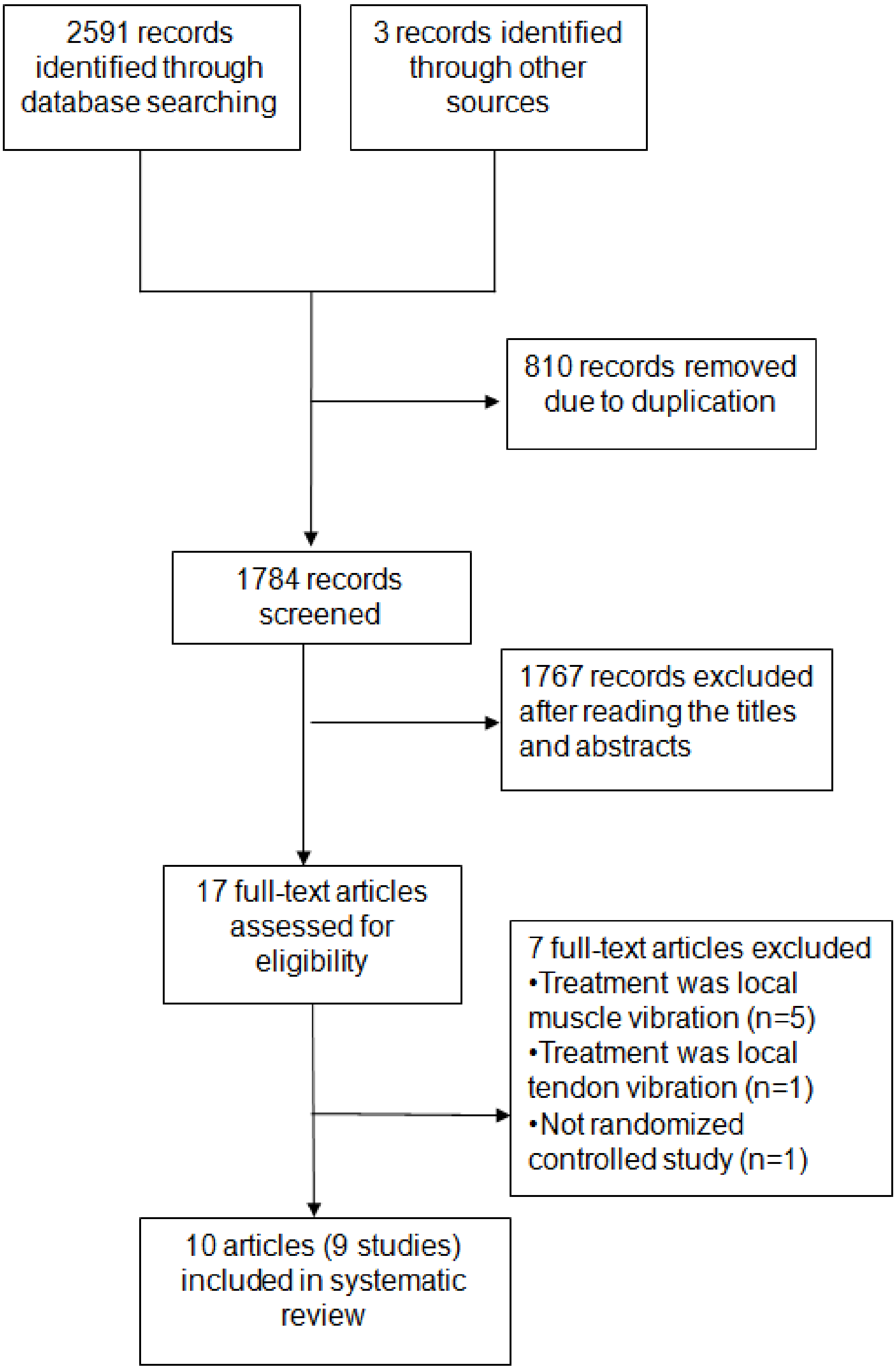

Figure 2.1 Flow diagram. Ten articles (nine studies) were included in this systematic review.

2.4.2 Quality of reviewed articles

We were able to retrieve the PEDro scores of other studies on the Physiotherapy Evidence Database website, except Tankisheva et al. (2014). Therefore, this article was reviewed and scored independently by two research team members who were experienced with using the PEDro scale (LRL and MYCP). The results are displayed in Table 2.1. Overall, only two studies were considered as level 1 evidence (PEDro score ≥6 and sample size >50) (van Nes et al., 2006; Lau et al., 2012; Pang et al., 2013b). The rest of the RCTs were all considered as level 2 evidence (Tihanyi et al., 2007; Tihanyi et al., 2010; Merket et al. 2011; Brogardh et al., 2012; Chan et al., 2012; Marı´n et al.,2013; Tankisheva et al., 2014).

2.4.3 Participants

The characteristics of the study participants are outlined in Table 2.2 Five studies used individuals with chronic stroke (onset ≥ 6 months) in their samples (Lau et al., 2012; Pang et al., 2013b; Brogardh et al., 2012; Chan et al., 2012; Marı´n et al., 2013; Tankisheva et al., 2014). People with sub-acute stroke were studied in four trials (van Nes et al., 2006; Tihanyi et al., 2007; Tihanyi et al., 2010; Merket et al., 2011). There was a tendency for the participants in the chronic stroke trials to have more severe physical impairments than those in the subacute stroke trials (Table 2.2).

Table 2.2 Subjects characteristics of studies

Study	Subject characteristics [a]						Inclusion criteria	Exclusion criteria	Severity of impairments at baseline[a]	
	Sample size	Age (y)	Sex	Post stroke duration	Paretic side, R/L	Type of stroke, infarct-ion/ Hemorr-hage			Measure	Values
Studies that assessed the effects of a single WBV session (comparison 1)										
Tihan-yi et al., 2007	Subacute stroke (n=16) WBV, n=8 CON, n=8	58.2± 9.4	F=6 M=10	27.2±10.4 (days)	10/6	11/5	- First-time stroke - 14 to 50 days after stroke onset - FIM score at admission of 60–110	- Unstable cardiac conditions - Peripheral arterial disease - Severe dementia, - Unable to follow simple commands - Painful orthopedic conditions involving the pelvis and lower limbs	BI (0-100) [b] FIM (18-126) [b]	46(25-85) 84(63-110)
Chan et al., 2012	Chronic stroke (n=30) WBV, n=15 CON, n=15	55.5± 9.4	F=9 M=21	34.7±32.6 (months)	11/19	15/15	- First stroke - Stroke onset >6 months - Ankle MAS ≥2 - Able to ambulate with or without assistive devices for at least 100 m - MMSE ≥24 - No joint contractures - Able to complete functional walking tests.	- Gallbladder or kidney stones - Recent leg fractures Internal fixation implants - Cardiac pacemaker, Intractable hypertension - Recent thromboembolism - Recent infectious diseases	Ambulatory device use, n Regular cane Quad cane MAS (0-5)	 6 8 2.4±0.5

Studies that assessed the effects of multiple WBV sessions (comparison 1)

Lau et al., 2012[4] and Pang et al., 2013b	Chronic stroke (n=82) WBV, n=41 CON, n=41	57.4± 11.2	F=24 M=58	5.0±3.9 (years)	48/34	41/41	• Hemispheric stroke • Stroke onset >6 months previously • Medically stable • AMT≥6 • Able to stand independently with or without aids for at least 1.5 minute • Age≥18 years	• Other neurological conditions • Serious musculoskeletal conditions • Pain that affected the performance of physical activities • Metal implants or recent fractures in the lower extremity • Vestibular disorders • Peripheral vascular disease • Other serious illnesses • Pregnancy	Walking aids indoors (none/cane/quad cane)	65/8/9
									CMSA leg score (out of 7)[b]	4 (3-6)
									CMSA foot score (out of 7)[b]	3 (1-6)
									No. subject with at least one fall in past 3 months	4
									FAC (1-5)[b]	5 (3-5)
									BBS	50.8±6.7
									Isometric knee concentric extension peak power (W/kg)	
									Paretic leg	0.65±0.33
									Non-paretic leg	1.18±0.45
Brogardh et al., 2012	Chronic stroke (n=31) WBV, n=16 CON, n=15	62.6± 7.3	F=6 M=25	35.3±30.6 (months)	15/16	27/4	• Able to walk ≥300m • ≥10% self-perceived muscle weakness in the knee extensors or knee flexors in the paretic leg • Not engaging in any heavy resistance or high-intensity training	• Epilepsy • Cardiac disease • Cardiac pace-maker • Osteoarthritis in the lower limbs • Knee or hip joint replacement • Thrombosis in the lower limbs in the past 6 months	FIM (18-126)	83.3±3.2
									BBS (0-56)	51.2±2.3
									Isometric knee extension (Nm)	
									Paretic leg	98.2±33.7
									Non-paretic leg	144.8±36.2
Marin et al.,2013	Chronic stroke (n=20) WBV, n=11 CON, n=9	63.2± 9.4	F=9 M=11	4.3±2.5	10/10	17/3	• Stroke onset ≥ 6 months • NIHSS score > 1 and < 20	• Dementia or severe cognitive impairment • Knee joint pain • Unable to remain standing without external support for ≥30 seconds.	NIHSS (0-42)	1.3±0.5
									BBS (0-56)	46.1±9.1

Studies that assessed the effects of multiple WBV sessions (comparison 2)

van Nes et al., 2006	Subacute stroke (n=53) WBV, n=27 CON, n=26	61.1± 10.1	F=23 M=30	36.6±9.7 (days)	28/25	38/15	• Stroke onset less than 6 weeks • Moderate or severe balance impairments BBS<40)	• Non-stroke related sensory or motor impairments • Medication that could interfere with postural control • Unable to follow simple verbal instructions Pregnancy • Recent fractures • Gallbladder or kidney stones • Malignancies • Cardiac pacemaker	MI (0-100) MAS (0-5)^b Knee flexion Knee extension Ankle DF Ankle PF BBS (0-56) BI (0-20) Trunk control Test (0-100) RMI (0-15) FAC (0-5) ^{b}	49.0±28.6 0(0-3) 0(0-4) 1(0-4) 0(0-2) 23.8±16.8 10.1±3.4 72.3±25.0 5.3±3.1 1(0-4)
Tihanyi et al., 2010	Subacute stroke (n=20) WBV, n=10 CON, n=10	58.6± 6.3	F=8 M=12	26.8±9.3 (days)	10/10	12/8	• Be able to stand for ≥2 minutes • Able to perform the outcome assessments	NR	BI (0-100) Maximal isometric knee extension torque (Nm) Paretic Non-paretic	48.0±14.9 39.5±27.6 89.5±33.9
Merkert et al., 2011	Subacute stroke (n=66) WBV, n=33 CON, n=33	74.5± 8.5	F=44 M=22	54.2±149. 9(days)	NR	NR	• Decreased stability of the trunk or lower limb • Aged ≥60 years	• Thrombosis • Acute illness or infections • Operations of the spine or lower extremities within the past 6 months • Implanted pacemakers or defibrillators • Severe cognitive impairment • Body weight >150 kg	BI (0-100) Tinetti Gait Test (0-12) TUG Functional test of the lower back (0-20) BBS (0-56)	42.0±21.1 7.7±3.0 30.0±10.6 13.8±7.3 20.5±16.4
Tankisheva et al., 2013	Chronic stroke (n=15) WBV, n=7 CON, n=8	61.6 ± 9.2	F=5 M=10	6.4±6.4	7/8	11/4	• Aged 40- 75 years • First-ever stroke • Stroke onset >6 months • Medically stable • Able to stand independently with or without aids for at least 20 minutes • Ability to perform the experimental treatment	• Acute thrombotic diseases • Severe heart and vascular diseases • Cardiac pacemaker • Acute hernia • Diabetes • Tumors • Other neurologic disorders Rheumatoid arthritis Arthrosis • Osteoarthritis • Diskopathy • Spondylosis	Isometric knee extension strength (Nm) Paretic leg Nonparetic leg BI (0-100) FAC (1-6) ^{b} Brunnstrom-Fugl-Meyer test Ashworth Scale composite score (0-24) ^{b}	 96.4±19.6 135.7±16.0 90.4±10.2 5(3-5) 22.9±5.3 4.5 (0-14)

independently	SOT	
	C1	92.7±2.4
	C2	89.9±3.0
	C3	89.4±4.1
	C4	73.8±6.5
	C5	41.8±28.9
	C6	51.3±19.5

AMT= Abbreviated Mental Test; C=Condition; CON=control group; BBS=Berg Balance Scale; BI=Barthel Index; CMSA=Chedoke McMaster Stroke Assessment; F=female; FAC=Functional Ambulation Category; FIM =Functional Independence Measure; L/R =left/right; M=male; MAS=Modified Ashworth Scale; MI=Motricity Index; MMSE=Mini-mental State Examination; NIHSS=National Institutes of Health Stroke Scale; NR=not reported; RCT=randomized controlled trial; RMI=Rivermead Mobility Index; s=second; SOT=Sensory Organization Test; TUG=Timed-Up-and-Go test; WBV=whole body vibration group; y=years.

[a] Mean±SD presented unless indicated otherwise.

[b] Median(Range).

2.4.4 Intervention protocol

2.4.4.1 WBV group

There were considerable differences in the WBV protocols adopted across the selected studies (Table 2.3). The frequency and amplitude of the vibration signals used were 5-45 Hz, and 0.44-5 mm, respectively. The peak vertical accelerations of the vibration platform covered a range from 0.2 to 15.8 units of g (Earth's gravitational constant) based on the theoretical relationship [peak acceleration= $(2\pi f)^2 A$], where f is the frequency and A is the amplitude of the vibration (Kiiski et al., 2008). Six studies used synchronous vertical vibrations (Tihanyi et al., 2007; Tihanyi et al., 2010; Lau et al., 2012; Pang et al., 2013b; Brogårdh et al., 2012a; Chan et al., 2012; Tankisheva et al., 2014), and two studies used side-alternating vertical vibrations (Van Nes et al., 2006; Marín et al., 2013). One study used Vibrosphere® to deliver the WBV without specifying the vibration type (Merkert et al., 2011). The vibration was usually delivered in bouts, with intermittent short rest periods. The number of vibration bouts delivered varied vastly, ranging from 1 to 12, for a period between 15 seconds and 10 minutes each. Two studies assessed the immediate effects of a single WBV session (Tihanyi et al., 2007; Chan et al., 2012), while seven studies examined the effects of WBV after 3 to 12 weeks of treatment (Van Nes et al., 2006; Tihanyi et al., 2010; Merkert et al., 2011; Lau et al., 2012; Pang et al., 2013b; Brogårdh et al., 2012a; Marín et al., 2013; Tankisheva et al., 2014). For the latter trials, the frequency of the training sessions varied from 1 to 5 sessions per week.

Five studies used only static exercises in WBV training (Van Nes et al., 2006; Tihanyi et al., 2007; Brogårdh et al., 2012a; Chan et al., 2012; Marín et al., 2013). The most common static exercises prescribed were semi-squat with knee flexion at 30° to 60° while standing on the WBV platform (Van Nes et al., 2006; Brogårdh et al., 2012a; Chan et al., 2012; Marín et al., 2013). A combination of static and dynamic exercises was used in three studies (Merkert et al., 2011; Lau et al., 2012; Pang et al., 2013b; Tankisheva et al., 2014), whereas dynamic exercises alone were used in Tihanyi et al. (2010). In three studies, the WBV group also received daily conventional rehabilitation in addition to WBV (Tihanyi et al., 2010; Merkert et al., 2011; Marín et al., 2013).

Table 2.3 Training protocols for WBV group and comparison group

Study	Protocol for WBV group [b]								Protocol for comparison group
	WBV treatment								
	Frequency of sessions × duration of program	Number of vibration bouts × duration per bout	Rest between bouts	Frequency (Hz) and amplitude (mm) and peak acceleration (g) of vibration signals	WBV type	Posture	Additional treatment	Super-vision	
Studies that assessed the effects of a single WBV session (comparison 1)									
Tihanyi et al., 2007	Single session	6 bouts× 1 min	120s	20Hz, 2.5mm, 4.0g	Synchronous Vertical	Standing on the platform with slightly knees flexion at 40 degrees and shifted their body mass to the paretic leg	None	NR	Same exercise but without vibration
Chan et al., 2012	Single session	2 bouts× 10 min	60s	12 Hz, 4mm, 2.3g	Synchronous Vertical	Positioned on the platform in a semi-squatting position with buttock support and were kept in an upright position with even weight distribution on both feet	None	NR	Followed the same procedures, but the vibration machine was not turned on.
Studies that assessed the effects of multiple WBV sessions (comparison 1)									
Lau et al., 2012 & Pang et al., 2013b	3/week × 8 week	1.5min×6 bouts to 2.5min×6 bouts	3min to 4.5min	20-30Hz 0.44-0.60mm1.0-1.6g	Synchronous Vertical	Side to side weight shift; Semi squat; Forward and backward ; weight shift; Forward lunge; Standing on one leg; Deep squat	15 minutes of warm-up exercises (general mobilization and stretching) in a sitting position	Therapist	Performed the same exercises on the same WBV platform as the WBV group but without vibration
Brogardh et al., 2012	2/week × 6 week	40s×4 bouts to 60s×12 bouts	60s	25Hz, 3.75mm, 9.2g	Synchronous Vertical	Standing barefoot on the platforms in a static position with the knees flexed 45° -60° and with	None	Physical therapist	Same exercises on a vibration platform with an amplitude of 0.20mm and

						handhold support, if needed			frequency 25Hz
Marin et al.,2013	1/week from week 1 to 7 and 2/week from week 8 to 12	1-2 session: 4 bouts×30s; 3-4 session: 5 bouts×30s; 5-6 session: 5 bouts×50s; 7-8 session: 5 bouts×60s; 9-12 session: 6 bouts×60s; 13-17 session: 7 bouts×60s	60s	5-21Hz 2-3mm 0.2-5.3g	Side-alternating Vertical	Standing on a vibration platform with a knee flexion of 30 degrees	Ten 2-hour rehabilitation sessions per month	Therapist	Performed the same exercises as that of the experimental group but was not exposed to vibration, and ten 2-hour rehabilitation sessions per month

Studies that assessed the effects of multiple WBV sessions (comparison 2)

van Nes et al., 2006	5/week × 6 weeks	4 bouts × 45s	60s	30Hz, 3mm, 10.9g	Side-alternating Vertical	Standing on the platform with knees slightly flexed	None	Physical therapist	Exercise therapy on music: regular exercises for the trunk, arm, and leg muscles
Tihanyi et al., 2010	3/week × 4 week	6 bouts × 1 min	60s	20Hz, 2.5mm, 8.05g	Synchronous Vertical	Knee flexed at 80°, then shifting body weight to each leg while flexing and extending the knee with a range of motion of 10°-15°	Daily conventional physiotherapy	NR	Daily conventional physiotherapy
Merkert et al., 2011	5/week × 3 week	2 bouts × 90s	15s-90s	20-45Hz Amplitude not reported	Vibrosphere®	Bridging in supine, sitting on Vibrosphere®, with trunk extension and flexion, and supported and unsupported standing	Conventional comprehensive geriatric rehabilitation	NR	Conventional comprehensive geriatric rehabilitation

Tankisheva et al., 2013	3/week × 6 week	1-12 session: 5 bouts×30s; 13-18 session: 17 bouts×60s	NR	35Hz, 1.7mm,8.4g 40Hz, 2.5mm,16.1g	Synchronous Vertical	Standing on their toes, knee flexion of 50° to 60° (high squat), knee flexion of 90° (deep squat), wide-stance squat, and 1-legged squat	None	Trainer	The participants of the CON group were not involved in any additional training program and were asked not to change their lifestyle.

[a] Mean±SD presented unless indicated otherwise.

[b] s=second; NR=not reported; WBV=whole body vibration.

CON=control group; F=female; M=male; RCT=randomized controlled trial; WBV=whole body vibration group.

2.4.4.2 Comparison group

Five studies incorporated an active exercise group which performed the same exercises while standing on the same platform as the WBV group but without vibration (4 studies) (Tihanyi et al., 2007; Lau et al., 2012; Pang et al., 2013b; Chan et al., 2012; Marín et al., 2013) or with sham vibration (1 study) (Brogårdh et al., 2012a) (Table 2.3) (i.e., comparison 1 as defined in Methods) (Tihanyi et al., 2007; Lau et al., 2012; Pang et al., 2013b; Chan et al., 2012; Marín et al., 2013). Four studies engaged the control group in different activities (e.g., conventional rehabilitation, exercise on music, habitual physical activity) (i.e., comparison 2 as defined in Methods) (Van Nes et al., 2006; Tihanyi et al., 2010; Merkert et al., 2011; Tankisheva et al., 2014).

2.4.5 Effects of a single session of WBV intervention

Two studies involving 46 participants investigated the immediate effects of a single WBV session (Table 2.4) (Tihanyi et al., 2007; Chan et al., 2012).

Table 2.4 Summary of immediate effects of a single session of WBV on body functions and structures, and activity in people with stroke

Study (comparator 1)	Aim	Measurement schedule	Outcome measures[a]		Conclusion
			No significant results	Significant results	
Tihanyi et al. 2007[38d]	"To determine the transient effect of WBV on maximal voluntary force and agonist and antagonist muscle activation" in people with stroke.	Pre-test, post-test	• Mechanical work during eccentric contraction	• ↑Maximum isometric knee extension torque (SES =0.50)[b] • ↑Maximum eccentric knee extension torque (SES =0.46) • ↑Rate of torque development (SES = 0.08) • ↑Maximal voluntary eccentric torque at 60 degrees of knee flexion (SES = 0.50) • ↓Co-activation quotient of BF during: • isometric knee extension (SES = 0.82) • eccentric knee extension (SES = 0.16)	"A single bout of WBV can transiently increase voluntary force and muscle activation of the quadriceps muscle affected by a stroke".
Chan et al. 2012[44]	"To investigate the effects of a single session of WBV training on ankle plantarflexion spasticity and gait performance" in people with chronic stroke.	Pre-test, post-test	• GS H-reflex in both legs • GS H_{max}/M_{max} ratio on affected side • Achilles deep tendon reflex on affected side • Cadence	• ↓GS H_{max}/M_{max} ratio on unaffected side (SES = 0.87)[b] • ↓MAS[c] • ↓VAS (perceived spasticity) (SES = 1.96) • ↓Time to complete TUG (SES =1.80) • ↑10MWT (maximal speed) (SES = 0.79) • ↑TBW % on affected side (SES = 0.87) • ↓TBW % on unaffected side (SES =0.87)	"A single session of WBV can reduce ankle plantar-flexion spasticity in chronic stroke patients, thereby potentially increasing ambulatory capacity."

[a] The results shown in this table referred to the difference between the WBV and comparison groups.

[b] The SES for this study were calculated based on the mean and SD of the change scores of the WBV and comparison groups.

[c] The SES was not reported because MAS is an ordinal variable.

[d] The EMG amplitude data of individual muscles were not included because they were not normalized, making it difficult to compare between groups.

10 MWT=10-meter walk test; ABC=activities-specific balance confidence; BBS=Berg Balance Scale; BF=biceps femoris; GS=gastrocnemius-soleus; H-reflex=Hoffmann reflex; Hmax/Mmax ratio=maximum Hoffmann reflex/maximum M response ratio; MAS=Modified Ashworth Scale; SES=standardized effect size ; TBW%=percentage of total body weight ; TUG=Timed Up & Go test; VAS=visual analogue scale; VL=vastus lateralis ; WBV=whole-body vibration ; ↑=increase; ↓=decrease

2.4.5.1 Body functions and structures

2.4.5.1.1 Leg muscle strength

Comparison 1: Tihanyi et al. (2007) showed that the WBV group had a significantly more increase in isometric (SES=.50, ***p***=.03) and eccentric knee extension torque (SES=.46, ***p***=.04) on the paretic side. The co-activation of the antagonist muscle biceps femoris (BF) during maximal isometric (SES=.80, ***p***=.03) and eccentric knee extension (SES=.16, ***p***=.01) was also significantly less in the WBV group compared with controls.

2.4.5.1.2 Spasticity

Comparison 1: Inconsistent findings were reported in Chan et al. (2012) Modified Ashworth Scale (MAS) (*p*≤.001) and visual analogue scale (VAS) scores (a measure of perceived spasticity; SES=1.96, *p*≤.001) were reduced significantly more in the WBV group. The ratio between the maximum H reflex (i.e., reflex motor response of the tested muscle to stimulation of the type Ia afferents innervating the same muscle) and maximum M response (i.e., motor response of tested muscle to stimulation of motor nerve innervating the same muscle) of the gastrocnemius-soleus muscle, as recorded by electromyography, was also used as an index of excitability of the stretch reflex pathway. The Hmax/Mmax ratio decreased significantly more in the WBV group after the intervention period in the unaffected leg only (SES=.87, *p*=.03), indicating a decrease in excitability of the stretch reflex pathway. The change in this ratio showed no significant between-group difference in the affected leg. The change in amplitude of the Achilles deep tendon reflex also showed no significant between-group difference after treatment.

2.4.5.1.3 Postural control

Comparison 1: Chan et al. (2012) showed that after WBV training, the percentage of total body weight borne by the affected leg had a significantly greater increase than the comparison group (SES=.87, ***p***=.02).

2.4.5.2 Activity and Participation

2.4.5.2.1 Functional mobility

Comparison 1: Chan et al. (2012) reported that the time taken to complete the Timed-Up-and-Go Test (TUG) was reduced significantly more in the WBV group than the comparison group after the treatment period (SES=1.80, $p \leq .001$). The WBV group also improved more in maximum walking speed as measured in the 10-meter walk test (SES=.79, *p*=.03), but not cadence (*p*=.10).

2.4.6 Effects of multiple sessions of WBV intervention

Seven studies (287 participants) assessed the effects of WBV interventions spanning 3-12 weeks (Table 2.5) (Van Nes et al., 2006; Tihanyi et al., 2010; Merkert et al., 2011; Lau e tal., 2012; Pang et al., 2013b; Brogårdh et al., 2012a; Marín et al., 2013; Tankisheva et al., 2014).

Table 2.5 Summary of effects of multiple WBV sessions on body functions and structures, activity and participation in people with stroke

Study	Aim	Measurement schedule	Outcome measures[a]		Conclusion
			No significant findings	Significant findings	
			Studies that invovled comparison 1		
Lau et al. 2012 &Pang et al. 2013b	To investigate the effects of WBV on bone turnover, neuromotor function, spasticity and reducing falls in people with chronic stroke.	Pre-test, post-test 1(week 8), post-test 2 (week 12) for all outcomes, except falls (monthly follow-up until 6 months after termination of training)	• BBS • Limit of Stability Test o MVL o EPE o MXE o DCL • 6 MWT • 10 MWT (comfortable speed) • CMSA of paretic leg and foot • Ankle spasticity (MAS) • ABC • CTx • BAP • Paretic leg isometric muscle strength o Knee extension o Knee flexion o Paretic and non-paretic knee peak power o Concentric extension o Concentric flexion o Eccentric extension o Eccentric flexion • Incidence of falls	↓Knee MAS (week 12)[c]	The addition of WBV to a leg exercise protocol was no more effective in improving neuromotor performance, bone turnover, paretic leg motor function and reducing the incidence of falls than leg exercises alone in chronic stroke patients who have mild to moderate motor impairments. WBV may have potential to modulate spasticity.

Brogardh et al. 2012	To evaluate the effects of WBV training on muscle function, balance, gait performance and perceived participation in individuals after stroke.	Pre-test, post-test (week 6)	• MAS • BBS • Muscle strength o Isokinetic knee extension in both legs (60°/s) o Isokinetic knee flexion in both legs (60°/s) o Maximum isometric knee extension in both legs • TUG • 10 MWT (comfortable and maximal speed) • 6MWT • SIS	Six weeks of WBV training had small treatment effects on balance and gait performance in chronic stroke individuals, but was not more effective than a placebo vibrating platform.
Marin et al. 2013	“To analyze the effects of WBV on lower limb muscle architecture, muscle strength, and balance in stroke patients.”	Pre-test, post-test (3 months)	• Muscle thickness of RF, VL and MG in both legs • Maximal isometric knee extension strength • BBS	“WBV exercise did not augment the increase in neuromuscular performance and lower limb muscle architecture induced by isometric exercise alone in stroke patients.”
Studies that involved comparison 2				
van Nes et al. 2006	“To examine whether WBV added to regular rehabilitation has beneficial effects on balance control and activities of daily living in patients with subacute stroke. ”	Pre-test, post-test 1 (week 6), post-test 2 (week 12)	• BBS • BI • Rivermead Mobility Index • Trunk Control Test • FAC • Motricity Index • Somatosensory threshold of affected leg	WBV was “not more effective in enhancing recovery of balance and activities of daily living than the same amount of exercise therapy on music in the post-acute phase of stroke.”

Tihanyi et al. 2010[f]	"To investigate the chronic effect of low frequency WBV on isometric and eccentric strength of knee extensors" in patients with stroke.	Pre-test, post-test (week 4)	• Rate of torque development during isometric knee extension in both legs • Mechanical work during eccentric knee extension in non-paretic leg • NP/P strength ratio during eccentric contraction in both legs • NP/P strength ratio during concentric contraction in non-paretic leg	• ↑Maximum isometric knee extension torque in paretic leg (SES = 0.46) and non-paretic leg (SES = 0.74)[d] • ↑Maximum eccentric knee extension torque in paretic leg (SES = 0.51) and non-paretic leg (SES = 0.51) • ↑Mechanical work during eccentric knee extension in paretic leg (SES = 0.16) • ↓NP/P strength ratio during concentric contraction in paretic leg[b]	WBV intervention can increase leg muscle strength after stroke and that the improvement was more pronounced in the paretic leg.
Merkert et al. 2011	"To investigate the effect of the Vibrosphere®, with its combined vibration therapy and strategic balance training, on trunk stability, muscle tone, and postural control in stroke patients compared with those receiving geriatric rehabilitation alone."	Pre-test, post-test (week 3)	• BBS • Functional test of the lower back • Tinetti Gait Test	• ↓ Time to complete TUG (SES = 0.60) • ↑BI (SES = 0.61)	"Combined vibration and balance training using Vibrosphere® may be a useful addition to current rehabilitation of stroke patients."

Tankisheva et al., 2013	"To explore the feasibility, safety, and possible benefits of 6 weeks of intensive WBV training in patients with chronic stroke in comparison to a control group."	Pre-test, post-test 1(week 6), post-test 2 (week 12)	• MAS • Muscle strength • Isokinetic knee extension in both legs (60°/s) • Isokinetic knee flexion in both legs (60°/s) • Isometric knee extension in nonparetic leg • Isometric knee flexion in both legs • Isokinetic knee extension in nonparetic leg (240°/s) • Isokinetic knee flexion in both legs (240°/s) • SOT • Equilibrium scores (%) in condition 1, 2, 3, 5, 6	• ↑Isometric knee extension torque in paretic leg (week 6) (SES = 1.74)[e] • ↑Isokinetic knee extension strength (240°/s) in paretic leg (week 12) (SES = 0.96) • ↑ Equilibrium scores (%) in condition 4: normal vision and sway-referenced support surface (week 6) (SES = 1.47)[e]	Six weeks of intensive WBV might "potentially be a safe and feasible way to increase some aspect of lower limb muscle strength and postural control in adults with chronic stroke."

[a] The results shown in this table referred to the difference between the WBV and comparison groups.

[b] The standardized effect size was not reported for this variable as the exact mean and standard deviation values were not presented.

[c] The SES was not reported because MAS is an ordinal variable.

[d] The SES for this study were calculated based on the mean and SD of the post-test scores of the WBV and comparison groups.

[e] The SES for this particular outcome was reported in the text by the authors.

[f] The EMG amplitude data of individual muscles were not included because they were not normalized, making it difficult to compare between groups.

6MWT=six-minute walk test; 10 MWT=10-meter walk test; ABC=activities specific balance confidence; BAP=bone-specific alkaline phosphatase; BBS=Berg Balance Scale; BI=Barthel Index; CGS= comfortable gait speed; CMSA= Chedoke-McMaster Stroke Assessment; CTx=Serum C-telopeptide of type I collagen cross-links; DCL=directional control; EPE=end point excursions; FAC=Functional Ambulation Categories; FGS=fast gait speed; MAS= Modified Ashworth Scale; MG= medial gastrocnemius; MVL= movement velocity; MXE=maximum excursion; NP/P=non-paretic to paretic; RF=rectus femoris; SES=standardized effect size; SIS=Stroke Impact Scale; TUG=Timed Up & Go test; VL=vastus lateralis; WBV=whole-body vibration; ↑=increase; ↓=decrease

2.4.6.1 Body function and structures

2.4.6.1.1 Bone turnover

Comparison 1: Pang et al. (2013b) demonstrated no significant change in levels of C-telopeptide of type I collagen cross-links (CTx; a bone resorption marker) and bone-specific alkaline phosphatase (BAP; a bone formation marker) in both the treatment and control groups after 8 weeks.

2.4.6.1.2 Leg muscle strength/motor function

Comparison 1: No significant results in Chedoke McMaster Assessment (CMSA) score (Pang et al., 2013b), isometric (Merkert et al., 2011; Brogårdh et al., 2012a; Marín et al., 2013) and dynamic knee extension strength (Pang et al., 2013b; Brogårdh et al., 2012a; Marín et al., 2013) were identified after WBV.

Comparison 2: Tihanyi et al. (2010) reported that WBV was superior in improving isometric knee extension strength on both the paretic (SES=0.46, *p*=.01) and non-paretic sides (SES=0.74, *p*=.03). Tankisheva et al. (2014) reported better improvement on the paretic side only (SES=1.74, *p*=.04). For dynamic knee extension strength, Tihanyi et al. (2010) reported significant results on both sides after WBV (paretic side: SES=.51, *p*=.01; non-paretic side: SES=.51, *p*=.02) while Tankisheva et al. (2014) reported significantly better improvement on the paretic side at a contraction speed of 240°/s (SES=.96, *p*=.04), but not 60°/s, at 12-week follow-up (Tankisheva et al., 2014). No significant between-group difference were reported for isometric and dynamic knee flexion torque (240°/s and 60°/s) (Tankisheva et al., 2014) and Motricity Index (Van Nes et al., 2006).

2.4.6.1.3 Muscle thickness

Comparison 1: The change in thickness of rectus femoris (RF), vastus lateralis (VL), and medial gastrocnemius (MG) muscles on both sides demonstrated no significant difference between the WBV and comparison groups, as determined by ultrasound (Marín et al., 2013).

2.4.6.1.4 Spasticity

Comparison 1: Using MAS, Brogardh et al. (2012) reported no significant treatment effect of WBV on leg spasticity. In contrast, Pang et al. (2013b) showed a decreasing trend in MAS score of the paretic knee in the WBV group, but not the comparison group, after treatment. Post-hoc analysis of the WBV group data showed that statistical significance was reached for the comparison between baseline and 1-month follow-up (p=.01), but not for that between baseline and immediately after the 8-week training period. No significant change of MAS score was observed at the ankle joint on the paretic side in both groups (Pang et al., 2013b).

Comparison 2: Tankisheva et al. (2014) reported no change in leg muscle spasticity after the intervention period in both groups.

2.4.6.1.5 Postural Control

Comparison 1: No significant results were found, regardless of the outcome measures used (Lau et al., 2012; Brogårdh et al., 2012a; Marín et al., 2013).

Comparison 2: Out of three studies (Van Nes et al., 2006; Merkert et al., 2011; Tankisheva et al., 2014), only Tankisheva et al. (2014) showed that WBV was superior. Significantly more improvement in the equilibrium score when standing on a sway-referenced support surface with eyes open (SES=1.47, p<.05) was reported in the WBV group, compared with habitual physical activity (Tankisheva et al., 2014). In the other two studies, similar and significant improvements in balance ability were reported in both the WBV and comparison groups (Van Nes et al., 2006; Merkert et al., 2011).

2.4.6.1.6 Falls

Comparison 1: Lau et al. (2012) reported no significant difference in fall incidence during the 6-month follow-up period between the WBV and comparison group.

2.4.6.1.7 Sensation

Comparison 2: The WBV and comparison groups had similar and significant improvement in somatosensory threshold in the affected leg (Van Nes et al., 2006).

2.4.6.2 Activity and Participation

2.4.6.2.1 Functional mobility

Comparison 1: No significant treatment effect was found on TUG (Brogårdh et al., 2012a), comfortable gait speed (Lau et al., 2012; Brogårdh et al., 2012a), fast gait speed (Brogårdh et al., 2012a), and Six-Minute-Walk-Test (6MWT) (Lau et al., 2012; Brogårdh et al., 2012a).

Comparison 2: Out of two studies that measured mobility function (Van Nes et al., 2006; Merkert et al., 2011), only Merkert et al. (2011) reported that WBV was superior in improving TUG score (SES=.60, p=.01). Van Nes et al. (2006), on the other hand, showed that mobility function (indicated by Rivermead Mobility Index and Functional Ambulation Categories) improved significantly to a similar extent in both groups.

2.4.6.2.2 Activities of Daily Living

Comparison 2: Merkert et al. (2011) reported the superiority of WBV in improving the Barthel Index (BI) score (SES=.61, $p \leq .01$) whereas van Nes et al. (2006) showed similar and significant improvement in BI score in both treatment arms.

2.4.6.2.3 Stroke Impact Scale

Comparison 1: No significant change in the Stroke Impact Scale (SIS) score was found in both the WBV and sham vibration groups (Brogårdh et al., 2012).

2.4.7 Adverse events

A total of 168 participants were exposed to WBV in the nine studies included in this review. Five studies explicitly stated whether there were any adverse events (Van Nes et al., 2006; Lau et al., 2012; Pang et al., 2013b; Brogardh et al., 2012; Marín et al. 2013; Tankisheva et al., 2014). In Lau et al. (2012), 5 out of 41 participants in the WBV group reported adverse symptoms that were potentially related to WBV exposure, such as knee pain, fatigue, and dizziness. Brogardh et al. (2012) reported that 15 out of 31 participants had transient mild muscle soreness or muscle fatigue, regardless of the group assignment (i.e., WBV or sham vibration). Tankisheva et al. (2014) reported that some of the subjects experienced itching in the legs. While adverse events were not uncommon, they were all mild and usually subsided after the first few sessions of training. Two studies reported no adverse events in all subjects exposed to WBV (n=38) (Van Nes et al., 2006; Marín et al., 2013). It was not clear whether any adverse events occurred in four studies (Tihanyi et al., 2007, 2010; Merkert et al., 2011; Chan et al., 2012).

2.5 DISCUSSION

This is the first systematic review to specifically examine the effects of WBV on body functions and structures, activity and participation in people with stroke. Overall, the WBV intervention is safe but no consistent benefits on bone turnover, leg motor function, balance, mobility, sensation, fall rate, activities of daily living, and societal participation were found.

2.5.1 Does vibratory stimulation alone confer any benefits?

By having the subjects in the comparison group perform the same activities without WBV or with sham vibration (comparison 1), the effects of the vibration stimuli on the following outcomes can be delineated in 5 studies (Van Nes et al., 2006; Lau et al., 2012; Pang et al., 2013b; Chan et al., 2012; Marín et al., 2013).

2.5.1.1 Body function and structures

2.5.1.1.1 Bone turnover

The review revealed that the effect of WBV on bone metabolism in individuals with stroke is far from conclusive, as only one study (Pang et al., 2013b) measured biochemical markers of bone turnover and no significant results were identified. Examining the literature in older adults also provides little insight as to what WBV protocols may be the best in inducing favorable bone outcomes. A number of studies showed that WBV training did not induce any significant effects on bone turnover rate compared with other exercise training or no-intervention control (Rubin et al., 2004; Verschueren et al., 2004; Von Stengel et al., 2012). Only Turner et al. (2011) showed that their 8-week WBV protocol (12Hz, 0.3g, 20 minutes per session with interspersed rest periods) resulted in a significant reduction in level of bone resorption marker (N-telopeptide X) in post-menopausal women, when compared with sham vibration exposure. Their protocol used a WBV frequency (12Hz), which was lower than that used by Pang et al. (2013b) and other studies (25-40Hz) in this review. Studying the effect of WBV on bone metabolism is an important question, as it is well documented that people with stroke sustain accelerated bone loss in the paretic limbs (Pang et al., 2010), elevated bone resorption and reduced bone formation marker levels (Levendoglu et al., 2004). More research on WBV and bone health post-stroke is definitely needed.

2.5.1.1.2 Muscle structure and function

Although Tihanyi et al. (2007) (level 2 study) demonstrated that WBV stimulation has additional effect on increasing knee muscle strength transiently after a single treatment session, no conclusion could be drawn because it was the only study that assessed this issue. In addition, out of the four studies that measured muscle strength or thickness after multiple WBV sessions, none showed significant results (Lau et al., 2012; Pang et al., 2013b; Brogårdh et al., 2013; Marín et al., 2013). These findings may indicate that the vibration stimulation itself may not confer additional benefits on muscle strength/structure after stroke, although it cannot be ruled out that their protocols used may not be optimal to facilitate gain in these outcomes. The frequency range used in these four studies was 5-30Hz. A meta-analysis by Marin et al. (2010) claimed that WBV frequencies of 35-40Hz are more effective than other frequencies (30-35 Hz and 40-45Hz) in inducing gain in muscle power. However, it is not clear whether the meta-analysis was preceded by a systematic review. The criteria for selection of articles were also not explicitly specified. For example, studies of different populations (e.g., young adults, athletes, older adults) or comparison groups might have been mixed together. It is not known whether only RCTs were included in their analysis. Inclusion of studies with poor scientific rigor may compromise the validity of the meta-analysis. Additionally, the effects of different vibration frequencies may also depend on the muscle group being stimulated (Hazell et al., 2010; Pollock et al., 2010).

2.5.1.1.3 Spasticity

Previous studies in healthy individuals and people with spinal cord injury suggested that WBV may modulate the excitability of the spinal motorneuronal pool, as reflected by the amplitude of the H-reflex or Hmax/Mmax ratio (Kipp et al., 2011; Sayenko et al., 2010). Based on our review, the evidence on the effect of WBV on spasticity post-stroke is somewhat conflicting.

The evidence related to the transient effect of a single WBV session on spasticity is based on one level 2 study and thus not conclusive (Chan et al, 2012). While the authors claimed that WBV significantly reduced spasticity (Chan et al, 2012), the reported improvement in MAS and VAS scores was not accompanied by other measurements of spasticity (Table 2.4). In addition, the VAS is only a subjective measure and its improvement can be easily explained by the placebo effect of the added WBV, as the study participants were not blinded.

Of the two studies that measured spasticity after multiple sessions of WBV treatment (Pang et al., 2013b; Brogårdh et al., 2012a), only Pang et al. (2013b) (level 1 study) reported some beneficial effects on knee spasticity. This is somewhat intriguing, as spasticity at the ankle joint, which is typically more severe than that at the knee, was not modified by their WBV protocol. Taken together, there is no consistent evidence to show that WBV stimulation can reduce spasticity. A common drawback of these two studies is that MAS was the only measure used to evaluate spasticity. MAS may not be the best assessment tool because it is ordinal in nature, with only moderate reliability and correlation with muscle activity and resistance in response to passive movements (Ansari et al., 2008; Fleuren et al., 2010), making it difficult to detect significant changes in spasticity level. The Modified Tardieu scale may be a better option to assess the effects of WBV on spasticity in future studies (Singh et al., 2011).

2.5.1.1.4 Postural control and falls

The beneficial effects of a single WBV session on postural control were supported by Chan et al. (level 2 study) only (Chan et al., 2012). However, postural control was only assessed by a single measure (weight distribution between the two legs). The placebo effect of WBV could not be ruled out, as the participants were not blinded.

The evidence is also insufficient to support the use of longer-term WBV training in improving balance. Of the three studies, none found significant between-group difference in balance outcomes after a training period of 6 weeks to 3 months (Merkert et al., 2011; Brogårdh et al., 2012a; Marín et al., 2013), suggesting that WBV has no real effects on postural control in people with stroke. An alternative explanation of the non-significant results may be related to the psychometric properties of the outcome measure used. BBS was used as the main balance outcome in these three chronic stroke trials. While BBS is a common balance measure used in clinical practice, its ceiling effect is well documented (Tsang et al., 2013). In all three studies, the balance ability of the participants was quite good already before treatment, as confirmed by the baseline data showing a mean BBS score varying from 46.1 to 51.2 points (Lau et al., 2012; Brogårdh et al., 2012a; Marín et al., 2013). This was probably due to the inclusion criteria used in these studies (e.g., able to remain standing without external support for at least 30 seconds (Marín et al., 2013), ambulate independently for >100m) (Table 2.2) (Brogårdh et al., 2012a). BBS may thus be unable to detect changes in balance ability for these individuals who have only mild impairments in balance performance, thereby contributing to the negative results.

Only one study measured incidence of falls and reported negative results (Lau et al., 2012). This is not surprising, given the lack of significant effects on neuromotor outcomes, and the fact that only a 10% of subjects had experienced at least one fall within 3 months before the training period. No recommendation can be made on the use of WBV to reduce fall rate after stroke (Lau et al., 2012).

2.5.1.2 Activity and participation

2.5.1.2.1 Functional mobility

No firm conclusion can be derived from the available evidence to determine whether a brief WBV session has significant transient effect on mobility, as this topic was addressed by only one level 2 study (Chan et al., 2012). Despite the positive results reported, their WBV group was substantially more impaired than the control group, as reflected by the considerably more time required to complete the TUG (mean difference=22 seconds) and 10-meter walk (mean difference=7 seconds) at baseline. The different mobility status of the subjects between the two groups may partially explain the difference in outcomes, as there may be more room for improvement in individuals with more severe limitations in mobility. The evidence is also inadequate to support the use of longer-term WBV training to improve mobility function post-stroke (Lau et al., 2012; Brogårdh et al., 2012a). Based on the two studies that incorporated mobility outcomes, WBV stimulation was shown to confer no additional benefit on mobility function after chronic stroke. This is reasonable, as the various measures of body functions/structures that are highly related to mobility (e.g., muscle strength, postural control) were not influenced by WBV stimulation, as discussed above.

2.5.1.2.2 Societal participation

No conclusion can be drawn concerning the effects of WBV on particpation (Brogårdh et al., 2012a), as it was evalucated in one level 2 study only, with unremarkable results when compared with sham vibration.

2.5.2 Is WBV exercise approach as a whole a viable alternative to other forms of physical exercise?

Whether the WBV is superior to other forms of physical exercise (**comparison** 2) can be determined in 4 studies (Van Nes et al., 2006; Tihanyi et al., 2010; Merkert et al., 2011; Tankisheva et al., 2014).

2.5.2.1 Body function and structures

2.5.2.1.1 Muscle strength

Out of the three studies that addressed muscle strength (Van Nes et al., 2006; Tihanyi et al., 2010; Tankisheva et al., 2014), Tihanyi et al. (2010) and Tankisheva et al. (2014) (both level 2) reported better outcomes in the WBV group, whereas van Nes et al. (2006) (level 1) reported comparable gain in muscle strength in the two groups. Several reasons may explain the discordance in results. First, the outcomes may be influenced by the interaction of many different factors, such as WBV protocols, subject characteristics and outcome measures used. As shown in Table 2.2, these factors demonstrated substantial diversity across the different studies. Upon closer examination of the data, we could not identify any specific trend that would explain the discrepancies in results. Second, the activities in the comparison group for the three studies were different, involving exercise on music (Van Nes et al., 2006), conventional exercise training (Tihanyi et al., 2010), and habitual physical activity respectively (Tankisheva et al., 2014). Third, the total treatment time may be a confounding factor. For the two studies that demonstrated results in favor of WBV, the intervention group might have had additional treatment time due to WBV training (Tihanyi et al., 2010; Tankisheva et al., 2014). This is in contrast with van Nes et al. (2006), in which the total treatment time was the same in the two groups. Based on the finding of Van Nes et al. (2006), one can argue that WBV exercise training as a whole may induce beneficial effects on muscle strength that are comparable to exercise on music. However, it cannot be determined whether the improvement in muscle strength detected in both groups was induced by the conventional exercise program (which both groups received) or the added WBV training or exercise on music.[37] Hence, it remains elusive as to whether WBV exercise training is a viable alternative to other forms of rehabilitative training to improve muscle strength post-stroke.

We do not have sufficient evidence to determine whether WBV is more effective in improving isometric muscle strength than dynamic (e.g., eccentric or concentric) strength. As demonstrated by Tankisheva et al. (2014), the outcome may also be highly dependent upon other factors as well, including functional role of the muscle (e.g., flexor Vs extensor), baseline muscle strength and contraction speed.

2.5.2.1.2 Spasticity

There is insufficient evidence to support or refute the notion that WBV is beneficial in reducing spasticity compared with other forms of exercise, as only one level 2 study addressed this issue and no significant change in leg muscle spasticity was found in both groups after the 6-week intervention period (Tankisheva et al., 2014).

2.5.2.1.3 Postural control

Two studies showed that WBV training yielded similar results on postural control when compared with other types of physical activity (Van Nes et al., 2006; Merkert et al., 2011). However, the WBV group had received more treatment time, which might have confounded the results (Van Nes et al., 2006; Merkert et al., 2011). Superiority of WBV training over habitual physical activity was reported by Tankisheva et al. (2014), in which the WBV group had more improvement in equilibrium score when standing on a sway-referenced platform. The authors, however, offered no convincing explanation why improvement was observed only in this variable, out of the many balance outcomes used. Thus, it remains uncertain whether WBV is a useful alternative treatment to enhance postural control post-stroke.

2.5.2.1.4 Sensation

While the WBV group and exercise on music group were shown to have comparable improvements in somatosensory threshold by van Nes et al. (2006), we cannot conclude the WBV is in fact effective because the improvement can be due to the conventional rehabilitation program that both groups received. Additionally, factors that are common in both groups, such as maturation effects, may also account for the observed improvement.

2.5.2.2 Activity and participation

2.5.2.2.1 Functional mobility

Of the two studies that compared WBV with other exercise approaches (Van Nes et al., 2006; Merkert et al., 2011), Merkert et al. (2011), but not van Nes et al. (2006), demonstrated better outcomes in the WBV group (Merkert et al., 2011). As aforementioned, the WBV group in the former study received more treatment time than the comparison group, which may partially explain the better outcomes.

2.5.2.2.2 Activities of daily living

Barthel Index was measured in two studies, which compared WBV with other forms of exercise, but the results were conflicting (Van Nes et al., 2006; Merkert et al., 2011). The additional treatment time from WBV training in Merkert et al. (2011) may contribute to the signficant results, as opposed to van Nes et al. (2006), in which the total treatment time for both groups was even. Due to the limited number of studies and conflicting findings, no conclusion can be driven regarding the therapeutic effects of WBV on this domain of function.

2.5.3 Relationship between treatment effect and characteristics of participants

Although the participants with subacute stroke tended to be more impaired than those in the chronic stage of recovery, their response to WBV did not seem to systematically differ. Of the two studies that investigated the effects of a single WBV session, both Tihanyi et al. (2007) (subacute trial) and Chan et al. (2012) (chronic trial) reported mixed results, with positive findings on some outcomes, but not others. With regards to the effects of multiple WBV sessions, since all studies that involved comparison 1 employed individuals after chronic stroke and the disability level was similar across studies, meaningful comparison can only be made among four studies [three subacute stroke trials (Van Nes et al., 2006; Tihanyi et al., 2010; Merkert et al., 2011) and 1chronic stroke trial (Tankisheva et al., 2014)] that involved comparison 2. The chronic stroke trial by Tankisheva et al. (2014) reported mixed results, just as Tihanyi et al. (2010) and Merkert et al. (2011) (both were subacute trials). Van Nes et al. (2006) (subacute trial) was the only study that reported no significant results across all outcomes but the characteristics of their participants were not distinctly different from the other two subacute trials. Taken together, no specific trend can be identified in terms of the relationship between the WBV treatment effect and characteristics of the participants.

2.5.4 Limitations of the Studies Reviewed

Only two of the nine studies were regarded as level 1 evidence. With few exceptions (Van Nes et al., 2006; Lau et al., 2012; Pang et al., 2013b), physiological justifications of the WBV protocol used were not provided. Additionally, four studies had very small sample sizes (≤20 subjects), which lowered the statistical power and representativeness of sample (Van Nes et al., 2006; Tihanyi et al., 2010; Merkert et al., 2011; Tankisheva et al., 2014). The total treatment time differed for the various treatment arms in a number of studies (Tihanyi et al., 2010; Merkert et al., 2011; Tankisheva et al., 2014), which posed a threat to internal validity.

2.5.5 Limitations of the Systematic Review

It is difficult to delineate the effects of each WBV parameter (WBV type, frequency, amplitude, peak acceleration, treatment duration and frequency) on treatment outcomes, as differences exist in multiple parameters across studies. Perhaps the most important limitation of this review is that we could not draw any conclusion as to whether WBV is an effective treatment for a specific deficit induced by stroke. However, it is difficult to identify a particular main problem in a given individual with stroke, as stroke often affects multiple domains of function which are highly inter-correlated. Apparently, none of studies reviewed here had considered this issue and described the participants as having a particular main deficit. In fact, there is considerable heterogeneity of participant characteristics within the individual studies, making it more difficult to detect significant effects.

2.5.6 Future research directions

This review has revealed many gaps of knowledge in the field. First, some fundamental questions have to be addressed before a large-scale clinical trial is conducted. For example, how the EMG responses of different muscle groups vary with different exercises during exposure to various WBV frequencies and amplitudes in people with stroke is largely unknown. Whether patients with different levels and types of motor impairment demonstrate different EMG response during the application of the same WBV protocol is also uncertain. The transmissibility of WBV signals to different parts of the body and how it varies with vibration frequency and amplitude should be studied as well. Such information would be useful in guiding the design of WBV exercise protocols for efficacy testing in future clinical trials. Second, to truly determine whether WBV has therapeutic value, RCTs with large sample sizes are required to compare the effects of different WBV protocols on various outcomes. Measures with good psychometric properties should be used. Measures of participation should also be incorporated in future clinical trials. More homogenous groups of patients with specific impairments should be used, in order to improve internal validity and allow for drawing conclusion that speaks to a particular problem or deficit. Once the therapeutic value of WBV is established, efforts should be made to decipher the mechanisms related to WBV therapy. For example, the improvement in muscle strength (if any) may be related to peripheral (e.g., change in contractile properties of muscle) or/and central mechanisms (change in excitability of cortical motoneurons), which may be worth investigating.

2.5.7 Conclusion

No solid evidence was found confirming the beneficial effects of WBV after a single treatment session or an intervention period of 3-12 weeks among people with stroke, compared with either no WBV under the same exercise condition, or other types of physical activities. This is partially due to the limited number of studies investigating the topic of WBV in stroke, lack of identification of the main impairment of the study participants, poor methodological quality and heterogeneity of samples used. In summary, based on the evidence available in the literature, clinical use of WBV in stroke rehabilitation is not supported.

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CHAPTER THREE

Measuring environmental barriers faced by individuals living with stroke: development and validation of the Chinese version of the Craig Hospital Inventory of Environmental Factors

Liao Lin Rong

3.1 ABSTRACT

Objective: To develop and validate a Chinese version of the Craig Hospital Inventory of Environmental Factors.

Design: Descriptive case-series

Subjects: 107 individuals with chronic stroke and 56 age-matched healthy subjects.

Methods: The English version of the 25-item Craig Hospital Inventory of Environmental Factors was translated into Chinese using standardized procedures, and then administered to both the stroke and control groups. The same questionnaire was administered again to the stroke group at 1-2 weeks after the first session.

Results: The Craig Hospital Inventory of Environmental Factors had good internal consistency (Cronbach's alpha = 0.916) and test-retest reliability (intra-class correlation coefficient = 0.845). It also had significant association with Personal Wellbeing Index ($r = -0.344$, $p < 0.001$) but not with Fugl-Meyer Assessment upper limb motor score ($r = -0.183$, $p = 0.088$) among stroke subjects, thus demonstrating convergent and discriminant validity, respectively. The mean Craig Hospital Inventory of Environmental Factors score in the stroke group was also significantly higher than that in controls ($p<0.05$), thus showing good known-groups validity.

Conclusions: The Chinese version of the Craig Hospital Inventory of Environmental Factors is a reliable and valid tool for evaluating the environmental barriers experienced by people with chronic stroke.

Key words: Cerebrovascular accident; community; environmental factors; participation; quality of life; chronic stroke.

3.2 INTRODUCTION

Stroke is a major public health problem and cause of long-term disability (Lynn et al., 2005). The sudden onset of disability following a stroke event may disrupt the continuity of an individual's life experience (Rittman et al., 2004). Individuals with stroke often suffer limitations in participation in community activities (Mayo et al., 2002; Pang et al., 2007; Cott et al., 2007; Rochette et al., 2001). According to the International Classification of Functioning, Disability and Health (ICF) developed by the World Health Organization (WHO) (WHO, 2001), the interaction between the individual and the environment can play a key role in determining the level of participation in the society (Rimmer et al., 1999; Fougeyrollas et al., 1995).

To obtain a clearer understanding of environmental barriers faced by patients after stroke and to better assess the effect of intervention programs, a standardized assessment of the environmental factors is essential. Several measures have been developed to quantify the environmental facilitators (i.e. factors that increase participation) or barriers (i.e., factors that reduce participation) in people with disabilities, such as the 84-item Measure of the Quality of the Environment (MQE) (Rochette et al., 2001; Fougeyrollas et al., 1999) and the 61-item Facilitators and Barriers Survey (FABS) (Gray et al., 2008). However, these questionnaires are quite lengthy and require a long period of time for completion, which may not be feasible in daily clinical practice, particularly in community rehabilitation settings where patient to therapist ratio is often high. Moreover, the MQE does not address the frequency of encountering environmental obstacles (Fougeyrollas et al., 1999; Geyh et al., 2004). The FABS, on the other hand, has shown only low to moderate internal consistency and test-retest reliability (Gray et al., 2008).

Another measure of environmental factors is the ICF Core Set for Stroke, which was originally developed to define the spectrum of problems in different aspects of functioning in patients with stroke (Algurén et al., 2009, 2010; Starrost et al., 2008). The extended version consists of 37 categories pertaining to the component of environmental factors. The inter-rater reliability of the Core Set, however, was found to be only moderate (kappa = 0.41) when used in patients with stroke (Starrost et al., 2008).

The 25-item Craig Hospital Inventory of Environmental Factors (CHIEF) (Whiteneck et al., 2004) is a common tool used to assess environmental barriers (Table 3.1). It has demonstrated good psychometric properties in samples of people with and without disabilities (Harrison-Felix, 2001). CHIEF addresses both the frequency and severity of the environmental barriers encountered, and covers different domains (i.e., physical, attitudinal, service, productivity, and policy) of barriers that hinder people from doing what they need to do and want to do. CHIEF also takes less time to administer compared with MQE and FABS. A short form containing 12 items is also available (Ephraim et al., 2006). The objectives of the study were to develop a Chinese version of CHIEF and to establish its reliability and validity when used in stroke patients of Chinese origin.

Table 3.1 Items in the CHIEF questionnaire

Item	Question
1	Transportation*
2	Design home
3	Design work
4	Design community
5	Natural Environment*
6	Surroundings*
7	Information*
8	Education/training
9	Medical Care*
10	Equipment
11	Technology
12	Help home*
13	Help work*
14	Help community
15	Attitudes home*
16	Attitudes work*
17	Attitudes community
18	Support home
19	Support work
20	Support community
21	Discrimination*
22	Services community
23	Policies business*
24	Education/Employment policies
25	Government policies*

*items included also in the short-form

3.3 METHODS

3.3.1 Sample size calculation

A previous study showed that the environmental factors (measured by MQE) were significantly associated with participation level (measured by the Assessment of Life Habits or LIFE-H), with a medium effect size (Rochette et al., 2001). We expected a similar effect size when CHIEF scores were correlated with personal wellbeing. Based on correlation analysis, the minimum sample size required for the study was 82 individuals with stroke [alpha = 0.05, power = 0.8, effect size = 0.3 (medium)].

In addition, a previous study has shown that the stroke group has lower level of community reintegration than controls, with a large effect size (Pang et al., 2011). We thus expected a similar between-group difference in environmental factors. Based on t-test analysis, a minimum sample size of 26 control subjects was required (alpha = 0.05, power = 0.8, effect size = 0.8).

3.3.2 Subjects

A convenience sample of people with stroke was recruited from stroke self-help groups in the local communities. The inclusion criteria were: 1) a diagnosis of stroke, 2) time since stroke onset of one year or longer (i.e., chronic stroke), 3) aged 18 years or above, 4) no significant cognitive deficits (Abbreviated Mental Test score ≥6), 5) community-dwelling, 6) had lived in Hong Kong for at least one year at the time of data collection, and 7) discharged home from the hospital at least six months previously. The exclusion criteria were: 1) living in nursing homes, 2) receptive or expressive aphasia, 3) other neurological conditions in addition to stroke, and 4) another serious illness that precluded participation.

A convenience sample of age-matched non-disabled controls was also recruited from the community in local elderly community centers and an existing database of non-disabled individuals who had enrolled in previous studies of the research group. The inclusion and exclusion criteria were the same as those for the stroke group except for the history of stroke. Ethical approval was granted by the Ethics Review Committee of the Hong Kong Polytechnic University. The study procedures were thoroughly explained to each participant by a research team member. Informed, written consent was obtained from each participant before the study began. The study was conducted in accordance with the Declaration of Helsinki.

All individuals who were interested in participating in the study were screened to determine whether they met the eligibility criteria through a telephone interview. For those individuals who were deemed eligible, a face-to-face interview was conducted in order to obtain the relevant information (e.g., medical history, mobility status).

3.3.3 Cultural adaptation of CHIEF

CHIEF is designed to identify the barriers in five major dimensions of the environment that may impede participation by people with disability, namely, accessibility, accommodation, resource availability, social support, and equality. It provides a characterization of the severity of perceived barriers to social participation based on self-report. Each item was rated based on two scales. First, a frequency score on a 5-point scale (0: never, 1: less than monthly, 2: monthly, 3: weekly, 4: daily) was used to indicate the frequency with which barriers were encountered. Second, a magnitude score on a 3-point scale (0: no problem, 1: little problem, 2: big problem) was used to denote the extent of the problem a barrier typically presents. Based on the rating of these two items, a frequency by magnitude product score was calculated (score range from 0 to 8) to indicate the overall impact of the barrier. The frequency by magnitude product score of different individual items were summed and then averaged to yield five subscale scores (Physical/Structural, Attitudes/Support, Services/Assistance, Work/School, and Policies) and total CHIEF score. A higher CHIEF score indicates a greater impact of environmental barriers.

Permission was obtained from the original authors of CHIEF before the initiation of the translation process. The cultural adaptation process was conducted in accordance with the standardized procedures outlined by Beaton et al. (Beaton et al., 2000). The first stage involved the forward translation of the English version of the CHIEF into Chinese by two bilingual translators whose mother language is Chinese. One of these translators is a physiotherapist, who may provide a more clinical perspective (Beaton et al., 2000). The other translator is a professionally trained translator with no clinical background. As this translator does not have prior knowledge of the concepts being measured by CHIEF (i.e., naive translator), it may be more likely for her to detect ambiguity in the original questionnaire and generate a translated questionnaire that is free of jargons (Beaton et al., 2000). Each of these two translators independently generated a Chinese version of the original CHIEF.

In the second stage, the two Chinese versions of CHIEF produced in the first stage and the original CHIEF were examined by the same two translators, and the results were then synthesized to generate a single Chinese version of the CHIEF. In the third stage, two different individuals independently translated the Chinese version of CHIEF back into English (i.e., backward translation). These two translators, with physiotherapy and psychology backgrounds respectively, were blinded to the original CHIEF in order to avoid bias in the backward translation process (Beaton et al., 2000). Amendments to the translated Chinese version were made if any inconsistencies were found.

In the fourth stage, a validation committee was formed. The committee consists of four individuals (a social worker, a clinical researcher, and two physiotherapists), who are competent in both Chinese and English. The committee examined the preliminary version of the translated questionnaire in four areas of equivalence, namely, experiential, semantic, idiomatic, and conceptual (Beaton et al., 2000), and make revisions as necessary. Next, five community-dwelling individuals with stroke who were naive to the CHIEF questionnaire were invited to participate in pilot testing of the revised version of the questionnaire and provide feedback on the translated questionnaire. Minor changes to the questionnaire were made to yield the final Chinese version of CHIEF (CHIEF-C).

3.3.4 Measurement procedures

In the first recording session, a trained interviewer administered the CHIEF-C to all participants in both the stroke and control groups. If the individual were not working or attending school, the items in the School/Work subscale were recorded as “not applicable” and re-coded as “0” for both frequency and magnitude scores for subsequent data analysis, as per the guidelines developed by the original developers of CHIEF (Harrison-Felix, 2001). Within one to two weeks after the first assessment session, the same interviewer re-administered the CHIEF-C to the stroke group, in order to establish test-retest reliability.

To assess convergent validity, the validated Chinese version of the Personal Wellbeing Index (PWI), a measure believed to assess a phenomenon closely related to CHIEF, was also administered to the stroke group in the first recording session (Portney et al., 2009). The PWI contains 7 items and is a generic measure of subjective well-being (Lau et al., 2005). Each item was rated on an 11-point scale (ranging from 0 to10). The scores for each item were multiplied by a factor of 10, and then summed and averaged to yield a mean PWI score (Lau et al., 2005).

To assess discriminant validity, the Fugl-Meyer Motor Assessment (FMA): upper limb section (Gladstone et al., 2002), a measure believed to assess a different characteristic than CHIEF, was administered to the stroke group in the first recording session. The 33-item FMA was used to assess the level of motor recovery in the hemiparetic upper extremity. A score of 0 to 2 was given to each item (0 = no performance, 1 = partial performance, 2 = complete performance). The scores for individual items were summed to yield the FMA upper limb motor score. FMA has demonstrated excellent intra-rater (r = 0.995-0.996) and inter-rater reliability (r = 0.89-0.95) (Gladstone et al., 2002).

3.3.5 Statistical analysis

All of the statistical analyses were performed using SPSS 17.0 software (SPSS, Inc., Chicago, Illinois, USA). A significance level of 0.05 was set for all analyses. The internal consistency of the CHIEF-C was assessed by Cronbach's alpha using the data obtained from the stroke group. The test-retest reliability of CHIEF-C subscale and total scores were tested by the intraclass correlation coefficients ($ICC_{3,1}$) (Portney et al., 2009).

The minimal detectable difference (MDD) value of the CHIEF-C total score was estimated using the following formula (Portney et al., 2009).

$$MDD = 1.96 \times SEM \times \sqrt{2},$$

where SEM is the standard error of measurement.

SEM of the CHIEF-C subscale and total scores were calculated using the following formula (Portney et al., 2009).

$SEM = Sx \sqrt{(1-rxx)}$,

where Sx is the standard deviation, and rxx is the reliability coefficient.

To assess construct validity (i.e., convergence and discrimination), Pearson's correlation coefficient was used to determine the degree of association of the CHIEF-C total scores with the PWI and FMA upper limb scores. The CHIEF scores were compared between the stroke and control groups using independent t-tests to establish known-groups validity. To further explore the clinical correlates of CHIEF scores in stroke patients, we used the Pearson's correlation coefficient or Spearmans' rho to examine the degree of association between the CHIEF-C total scores and other relevant demographic variables (e.g. age, post-stroke duration), depending on whether the criteria for parametric statistics were met. All of the above analyses were repeated for the 12 items included in the short form of the questionnaire.

3.4 RESULTS

3.4.1 Participant characteristics

A total of 107 individuals with stroke participated in the study (Table 3.2). The mean CHIEF-C score was 0.51 (SD = 0.63). On average, the motor impairment level of the hemiparetic upper limb was moderate, as reflected by the Fugl-Meyer upper limb score (mean = 40.6, SD = 18.6). Among the various demographic variables measured, a higher CHIEF-C score was significantly correlated with younger age ($r = -0.335$, $p<0.001$). Living alone was also associated with higher CHIEF-C score ($\rho = -0.218$, $p = 0.027$).

Table 3.2 Subject characteristics

Variable	Stroke group (n=107)	Control group (n=56)
Basic demographics		
Age, years, mean (SD)	62.6 (11.6)	64.0 (11.9)
Sex, men/women, n	68/39	31/25
Education, none/elementary/secondary/post-secondary, n	16/43/40/7	10/18/23/5
Marital status, single/married/divorced/widowed, n	9/79/8/11	3/48/2/3
Living situation, living alone/living with someone, but usually alone/ living with someone and rarely alone throughout the day, n	15/31/61	6/45/5
Use of walking aid required in outdoor environment, n	42	0
Number of co-morbid conditions, median (Range)	2 (0-7)	0 (0-5)
Number of medications, median (Range)	3 (0-15)	0 (0-10)
Stroke characteristics		
Number of subjects with recurrent stroke, n	28	
Duration since first stroke, years, mean (SD)	4.6 (4.3)	
Type of stroke, hemorrhagic/ischemic/unknown, n	36/65/7	
Side of paresis, left/right, n	47/60	

SD: standard deviation.

3.4.2 Reliability

The internal consistency of the CHIEF-C long form was excellent (Cronbach's $\alpha = 0.916$). Seventy-six of the 107 individuals with stroke participated in a second assessment session, in which the CHIEF-C was administered again for establishing test-retest reliability. Comparison of the scores obtained in the first and second recording sessions revealed moderate to good test-retest reliability, with $ICC_{3,1}$ values ranging from 0.669-0.793 for the 5 subscale scores, and 0.845 for the total score (Table 3.3). The level of agreement for all subscale and total scores between the two sessions was above that expected by chance ($p<0.005$). The MDD value for the CHIEF-C total score was 0.62.

When only the 12 items included in the short form were analyzed, the internal consistency remained high (Cronbach's $\alpha = 0.889$). The test-retest reliability was slightly decreased when the short form was used, with $ICC_{3,1}$ values varying from 0.595-0.774 for the subscale and 0.800 for the total scores (Table 3.3). The MDD of the total score was slight increased to 0.87 if the short form was used.

Table 3.3 Test-retest reliability of CHIEF-C scores in the stroke group (n=71)

	CHIEF-Time 1		CHIEF-Time 2			
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	$ICC_{3,1}$	p-value
Long-form						
Subscale						
Policies	0.58 (1.03)	0.00 (1.00)	0.55 (1.09)	0.00 (0.50)	0.686	<0.001**
Physical/Structural	0.66 (0.84)	0.33 (1.00)	0.80 (1.12)	0.33 (1.00)	0.708	<0.001**
Work/School	0.15 (0.38)	0.00 (0.00)	0.14 (0.40)	0.00 (0.00)	0.672	<0.001**
Attitudes/Support	0.44 (0.78)	0.20 (0.60)	0.41 (0.67)	0.20 (0.00)	0.793	<0.001**
Services/Assistance	0.53 (0.65)	0.29 (0.71)	0.50 (0.79)	0.14 (0.57)	0.669	<0.001**
Total	0.51 (0.57)	0.28 (0.56)	0.52 (0.69)	0.28 (0.60)	0.845	<0.001**
Short-form						
Policies	0.73 (1.31)	0.00 (1.00)	0.77 (1.43)	0.00 (1.00)	0.595	<0.001**
Physical/Structural	0.93 (1.27)	0.50 (1.50)	1. 20 (1.61)	0.50 (2.00)	0.697	<0.001**
Work/School	0.18 (0.49)	0.00 (0.00)	0.18 (0.53)	0.00 (0.00)	0.515	<0.001**
Attitudes/Support	0.58 (1.03)	0.00 (1.00)	0.58 (0.95)	0.00 (1.00)	0.689	<0.001**
Services/Assistance	0.67 (0.88)	0.00 (1.00)	0.78 (1.00)	0.25 (0.75)	0.774	<0.001**
Total	0.63 (0.70)	0.33 (0.84)	0.66 (0.84)	0.42 (0.92)	0.800	<0.001**

**p<0.01

ICC: intraclass correlation coefficient

IQR: interquartile range

3.4.3 Validity

When all items were analyzed, the CHIEF-C total score showed a significant moderate correlation with PWI score (r = -0.391, p = 0.001), thus demonstrating convergent validity. No significant correlation wad found, however, between CHIEF-C total score and FMA upper limb score (r = -0.183, p> 0.088) (i.e., discriminant validity). The CHIEF-C scores obtained from the stroke group were then compared with those from the control group (n=56, mean age = 64.0 years, SD = 11.9 years). The CHIEF-C scores were significantly higher in the stroke group than controls (p < 0.001), except the Work/School (p = 0.103) and Attitude/Support (p = 0.115) subscales (Table 3.4).

When only the items contained in the short form were analyzed, the results were similar. The CHIEF-C total score remained significantly associated with the PWI score (r = -0.379, p = 0.001) but not with the FMA upper limb score (r = -0.126, p = 0.243). When compared with controls, the stroke group had significantly higher ratings in the CHIEF-C total score (p = 0.003) and all subscale scores (p < 0.05), except the Work/School subscale (p = 0.273) (Table 3.4).

Table 3.4 Comparison of the CHIEF-C scores between the stroke and control groups

	Stroke (n=107)		Control (n=56)		
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	p-value
Long-form					
Subscale					
Policies	0.49 (0.98)	0.00 (0.50)	0.25 (0.75)	0.00 (0.00)	0.183
Physical/Structural	0.72 (0.93)	0.33 (1.00)	0.43 (0.59)	0.17 (0.79)	0.040*
Work/School	0.11 (0.33)	0.00 (0.00)	0.17 (0.58)	0.00 (0.00)	0.432
Attitudes/Support	0.47(0.84)	0.20 (0.60)	0.29 (0.49)	0.00 (0.40)	0.065
Services/Assistance	0.55 (0.78)	0.29 (0.86)	0.30 (0.41)	0.14 (0.57)	0.034*
Total	0.51 (0.64)	0.24 (0.52)	0.31 (0.36)	0.16 (0.43)	0.020*
Short-form					
Subscale					
Policies	0.59 (1.24)	0.00 (0.50)	0.23 (0.77)	0.00 (0.00)	0. 128
Physical/Structural	1.10 (1.41)	0.50 (1.50)	0.49 (1.26)	0.00 (0.50)	0.001*
Work/School	0.12 (0.41)	0.00 (0.00)	0.17 (0.48)	0.00 (0.00)	0.325
Attitudes/Support	0.64 (1.12)	0.00 (1.00)	0.27 (0.57)	0.00 (0.38)	0.009*
Services/Assistance	0.70 (0.94)	0.25 (1.00)	0.39 (0.59)	0.00 (0.69)	0.042*
Total	0.64 (0.73)	0.42 (0.75)	0.32 (0.43)	0.13 (0.50)	0.001*

*Significant between-group difference ($p<0.05$).

SD: standard deviation.

IQR: interquartile range

3.5 DISCUSSION

In this study, a cultural adaptation of the CHIEF questionnaire was performed to facilitate measurement of environmental barriers among Chinese individuals with chronic stroke. The results showed that the CHIEF-C has good psychometric properties when used in the Chinese stroke population in Hong Kong.

3.5.1 Environmental barriers faced by individuals with stroke

The mean CHIEF-C total score obtained from our stroke group was 0.51, which is actually quite comparable to the CHIEF total score previously reported in people with traumatic brain injury (mean = 0.89) but slightly lower than people with spinal cord injury (mean = 1.25)(Harrison-Felix, 2001). Among the five subscales, the Physical/Structural subscale shows the highest score, just as in patients with spinal cord injury and traumatic brain injury (Harrison-Felix, 2001). In Hong Kong, which is an extremely densely populated city characterized by heavy traffic, crowded public places and relative lack of wheelchair accessible buildings and facilities, it is not surprising that individuals living with residual stroke impairments may encounter some physical environmental barriers that restrict their social participation.

Previous studies have found a higher impact of environmental factors than ours. For example, using the ICF Core Set for Stroke, Algurén et al. (2009) showed that about half of the stroke patients reported “physical geography” as a barrier to participation. About 24 % of the sample also perceived “transportation services, systems and policies” as a barrier. In Rochette et al. (2001), various environmental factors (e.g., governmental and public services, physical environmental and accessibility, equal opportunity and political orientations) were identified to be moderate environmental barriers (MQE score at about 2 out of 3) by their chronic stroke patients. Apart from the difference in instruments used, the discordance in results may be due to the difference in subject characteristics. Our stroke group is substantially more chronic (mean post-stroke duration = 4.6 years) than that in previous studies (3-6 months post-stroke) and may thus have better adjusted to the restrictions imposed by the environmental barriers (Rochette et al., 2001; Algurén et al., 2009). Another explanation of the relatively modest CHIEF score may be related to the fairly good level of mobility demonstrated by our subjects, with 39% of individuals with stroke being able to walk without any walking aids (Table 3.2).

It is intriguing that younger age was associated with more perceived environmental barriers in the stroke group. Further examination of the data revealed that younger age was significantly associated with less co-morbid conditions ($\rho = 0.384$, $p<0.001$). The proportion of walking aid users among stroke patients younger than the age of 65 was also significantly lower than their older counterparts. Thus, one potential explanation of the inverse relationship between age and environmental barriers is that the younger stroke survivors may be more inclined to venture out and participate in community activities due to their better general health condition and mobility level. However, the more frequent participation in community activities also inevitably lead to more frequent encounter with potential environmental barriers, compared with those who choose to stay at home. Another possible explanation is that the younger individuals living with stroke may compare their level of activity and participation with their non-disabled peers of similar age, and thus set a higher expectation for themselves, which may in turn contribute to the higher level of perceived environmental barriers.

It was found that the stroke survivors who were living alone tended to have a higher degree of perceived environmental barriers. It is consistent with the results of a previous stroke study in showing that living alone was associated with a lower level of satisfaction with community reintegration (Pang et al., 2011). Community support thus becomes even more important for these individuals who have less family support. The coordination of patient care after hospital discharge should ensure that these individuals have access to community resources.

3.5.2 Reliability

The Cronbach's α value (0.916) and test-retest reliability reported here (ICC = 0.845) are very similar what was previously reported by the original authors of CHIEF (ICC = 0.926) (Harrison-Felix, 2001). However, their data were collected from a mixed sample of 103 individuals with and without disability (spinal cord injury, traumatic brain injury and others). Our study is the only one that assesses the reliability of the CHIEF in the stroke population and the results demonstrate good reliability. This study also yields the MDD value (0.62), which represents the smallest difference that would reflect a real change in the CHIEF-C score (Portney et al., 2009). The MDD value found here would be useful in determining whether the experimental intervention has caused any real difference in perceived environmental barriers in future stroke intervention trials.

3.5.3 Validity

The results showed that CHIEF-C total score was significantly associated with PWI scores, but not the FMA upper limb scores, thus demonstrating good construct validity. Specifically, higher CHIEF scores (more perceived environmental barriers) were significantly associated with lower PWI scores (less personal wellbeing). Our results are thus consistent with previous studies in showing the negative impact of environmental barriers on activity and participation. For example, Rochette et al. (2001) found that the environmental factors as measured by MQE remained independently associated with handicap level as measured by LIFE-H among individuals with stroke, accounting for 6.2% of the variance. In another study by Han et al. (2005), higher CHIEF scores were significantly related to poorer performance in activities of daily living as measured by Barthel Index (r = -0.577) in a sample of people with and without stroke.

When the CHIEF-C scores from the stroke group were compared with the control group, significant between-group differences were found in the total scores and most subscale scores, thus indicating good known-groups validity. The Work/School subscale score did not demonstrate any significant between-group difference, however (Table 3.4). It is probably due to the fact that in our study, 93 out of 107 individuals in the stroke group were not working or attending school at the time of data collection and therefore "not applicable" was chosen for the items in the Work/School subscale. We used the established guidelines described by original authors of CHIEF (Harrison-Felix, 2001) to re-code the items in the Work/School subscale to zero for both frequency and magnitude, indicating "no environmental barrier". This may account for the lack of difference in Work/School subscale score between the two groups. The Attitude/Support subscale showed a significant between-group difference in the short form version, but not in the long from version. When analyzing this subscale in more detail, it was found that item 18 (Support in home), which only exists in the long form version, did not show a significant between-group difference. The results may indicate that overall, the participants in the stroke group perceived that they had received adequate support and encouragement from others at home. As aforementioned, those who were living alone tended to have a higher level of perceived environmental barrier. However, these individuals only constitute 14% of our sample (Table 3.2).

3.5.4 Long form Vs short form

Overall, regardless of whether the items for the long form or short form were used for analysis, similar results were generated. The internal consistency values were good for both versions (Cronbach's alpha >0.85). Although a slight decrease in test-retest reliability was detected in a few subscales if only the items of the short form were analyzed, the overall test-retest reliability of the scale was largely unaffected (ICC values close to 0.9). Convergent, discriminant and known-groups validities remained well established when the short form was used. The CHIEF short form is thus a reasonable alternative if time constraints do not allow the administration of the long form.

3.5.5 Limitations and future research directions

This study has several limitations. First, CHIEF only assesses the environmental barriers but not the facilitators, whereas conceptual models of disability suggest that the environment can act as a facilitator and as a barrier to participation (Whiteneck & Dijkers, 2009). Further research is needed to compare measures such as the CHIEF that focus on barriers with those such as the MQE that also consider the positive aspects of the environment when used in the stroke population.

Second, CHIEF only assesses the subjective perceptions of the impact of the environmental barriers. The relation between the perceived and actual barriers is not uncertain (Whiteneck et al., 2004). More study is required to examine the relationship between individual perceptions and more objective community assessments.

Third, we did not evaluate subject-proxy agreement. A moderate subject-proxy agreement (ICC = 0.618) was found in the original CHIEF, using a mixed sample of people with and without disabilities (Harrison-Felix, 2001). Future research should address the subject-proxy agreement of the CHIEF-C.

Finally, the participants in this study have fairly good mobility level, which may affect the generalizability of the results. However, in Hong Kong, those with severe disability after stroke are likely to be institutionalized. Thus, our sample is actually quite a good representation of community-dwelling people living with chronic stroke in the local context.

3.5.6 Conclusion

In conclusion, the CHIEF-C is a reliable and valid tool for evaluating the environmental barriers experienced by people with chronic stroke. The CHIEF-C short form is a reasonable alternative if administering the long form is not feasible due to time constraints.

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Conflict of interest: none

CHAPTER FOUR

Leg Muscle Activity during Whole-body Vibration in Individuals with Chronic Stroke

Liao Lin Rong

4.1 ABSTRACT

Purpose: It has been previously shown that whole-body vibration (WBV) can augment muscle activity in young healthy adults. However, the electromyography response of leg muscles during WBV in individuals with stroke is unknown. The objective of this study was to determine the influence of WBV on the activity of the vastus lateralis (VL) and gastrocnemius (GS) muscles during the performance of different exercises in chronic stroke patients.

Methods: Forty-five chronic stroke patients were studied. Each subject was exposed to three WBV conditions of 1. no WBV, 2. low-intensity WBV protocol [peak acceleration: 0.96 unit of gravitational constant (G)], and 3. high-intensity WBV protocol (peak acceleration: 1.61G) while performing 8 different static exercises involving upright standing, semi squat, deep squat, weight-shifted-forward, weight-shifted-backward, weight-shifted-to-the-side, forward lunge and single-leg-standing. Bilateral VL and GS muscle activity was recorded with surface electromyography (EMG), and expressed as percentage of the EMG amplitude recorded during a maximal voluntary contraction of the respective muscles (%MVC).

Results: Two-way analysis of variance with repeated measures revealed that exposure to WBV (low- and high-intensity protocols) significantly increased VL and GS EMG amplitude (large effect size, partial $\eta^2 = 0.135\text{-}0.643$, $p<0.001$) on both the paretic and non-paretic sides in different exercise conditions, compared with no WBV. No significant difference in EMG magnitude was found between the high- and low-intensity WBV protocols ($p>0.05$). With a few exceptions, WBV enhanced EMG activity in the paretic and non-paretic leg muscles to a similar extent in different exercise conditions.

Conclusions: Leg muscle activity was increased significantly with addition of WBV. Further clinical trials are needed to determine the effectiveness of different WBV protocols for strengthening leg muscles in chronic stroke patients.

Key words: cerebrovascular accident; rehabilitation; exercise; hemiparesis

4.2 INTRODUCTION

Stroke is one of the most common disabling conditions, and presents a major public health problem worldwide (Feigin et al., 2009). Following a stroke, central excitatory drive to motor units is disrupted due to lesion in the descending motor pathways (Gracies, 2005), causing impaired ability to voluntarily generate muscle force. In addition, other factors such as muscle atrophy, and lack of physical activity may also contribute to muscle weakness (Patten et al., 2004). Muscle weakness has been identified as a major contributing factor to disability among people with stroke (Patten et al., 2004). For example, decreased leg muscle strength has been associated with reduction in gait speed and quality, walking endurance, transfer capacity, stair climbing ability and balance function (Flansbjer et al., 2006; Kluding & Gajewski, 2009).

Recent observations have shown the possibility of utilizing whole body vibration (WBV) as a training tool in rehabilitation to improve muscle strength in a variety of populations, including young athletes, seniors and people with chronic conditions (Ahlborg et al., 2006; Issurin & Tenenbaum, 1999; Lau et al., 2011; Madou, 2011). A number of studies have shown that muscle activity can be enhanced during the application of WBV (Brogardh et al., 2012; Hazell et al., 2010; Pollock et al., 2010; Roelants et al., 2006). Roelants et al. (2006) examined the electromyography (EMG) response of rectus femoris, vastus lateralis (VL), vastus medialis, and gastrocnemius (GS) during the performance of three isometric exercises (high squat, low squat and one-legged squat) with WBV. Compared with the no-WBV condition, adding WBV significantly increased the EMG amplitude for all four muscles measured during the performance of all three squatting exercises, by 49%-361% (36). Because of its ability to enhance muscle activity, increasing research has explored whether WBV training for a longer time period can lead to an increase in muscle strength in older adults, who often suffer from muscle weakness

(Lau et al., 2011). A recent meta-analysis showed that WBV has significant treatment effect on enhancing certain aspects of leg muscle strength in older adults after 6-10 weeks of training (Lau et al., 2011).

Since most WBV treatment programs involve relatively brief treatment sessions and simple body movements (Lau et al., 2011), it is deemed suitable for those with neurological conditions, who often sustain considerable motor and cognitive deficits. Indeed, WBV therapy has been reported to have positive effects on muscle strength and motor performance in adults with cerebral palsy (Ahlborg et al., 2006; Flansbjer et al., 2012). Apart from resistance exercise training (Flansbjer et al., 2012), WBV may thus offer a viable intervention approach for persons with stroke to improve muscle strength. A number of randomized controlled studies have investigated the effects of 4-8 weeks of WBV therapy on leg muscle strength in stroke patients. The results are mixed, with significant effects reported in some studies (37,39), but not others (Brogardh et al., 2012; Lau et al., 2012). Perhaps the difference in subject characteristics and WBV exercise protocols such as vibration settings, program duration, and exercise posture used in these studies may account for the difference in outcomes. In particular, the vibration intensity used across the different studies varied greatly (peak acceleration ranging from (9.5m/s^2 to 92.5m/s^2) (Brogardh et al., 2012; Lau et al., 2012; Tihanyi et al., 2010; van Nes et al., 2006), and the rationale for the protocols used with physiologically based justifications were often not provided (Brogardh et al., 2012; Tihanyi et al., 2010). Before effective WBV exercise protocols can be identified for this subject group, it is essential to address a more fundamental yet important question: what occurs to the leg muscle activity level *during* exposure to WBV of different intensities? Understanding the relationship between leg muscle activation and WBV intensity and exercise is essential as it would inform the design of WBV protocols for further efficacy studies (e.g., randomized controlled trials). Additionally, it would also provide a physiological basis for the therapeutic effects (or lack thereof) induced by different WBV exercise protocols.

Although it is well known that exercise training is an important adjunct therapy in patients with chronic stroke that can lead to improvements in function (Mehta et al., 2012; Pang et al., 2013b), research evidence is scarce on examining the relationship between outcomes and different modes of exercise, including the effects of WBV exercise. To date, no study has systematically examined the effects of WBV on leg muscle activity in individuals with chronic stroke. The purpose of this study was to determine the influence of different WBV protocols on the amplitude of EMG activity in the VL and GS muscles during the performance of various exercises among people with chronic stroke.

4.3 METHODS

4.3.1 Study Design

This was an experimental study, with subjects undergoing three different WBV conditions of no WBV, low-WBV intensity protocol, and high-WBV intensity protocol. In each condition, the subjects were asked to perform eight different exercises while leg muscle activity on both sides was measured using surface electromyography (EMG). The sequence of WBV intensities used and exercises performed was randomized by drawing ballots using an opaque envelope to avoid order effect. For each subject, all measurement procedures were performed on the same day.

4.3.2 Subjects and sample size estimation

As no study has examined the EMG response during WBV in people with stroke, previous research investigating the EMG response during WBV in healthy adults was used to estimate the sample size needed for this study. In a study involving 15 healthy men, Roelants et al. (2006) obtained a large effect size (Cohen's d = 5-8) for various muscle groups when WBV (35 Hz) was applied. Based on ANOVA analysis (3 WBV conditions), assuming an effect size f=0.6 (large), with an alpha of 0.05, power of 0.8, a minimum of 30 subjects would be required.

Subjects were recruited from stroke self-help groups in the community via convenience sampling. The inclusion criteria were: a diagnosis of a hemispheric stroke with onset ≥ 6 months (i.e. chronic stroke), community-dwelling (i.e., non-institutionalized), abbreviated Mental Test score ≥6, having hemiparesis in the lower extremity, as indicated by a composite leg and foot motor score of 13 or lower according to the Chedoke-McMaster Stroke Assessment (Gowland et al., 1993). The exclusion criteria were: neurological conditions in addition to stroke, brainstem or cerebellar stroke, significant musculoskeletal conditions (e.g. recent fractures, amputations), substantial vestibular dysfunctions (e.g., vertigo), peripheral vascular disease, unable to maintain standing for 1 minute with standby guarding assistance of one person, severe cardiovascular conditions (e.g., unstable angina, uncontrolled hypertension, uncontrolled cardiac dysrhythmia), and pain conditions that affected performance in standing, walking or other daily functional activities.

The study was approved by the Research Ethics Committee of the administrating institute before commencement. The experimental procedures were first fully explained to each subject before written informed consent was obtained. The study was conducted in accordance with the Declaration of Helsinki.

4.3.3 Basic demographics and spasticity

The basic demographic information (e.g., age, medical history, medications, etc.) was obtained from interviewing the subjects. To test spasticity on the paretic side, subjects were placed in a supine position and asked to relax. The researcher then moved the knee on the paretic side into flexion and extension alternately and the resistance to passive motion was noted. The same test was done on the ankle joint on the paretic side. The Modified Ashworth Scale was used to indicate the severity of spasticity in each joint tested. A higher score is indicative of more severe spasticity (0: normal muscle tone, 4: tested part rigid) (Bohannon et al., 1987).

4.3.4 WBV Protocol

The Jet-Vibe System (Danil SMC Co. Ltd., Seoul, Korea) was used to deliver the WBV stimulation. This device generates vertical vibrations and has an adjustable frequency range between 20-55Hz with corresponding preset amplitudes.

The intensity of WBV, represented by the peak acceleration (a_{peak}), was calculated by the formula: $a_{peak}= (2\pi f)^2 A$**,** where A is the amplitude, and f is the frequency (Kiiski et al., 2008). The a_{peak} is usually represented as a unit of the gravitational constant ($1G = 9.81 m/s^2$). The peak acceleration values generated by the device were validated by a triaxial accelerometer (Model 7523A5, Dytran Instruments Inc., Chatsworth, CA, USA).

Each participant was subject to three different WBV conditions: (a) no WBV, (b) low-intensity WBV protocol (peak acceleration: 0.96 G, frequency: 20 Hz, amplitude: 0.60mm), and (c) high-intensity WBV protocol (peak acceleration: 1.61 G, frequency: 30 Hz, amplitude: 0.44mm) while performing different exercises. We chose these frequencies because WBV frequencies lower than 20 Hz may cause destructive resonance effects to the body (Randall et al., 1997). On the other hand, our pilot experiments showed that frequencies higher than 30 Hz caused discomfort and fatigue in some individuals. The higher peak acceleration values associated with higher frequencies may also be a potential hazard for people with compromised bone mass, such as chronic stroke survivors (Pang et al., 2012).

4.3.5 Exercise protocol

The subjects were required to perform eight different exercises while being exposed to the three WBV conditions as described in Table 4.1. These exercises are commonly used in previous WBV trials in different populations (Cardinale & Lim, 2003; Lam et al., 2012; Lau et al., 2011; Pollock et al., 2010; Roelants et al., 2006; Torvinen et al., 2002b). Practice trials were given to ensure that the subjects were able to perform the exercises properly before actual data collection. The knee angle was measured by a manual goniometer (Baseline® HiRes™ plastic 360º ISOM Goniometer, Fabrication Enterprises, White Plains, NY, USA) to indicate the desired knee flexion angle in standing (10°), semi-squat (30°), and deep-squat (90°) exercises. All experimental procedures were monitored closely by the researcher throughout, to ensure that the subjects were performing the exercises properly and consistently. For standardization, all subjects were encouraged to gently hold on to the handrail of the WBV device for balance only. To ensure safety, the researcher provided standby guarding assistance while the patient was standing on the vibration platform. The researcher was standing by the patient in a guarding position, using his hands to be ready to guard or guide the patient.

TABLE 4.1 Static exercises performed while standing on the vibration platform

Static Exercise	Description
1. Standing (ST)	Feet placed apart at shoulder width, trunk upright, knees at 10^{o} flexion
2. Semi squat (SS)	Feet placed apart at shoulder width, trunk upright, bilateral knees at 30^{o} flexion.
3. Deep squat (DS)	Feet placed apart at shoulder width, trunk upright, bilateral knees at 90^{o} flexion.
4. Weight-shifted-forward (FWS)	Feet placed apart at shoulder width, trunk upright, body leaned forward with heels off the platform.
5. Weight-shifted-backward (BWS)	Feet placed apart at shoulder width, trunk upright, body leaned backward with forefoot off the platform.
6. Weight-shifted-to-the-side (WSTS)	Feet placed apart at shoulder width, trunk upright, body weight shifted to the paretic leg as much as possible. The same exercise was performed with the weight shifted to the non-paretic leg as much as possible.[b]
7. Forward lunge (FL)	Paretic leg placed in front, body leaned forward and weight shifted onto the paretic leg as much as possible. The same exercise was performed after the positions of the two legs were switched.[c]
8. Single-leg-standing (SLS)	Standing on the paretic leg, with knee at 10^{o} flexion. The same exercise was repeated on the non-paretic side.[d]

[a] Subjects were required to hold the posture as described above for 10 seconds.
[b] Analysis was based on the EMG data recorded from the weightbearing leg.
[c] Analysis was based on the EMG data recorded from the front leg.
[d] Analysis was based on the EMG data recorded from the weightbearing leg.

4.3.6 Measurement of leg muscle activity responses

Surface EMG was used to measure activity of the VL and GS muscles in all test conditions. After proper skin preparation, the bipolar bar electrodes (Bagnoli EMG system, Delsys, Inc., Boston, MA, USA) were placed on the muscle belly of GS and distal one third of VL muscles, according to the specifications of the Surface EMG for a Non-invasive Assessment of Muscles (SENIAM) project (Hermens et al., 2000). A reference electrode was placed at the head of fibula. Insulated EMG cables were fastened to avoid movement artifacts.

For each WBV condition, subjects were asked to assume each of the 8 postures (Table 4.1) for 10 seconds while VL and GS EMG activity was being recorded. A total of 3 trials were performed for each of the 8 exercises in a given WBV condition, with a 1-minute rest period in-between trials. After all 8 exercises were completed in the first WBV condition, the subjects were then asked to do the same 8 exercises in the second and third WBV conditions. A 10-minute rest period was given between each WBV condition. Only the EMG data obtained during the middle six seconds of each trial was extracted to obtain the EMG root mean squares (EMGrms), and the mean value of the three trials was used for subsequent analysis.

All EMG data collected were pre-amplified (×1000) and sampled at 1 kHz (Bagnoli-8, DelSys, Inc., Boston, MA, USA), using a personal computer with LabView version 7 software (National Instruments Corp., Austin, TX, USA). Data processing was performed using MyoResearch XP, Master Package version 1.06 (Noraxon USA, Inc., Scottsdale, AZ, USA). The EMG data were filtered with 20-500 Hz band-pass Butterworth filter, and the Infinite Impulse Response (IIR) rejector was implemented to eliminate the associated harmonics at the frequencies of 20 Hz, 30 Hz and 60 Hz. After filtering, bias was calculated and removed from each EMG signal, and then the data were rectified and the EMGrms calculated in 100-ms windows around every data point (Abercromby et al., 2007).

At the beginning of the session, the EMG activity of VL and GS during maximal voluntary isometric contraction (MVC) was first recorded. For measuring the EMG amplitude of VL during MVC of knee extension, each subject was comfortably seated and the tested leg was fixed horizontally on a dynamometer (Cybex Norm Testing & Rehabilitation System, Stoughton, MA, USA) with hip and knee stabilized at 90 degrees. Subjects were then asked to perform isometric knee extension for 10 seconds. The same device was used to stabilize the hip and knee when measuring the EMG amplitude of GS during MVC of ankle plantarflexion. The foot was placed at 90 degrees on a wedged platform and the subjects were instructed to isometrically plantarflex the ankle against the wedge with maximal effort and sustain for 10 seconds. Subjects were provided with verbal encouragement to ensure a maximal effort during testing.

EMG root mean square values (EMGrms) were calculated during intervals of 0.5 seconds (Eckhardt et al., 2011). For each muscle, the maximum EMGrms values from the three MVC trials were averaged to obtain the mean value, which was then used for normalization of the EMGrms value obtained in each WBV condition. Therefore, the EMG amplitude of each muscle obtained in all WBV conditions was expressed as a percentage of the EMG amplitude obtained during the MVC (%MVC). The reliability of the EMGrms data obtained from the three MVC trials was excellent, as demonstrated by the intraclass correlation coefficients ($ICC_{3,1}$) (paretic VL: 0.99, paretic GS: 0.94, non-paretic VL: 0.99, non-paretic GS: 0.99).

4.3.7 Statistical analysis

Analysis was performed with IBM SPSS Statistics software (version 20.0, IBM, Armonk, NY, USA). The level of significance was set at $p \leq 0.05$. Two-way analysis of variance (ANOVA) with repeated measures [within-subject factors: 1. intensity (no WBV Vs low-intensity WBV Vs high-intensity WBV); and 2. exercises] was used to compare the normalized EMGrms data across the different conditions. When sphericity assumption was violated, the Greenhouse-Geisser epsilon adjustment was used. Contrast analysis using paired t-test with Bonferroni adjustment was performed if any overall significant results were obtained for the EMG data. To compare the influence of WBV on the paretic side Vs the non-paretic side, the ratio of normalized EMGrms (%MVC) of the VL and GS on the paretic side to the corresponding muscles on the non-paretic side was computed. A ratio greater than 1 indicated that the paretic side achieved a higher %MVC than the non-paretic side. A second two-way repeated measures ANOVA model [within-subject factors: 1. WBV intensity and 2. Exercises] was then constructed, using the EMGrms ratio as the dependent variable. Effect size was denoted by partial eta-squared (partial η^2). Large, medium and small effect sizes were represented by partial η^2 values of 0.14, 0.06, and 0.01, respectively (Pallant, 2007). To examine the potential impact of spasticity on the EMG data, Spearman's rho was used to examine the relationship between a) paretic knee spasticity score and normalized EMGrms of paretic VL, and b) paretic ankle spasticity score and normalized EMGrms of paretic GS in each testing condition.

4.4 RESULTS

4.4.1 Demographic characteristics of subjects

A total of 64 individuals with chronic stroke were screened, and 45 of these (34 men and 11 women) fulfilled all criteria and completed all assessments (Figure 4.1). The median lower extremity composite motor score (Chedoke-McMaster Stroke Assessment) was 7 out of 14, indicating moderate impairment. The majority of subjects had no spasticity in the paretic knee (i.e., spasticity score = 0; n=28) but mild to moderate spasticity in the paretic ankle (spasticity score = 1-2; n=37). Severe spasticity (i.e., spasticity score =3-4) in the paretic knee (n=1) and ankle (n=1) was rare. The demographic data are summarized in Table 4.2.

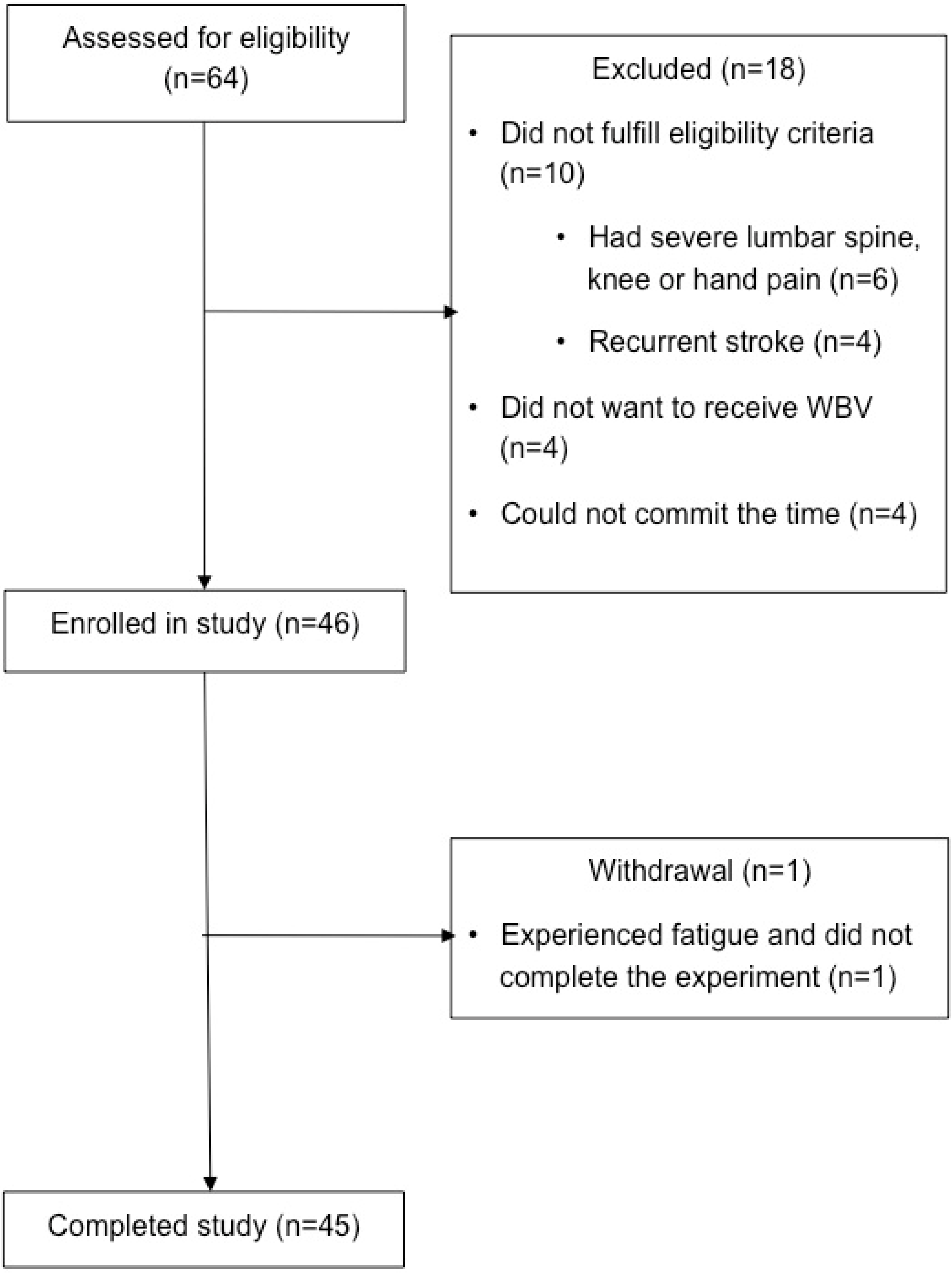

Figure 4.1 Study flow chart A total of 45 subjects with stroke completed all assessment procedures.

TABLE 4.2 Characteristics of subjects (N=45)

Variable	**Value**[a]
Basic demographics	
Age, years	56.1±10.2
Sex, men/women, n	34/11
Body mass index, kg/m^2	24.6±3.3
Required walking aid for indoor mobility, none/cane/quadrupod, n	40/2/3
Required walking aid for outdoor mobility, none/cane/quadrupod, n	15/24/6
Stroke characteristics	
Post-stroke duration, years	4.7±3.2
Type of stroke, hemorrhagic/ischemic/unknown, n	21/19/5
Side of paresis, left/right, n	18/37
CMSA Leg Score (1- 7) (median; IQR) [b,c]	4; 4-4
CMSA Foot Score (1- 7) (median; IQR)	3; 3-4
CMSA Lower Extremity Composite Score (Out of 14) (median; IQR)	7; 7-9
Paretic knee Modified Ashworth Scale of spasticity score (0-4)[d]	
0/1/1.5/2/3/4, n	7/10/13/14/1/0
Median; IQR	1.5; 1-2
Paretic ankle Modified Ashworth Scale of spasticity score (0-4)	
0/1/1.5/2/3/4, n	28/11/5/0/1/0
Median; IQR	0; 0-1
Maximal voluntary contraction EMG (μV)	
Paretic leg gastrocnemius	151.4±128.9
Non-paretic leg gastrocnemius	212.0±180.6
Paretic leg vastus lateralis	188.2±148.6
Non-paretic leg vastus lateralis	245.7±137.4

[a] Mean±SD presented for continuous variables.

[b] IQR = interquartile range

[c] CMSA = Chedoke McMaster Stroke Assessment

[d] Modified Ashworth Scale is a 6-point ordinal scale. The category 1+ was converted to 1.5 for statistical analysis.

4.4.2 EMG activity of Paretic leg VL

There was an overall significant main effect of WBV intensity ($F_{2,88}$=27.006, $p<0.001$, partial η^2=0.380) and exercise ($F_{7,308}$=29.846, $p<0.001$, partial η^2=0.404) (Figure 4.2A). The intensity × exercise interaction effect was also significant ($F_{14, 616}$=2.312, p=0.031, partial η^2=0.050). In post-hoc analysis of the main effect of intensity, both the low WBV intensity ($p<0.001$) and high WBV intensity ($p<0.001$) protocols induced significantly higher EMG amplitude than the control condition, no matter what exercise was performed. The difference in EMG amplitude was not significant, however, between the low-intensity and high-intensity WBV protocols (p=0.744). Regarding the main effect of exercise, deep squat position induced significantly higher paretic VL EMG amplitude than other exercises, regardless of WBV intensity (all $p<0.001$).

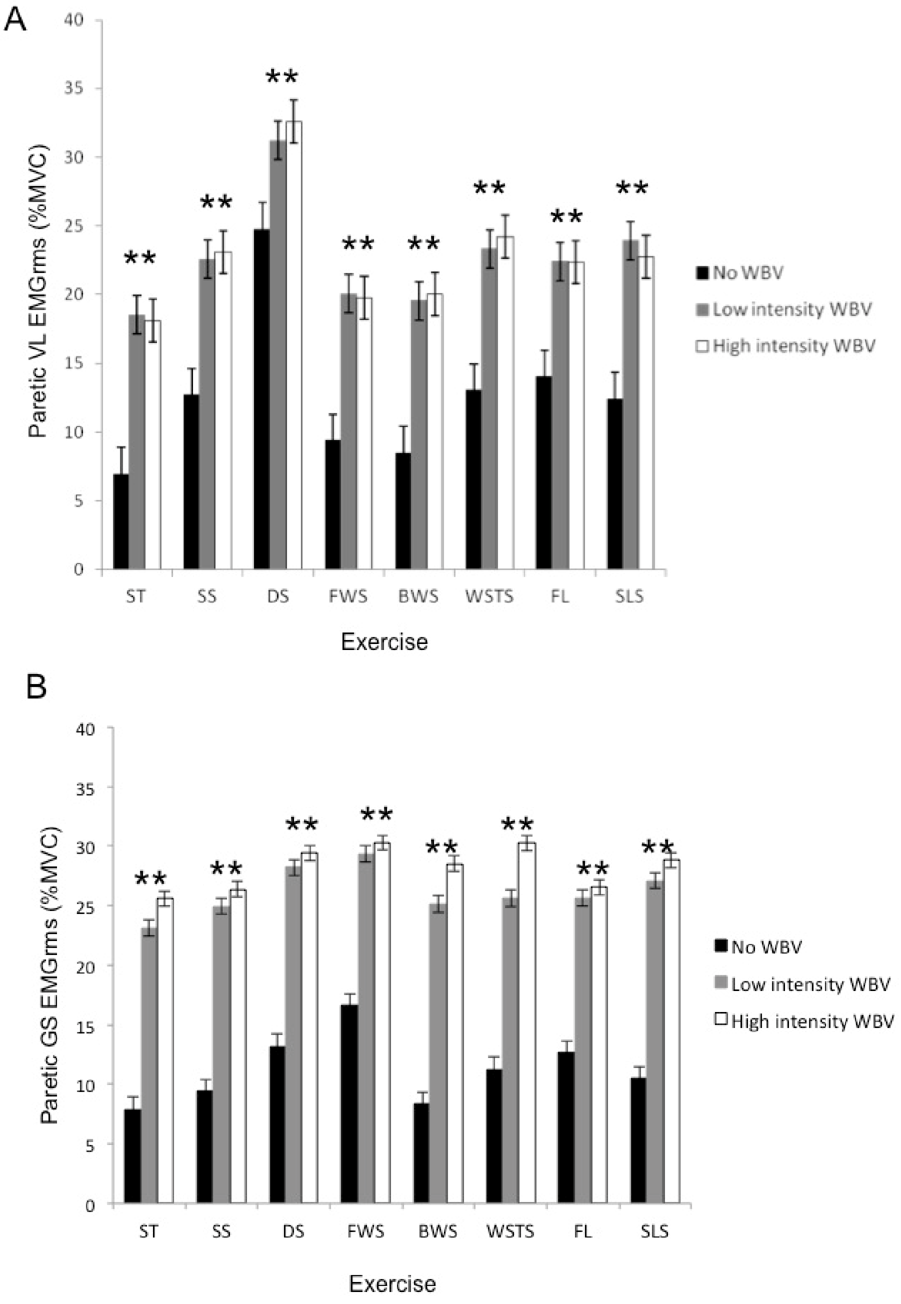

Figure 4.2 Effect of WBV on EMG amplitude in the paretic leg. The EMGrms amplitude of the VL (Figure 4.2A) and GS (Figure 4.2B) was expressed as a percentage of that recorded during the MVC (vertical axis) in each test condition is displayed. The EMG amplitude recorded in the no-WBV, low-intensity WBV and high-intensity WBV conditions is represented by black,

gray, and white vertical bars, respectively. Eight exercises were tested: upright standing (ST), semi squat (SS), deep squat (DS), weight-shifted-forward (WSF), weight-shifted-backward (WSB), weight-shifted-to-the-side (WSTS), forward lunge (FL), and single-leg-standing (SLS). The error bars represent 1 standard deviation from the mean. * indicates significant difference from the no-WBV condition. The same conventions are used in other figures. Adding WBV led to significant increase in paretic leg VL and GS EMG amplitude.

4.4.3 EMG activity of Paretic leg GS

The main effect of intensity ($F_{2,88}$=36.728, p<0.001, partial η^2=0.465) and exercise ($F_{7,308}$=6.858, p<0.001, partial η^2=0.135), as well as the intensity × exercise interaction effect ($F_{14,616}$=2.701, p=0.046, partial η^2=0.058) were all significant (Figure 4.2B). Post-hoc analysis of the main effect of WBV intensity revealed that the EMG amplitude among the three WBV conditions were all significantly different from each other (p<0.01). However, the difference in EMG amplitude between the low-intensity and high-intensity protocols was not significant in any of the exercises after Bonferroni adjustment. Post-hoc analysis of the main effect of exercise showed that the weight-shifted-forward position resulted in higher EMG than most of the other exercises (p<0.01).

4.4.4 EMG activity of Non-Paretic leg VL

The main effect of intensity ($F_{2,88}$=30.887, p<0.001, partial η^2=0.412) and exercise ($F_{7,308}$=79.302, p<0.001, partial η^2=0.643) and the intensity × exercise interaction were all significant ($F_{14,616}$=8.380, p<0.001, partial η^2=0.160) (Figure 4.3A). Post-hoc analysis on the effect of WBV intensity showed that adding the low-intensity or high-intensity WBV induced an overall increase in EMG amplitude when compared with the control condition (p<0.001). There was no significant difference in EMG amplitude between low-intensity and high-intensity WBV conditions, however (p=0.071). Post-hoc analysis on the effect of exercise showed that the EMG amplitude during the deep squat position was significantly higher than other body postures (p<0.001). Deep squat position was also the only exercise in which adding WBV induced no significant increase in non-paretic VL EMG amplitude (p>0.05)(Figure 4.3A).

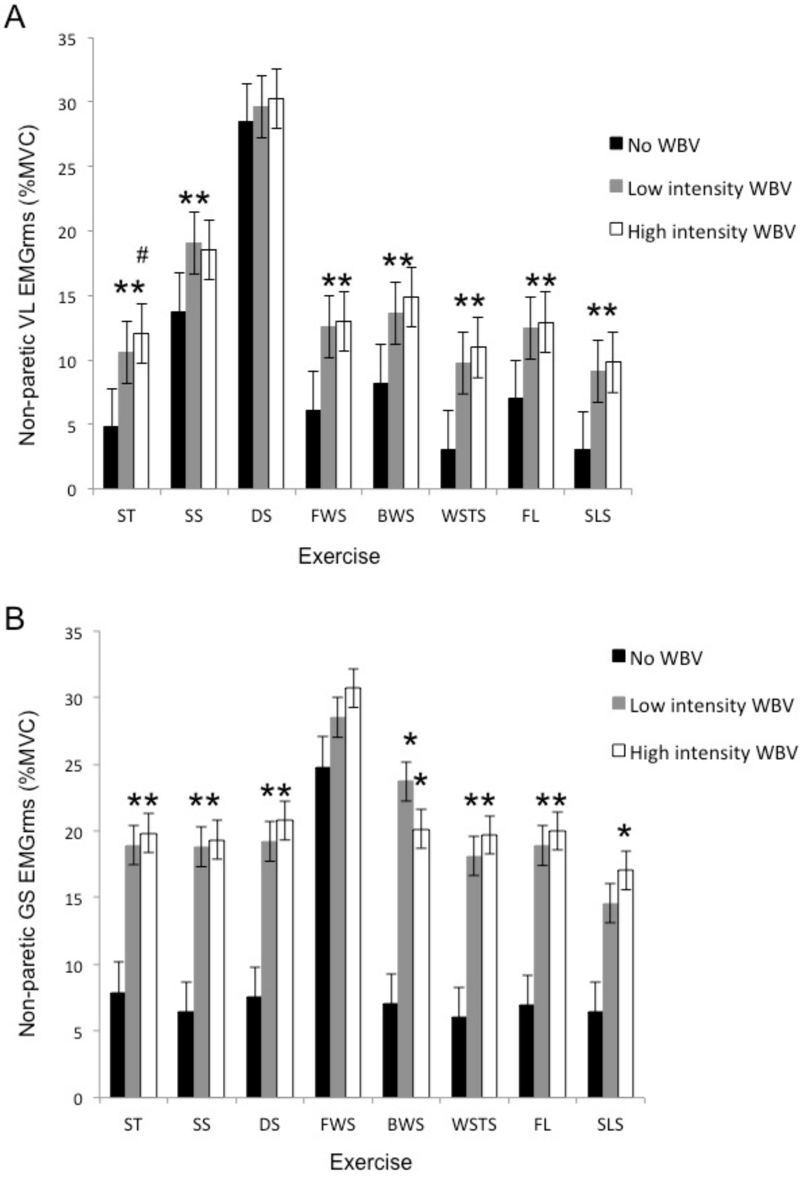

Figure 4.3 Effect of WBV on EMG amplitude in the non-paretic leg. Both high- and low-intensity WBV significantly increased non-paretic leg VL (Figure 4.3A) and GS (Figure 4.3B) muscle activity. # indicates significant difference between the low-intensity and high-intensity WBV conditions.

4.4.5 EMG activity of Non-Paretic leg GS

Significant main effects of intensity ($F_{2,88}$=19.062, $p<0.001$, partial $\eta^2=0.302$) and exercise ($F_{7,308}$=17.080, $p<0.001$, partial $\eta^2=0.280$) were found (Figure 4.3B). The intensity × exercise interaction was also significant ($F_{14,616}$=2.994, $p=0.033$, partial $\eta^2=0.064$). Post-hoc analysis showed that the non-paretic GS EMG amplitude was significantly lower when no WBV was added ($p<0.001$). No significant difference in EMG amplitude was found between low-intensity and high-intensity WBV conditions ($p=0.109$). Contrast analysis of the effect of exercise revealed that weight-shifted-forward position had significantly higher EMG amplitude than other postures ($p<0.01$). It was also the only exercise that did not show a significant increase in EMG when WBV was added ($p>0.05$) (Figure 4.3B).

4.4.6 Paretic to non-paretic EMG amplitude ratio

The EMGrms ratio of paretic to non-paretic side is shown in Figure 4.4. The ratio was greater than 1 in all conditions, denoting that the paretic leg achieved a greater %MVC in these conditions than the non-paretic side. For the VL muscle (Figure 4.4A), the main effect of WBV intensity was not significant ($p=0.34$, partial $\eta^2=0.02$), whereas the main effect of exercise was significant ($p<0.001$, partial $\eta^2=0.37$), with the weight-shifted-to-the-side and single-leg-standing positions yielding significantly higher paretic to non-paretic EMG ratios than other exercises ($p<0.01$). There was an overall significant frequency × exercise interaction effect ($p<0.001$, partial $\eta^2=0.20$), with the weight-shifted-to-the-side and single-leg-standing showing significant reduction in the EMG ratio as high-intensity WBV was added ($p=0.002$). For the GS muscle (Figure 4.4B), there was an overall significant main effect of exercise ($p<0.001$, partial $\eta^2=0.15$), with the weight-shifted-forward exercise showing significantly lower level of EMG than all other exercises ($p<0.05$), except upright standing. The main effect of intensity ($p=0.53$, partial $\eta^2=0.01$) and intensity × exercise interaction effect ($p=0.39$, partial $\eta^2=0.03$) were not significant.

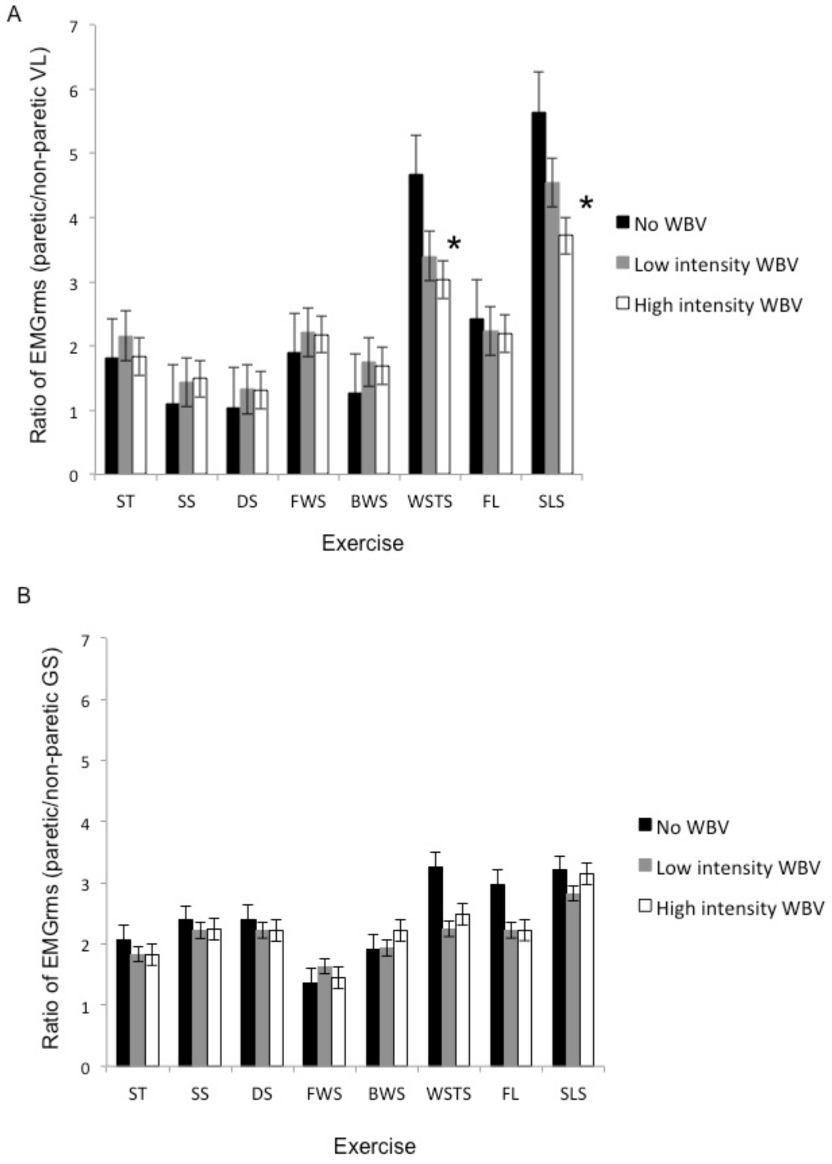

Figure 4.4 Ratio of EMG amplitude of the paretic leg to the non-paretic leg. A ratio greater than 1 is indicative of higher %MVC achieved on the paretic side relative to the non-paretic side for VL (Figure 4.4A) and GS (Figure 4.4B). The WSTS and SLS exercises showed a significant reduction in the VL EMG ratio as WBV intensity was increased (Figure 4.4A).

4.4.7 Relationship between spasticity and EMG data

Generally, no relationship was found between normalized EMGrms and spasticity of the paretic knee and ankle ($p>0.05$). The only exceptions were a negative association of the ankle spasticity score with the standing posture in the low-intensity WBV (rho = -0.356, p = 0.016) and high-intensity WBV (rho = -0.316, p = 0.035) conditions.

4.5 DISCUSSION

This is the first study to investigate the influence of different WBV intensities and exercises and their interactions on leg muscle activity in individuals with chronic stroke. The hypothesis of this study was confirmed because the results showed that adding WBV significantly enhanced muscle activity in VL and GS on both the paretic and non-paretic sides in all eight different exercise conditions. With a few exceptions, the added WBV enhanced EMG activity in the paretic and non-paretic leg muscles to a similar extent in a variety of exercise conditions.

4.5.1 Effect of WBV intensity

The results showed that the EMG amplitude of all leg muscles measured was significantly enhanced by adding either the low-intensity or high-intensity WBV. The increase in EMG amplitude ranged from 26% to 165%, 76% to 243%, 4% to 253%, and 14% to 236% for paretic VL, paretic GS, non-paretic VL, and non-paretic GS, respectively, depending on the exercises performed. Our results are generally in line with those from other studies in healthy adults, which also reported a significant increase in EMG magnitude of different leg muscle groups during WBV exposure (Cardinale & Lim, 2003; Roelants et al., 2006). The magnitude of

WBV-induced increase in EMG activity differed across the various studies probably due to the use of different populations, vibration devices, frequencies, amplitudes, and data processing methods. For example, Pollock et al. (2010) found that adding WBV (5Hz-30Hz, 2.5-5.5mm) increased EMG amplitude of various leg muscles by 5-50% in a sample of 12 healthy adults. Other studies have shown that WBV at 30-45Hz and amplitudes of 2-5mm led to augmentation of leg muscle activity up to 34.5% in young adults (Cardinale & Lim, 2003; Roelants et al., 2006).

It is unlikely that the increase in EMG was due to increased spasticity on the paretic side. First, spasticity should have little influence on our results as severe spasticity in either the knee or ankle in the paretic leg was observed in one subject only. Second, no strong relationship was found between the severity of spasticity and EMG amplitude. Of the two significant correlations identified, the direction of the relationship was negative, indicating that higher EMG amplitude was associated with less severe spasticity. Finally, a previous study reported that ankle spasticity in stroke patients, as indicated by the Modified Ashworth Scale, was significantly reduced in the WBV group, but not in the control group, after a single session of WBV (Chan et al., 2012).

It is interesting that our low- and high-intensity WBV protocols are equally effective in increasing the EMG activity of all measured muscles in subjects with chronic stroke. This is in contrast with previous studies in young adults, which showed that higher WBV frequencies are associated with higher EMG amplitude (Cardinale & Lim, 2003; Hazell et al., 2010; Pollock et al., 2010). The discrepancies in results may be due to several reasons. First, the subject characteristics are different (chronic stroke vs. young healthy adults). The presence of neurological pathology and changes in muscle properties post-stroke may lead to very different response to the same WBV stimuli. Second, the WBV protocols used also differ. The protocols used in this study have enabled us to determine the differential effects of a sub-gravity protocol (0.96G) and a supra-gravity protocol (1.61G). However, the difference in intensity between the two protocols may not be substantial enough to induce different levels of muscle activity. Perhaps the difference in muscle activation would have been significant if a higher WBV intensity had been used. We did not use a higher WBV intensity because higher peak accelerations would potentially lead to more substantial health hazards (Abercromby et al., 2007; Kiiski et al., 2008). This study examined the leg muscle activity during high- and low-intensity WBV only. Whether the two protocols are equally effective in improving muscle function after long-term WBV exercise training awaits further research. To date, only one study has compared the effects of a high-intensity WBV protocol (9.43G, 25Hz, 3.75mm) with a low-intensity one (0.50G, 25Hz, 0.2mm) in stroke patients after 12 sessions of training over a 6-week period (4). A significant improvement in paretic knee extension strength was found only in the low-intensity WBV group, but the magnitude of improvement was within the limits of measurement errors, denoting no real clinical change. Certainly, more study is required in this area.

4.5.2 Interaction between exercise and WBV intensity

A unique aspect of this study is that we examined a number of different exercises during WBV exposure in an effort to identify what combination of exercise and WBV intensity may induce the highest level of muscle activity. The exercises chosen in this study are commonly used in other WBV trials and stroke rehabilitation (Lau et al., 2011; Pang et al., 2005a,b,c&d; Yang et al., 2006). Regular training using functional leg strengthening exercises such as squatting movements and heel raises without WBV (e.g., exercise 2, 3 and 4 in Table 4.1) has been shown to be effective in increasing leg muscle strength in individuals with stroke (Pang et al., 2005a,b,c&d; Yang et al., 2006). Interestingly, this study found that the muscle activation levels during these exercises are not particularly high (Figure 4.2-4.4, black bars). It may indicate that the threshold intensity for inducing a positive strength training effect may be less than the typical training intensity (50-80% maximal effort) used in many previous resistance training trials in stroke (Patten et al., 2004). Nevertheless, this study showed that for all 8 exercises, adding WBV would significantly augment the muscle activation levels. WBV may thus be a viable option for further increasing muscle activity during leg strengthening exercises, thereby leading to better strength gains. Further randomized controlled trials are required to test this hypothesis.

The results also showed that the intensity and exercise interaction effect was significant for all four muscle groups, indicating that the WBV-induced increase in EMG activity achieved differed depending on the exercise. For the VL muscle in both the paretic and non-paretic legs, the increase in muscle activation with the addition of WBV was significantly less in deep squat exercise when compared with other exercises. For GS, the WBV-induced increase in muscle activation in weight-shifted-forward exercise was significantly less when compared with most of the other exercises. Muscle pre-activation could be a potential factor affecting the extent of muscle activation caused by WBV (Issurin & Tenenbaum, 1999). For example, it is noted that the level of activation in VL and GS muscles are already quite high in deep squat exercise and weight-shifted-forward exercise, respectively, even without vibration. The potential for a further increase in muscle activation upon the addition of WBV is thus smaller.

Overall, the deep squat and forward-weight-shift exercises, when combined with WBV, resulted in the highest level of EMG activity in paretic VL and GS, respectively. The results thus suggested that these two exercises may be more effective in WBV training programs for enhancing strength of the respective muscles in subjects with chronic stroke. Mikhael et al. (2010a) studied the effect of standing posture during WBV training on muscle strength outcomes. Interestingly, they found that WBV with flexed knees induced similar gain in leg press strength compared with WBV with locked knees following 29 sessions of training over a 13-week period. However, the sample size is small (19 subjects), thus making it difficult to draw meaningful conclusions.

4.5.3 Analysis of paretic to non-paretic EMG amplitude ratio

The analysis of the paretic EMG to non-paretic EMG ratio provided us with some insight into the activation of the paretic leg relative to the non-paretic leg in different WBV conditions. The ratio was greater than 1.0 in all test conditions, indicating that the muscle activity in the paretic leg achieved a greater %MVC in these conditions relative to the non-paretic side. It was most likely due to the fact that the non-paretic leg was much stronger than the paretic leg, as reflected by the greater EMG amplitude recorded during MVC (Table 4.1). As the EMG amplitude measured in different WBV conditions was normalized according to the EMG data recorded during MVC, it is not surprising that the paretic leg would tend to show a higher normalized EMGrms value compared with the non-paretic leg when performing the same activity, which explained why the ratios were greater than 1.0. The results showed that the choice of exercise did affect the EMG ratio. In general, the weight-shifted-to-the-side and single-leg-standing positions resulted in the highest ratios (Figure 4.4), mostly due to the relative low level of muscle activation in the non-paretic leg when these two postures were assumed (Figure 4.3). In contrast, the semi-squat and deep-squat positions, which involved greater knee and ankle flexion angles, required a higher level of VL muscle activation even on the non-paretic side

(Figure 4.3). This may in turn account for the lower paretic/non-paretic EMG ratio in VL (Figure .44A). Similarly, the weight-shifted-forward posture induced a high level of EMG activity in the non-paretic GS muscle, thereby accounting for the lower EMG amplitude ratios (Figure 4.4B).

There was no main effect of WBV intensity for both VL and GS EMG amplitude ratios, meaning that application of WBV resulted in similar activation of the paretic and the non-paretic leg muscles in general. The only exception was the weight-shifted-to-the-side and single-leg-standing exercises, which demonstrated substantial reduction in the VL EMG ratio as WBV intensity was increased (Figure 4.4A), thereby contributing to the significant exercise × intensity interaction effect. This finding indicated that the increasing WBV intensity induced a greater EMG response in the non-paretic VL than the paretic VL when performing the weight-shifted-to-the-side and single-leg-standing exercises. The differential response to alterations in WBV intensity was more apparent in these two exercises, probably because the body weight was borne primarily by the exercising leg whereas in the other six exercises, the weight bearing was shared by both legs.

4.5.4 Limitations and future research directions

Firstly, since all of our subjects are ambulatory and community-dwelling, the results are only generalizable to a population with similar characteristics. Secondly, we studied the effects of the overall intensity of WBV (indicated by peak acceleration) on leg EMG activity. However, WBV frequency and amplitude could have independent contribution to muscle activation (Patten et al., 2004). Torvinen et al. (2002b) demonstrated that WBV amplitude is positively correlated with muscle performance while others believed that frequency is the most important variable in

WBV. However, the vibration platform used in this study did not allow us to adjust the frequency and amplitude of WBV independently. Hence, the isolated contribution of frequency and amplitude on leg muscle activation requires further study. Thirdly, the EMG amplitude was used as the outcome. Although no muscle torque measurements were done, it is known that EMG amplitude has a strong, positive relationship with muscle force in isometric conditions (Kuriki et al., 2012). It is thus reasonable to assume that the muscle force was increased during WBV exposure among our subjects. Additionally, the VL and GS muscles were measured because of their key roles in gait and other functional tasks (Flansbjer et al., 2006; Kluding & Gajewski, 2009). Among the various knee extensor muscles (e.g., rectus femoris, vastus medialis, etc.), VL was selected because it has been examined in several previous studies, and would facilitate the comparison of results (Cardinale & Lim, 2003; Hazell et al., 2010; Roelants et al., 2006). There is also no consistent evidence proving that the activation of VL relative to other knee extensors is significantly different in various knee extension or squatting exercises in healthy individuals (Earl et al., 2001; Jakobsen et al., 2012). However, it is acknowledged that the flexor muscle groups are also important for daily function. For example, toe drag during the swing phase of walking owing to decreased activation of the ankle dorsiflexors on the paretic side is a common clinical observation in hemiparetic gait (Lin et al., 2006). The response to WBV in the flexor muscle groups after stroke will need further investigations. Finally, while this study showed that WBV could significantly augment leg muscle activity during the performance of various static exercises, whether improvement in muscle strength can be induced by these WBV protocols after a longer intervention period (e.g., 8-10 weeks) is uncertain. A randomized controlled study with measurement of maximum voluntary torque as the outcome will be required to test this hypothesis.

4.5.5 Conclusion

In conclusion, the present study suggested that leg muscle activity on both the paretic and non-paretic sides was increased significantly by adding the low-intensity and high-intensity WBV. The added WBV induced a similar increase in EMG activity in the paretic and non-paretic legs, except in weight-shifted-to-the-side and single-leg-standing exercises, where the non-paretic leg VL was more responsive to the added WBV than the paretic VL muscle. A randomized controlled trial will be required to determine whether these two protocols could induce any gain in muscle strength in stroke patients following long-term WBV exercise training, and whether the high-intensity protocol could lead to better muscle strength than the low-intensity one.

ACKNOWLEDGMENT

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CHAPTER FIVE

Effect of Vibration Intensity, Exercise and Motor Impairment on Leg Muscle Activity Induced by Whole-Body Vibration in People with Stroke

Liao Lin Rong

5.1 ABSTRACT

Background. Whole-body vibration (WBV) has increasingly been used as an adjunct treatment in neurological rehabilitation. However, how muscle activation level changes during exposure to different WBV protocols in individuals after stroke remains understudied.

Objective. To examine the influence of WBV intensity on the magnitude of biceps femoris (BF) and tibialis anterior (TA) muscle activity and its interaction with exercise and severity of motor impairment and spasticity among individuals with chronic stroke.

Methods. Each of the 36 individuals with chronic stroke (mean age±standard deviation=57.3 ±10.7 years) performed eight different static exercises under three WBV conditions: (1) no WBV, (2) low-intensity WBV [20Hz, 0.60mm, peak acceleration: 0.96 units of gravity of Earth (g)], and (3) high-intensity WBV (30Hz, 0.44mm, 1.61g). The levels of bilateral TA and BF muscle activity were recorded using surface electromyography (EMG).

Results. The main effect of intensity was significant. Exposure to the low-intensity and high-intensity protocols led to a significantly greater increase in BF and TA EMG magnitude in both legs compared with no WBV. The intensity × exercise interaction was also significant, suggesting that the WBV-induced increase in EMG activity was exercise-dependent. The EMG responses to WBV were similar between the paretic and non-paretic legs, and were not associated with level of lower extremity motor impairment and spasticity.

Limitations. Leg muscle activity was measured during static exercises only.

Conclusions. Adding WBV during exercise significantly increased EMG activity in TA and BF. The EMG responses to WBV in the paretic and non-paretic legs were similar, and were not related to degree of motor impairment and spasticity. The findings are useful for guiding the design of WBV training protocols for people with stroke.

5.2 INTRODUCTION

Stroke is a major public health issue that poses challenges to healthcare systems worldwide (Lee et al., 2014). Muscle weakness is one of the most common physical post-stroke impairments (Lomaglio et al., 2008), and is related to poor balance, functional limitations, and a lower level of participation in community activities (Bohannon, 2007; Kim & Eng, 2003; Flansbjer et al., 2006). Therefore, researchers have been investigating effective rehabilitation strategies to tackle post-stroke muscle weakness.

Whole-body vibration (WBV) training has attracted much attention in both clinical practice and research recently (Luo et al., 2005; Cochrane, 2011). Recent meta-analyses have revealed that WBV has significant therapeutic effects on balance, muscle strength, and mobility in older adults, although the optimal WBV protocol is unknown (Lam et al., 2012; Lau et al., 2011). There are two major types of WBV, namely synchronous vibrations and side-alternating vibrations (Abercromby et al., 2007). In the former, the vibration platform generates vibrations in a predominantly vertical direction, and so the amplitude of the vibrations received would be largely the same regardless of the position of the feet on the vibration platform (Abercromby et al., 2007). In contrast, in side-alternating vibrations, the platform rotates about an anteroposterior horizontal axis. Therefore, a greater distance from the axis of rotation would result in vibrations of larger amplitude. Side-alternating WBV also differed from synchronous WBV in that the force is applied alternately between the two sides, and that a mediolateral component of the force is also produced (Abercromby et al., 2007). The use of synchronous (Cardinale & Lim, 2003; Ritzmann et al., 2013; Hazell et al., 2007, 2010; Krol et al., 2011; Lienhard et al., 2014; Marín et al., 2009; Roelants et al., 2006) or side-alternating (Ritzmann et al., 2013; Pollock et al., 2010; Abercromby et al., 2007) WBV during exercise has also been shown to increase the level of muscle activation in young adults, as measured by surface electromyography (EMG).

More recently, research has focused on the effects of WBV in people with neurological disorders (Tihanyi et al., 2007; Van Nes et al., 2006; Pang et al., 2013b; Lau et al., 2012; Marín et al., 2013). A recent systematic review of RCTs found insufficient evidence to refute or support the use of WBV in individuals with stroke to improve neuromuscular function, mainly due to the limited number of studies and methodological weaknesses of the studies reviewed (Liao et al., 2014b). The systematic review also emphasized that more fundamental research questions need to be addressed before a large-scale RCT is conducted (Liao et al., 2014b). One of the important questions pertains to the relationship between WBV intensity and the activation levels of different muscle groups, and how these factors interact with the different exercises performed and the severity of stroke.

Only one study has examined leg muscle activity during WBV in people after stroke (Liao et al., 2014a). Their results showed that leg muscle activity in both the vastus lateralis (VL) and gastrocnemius (GS) muscles could be significantly increased by 10%-20% [expressed as a percentage of maximal voluntary contraction (MVC)] during WBV exposure in people with chronic stroke, depending on the exercise performed (Liao et al., 2014a). In addition, the EMG responses in the VL and GS muscles on the paretic and non-paretic sides during WBV were similar, and were not associated with spasticity (Liao et al., 2014a). However, the EMG responses of the knee flexors and ankle dorsiflexors were not investigated, even though these muscles are equally, if not more highly, affected by stroke (Kim & Eng, 2003). The weakness in these muscles contributes to abnormal gait patterns, including the failure to attain a heel strike at initial contact, and ineffective ankle dorsiflexion during the swing phase, causing the ‘drop foot’ phenomenon (Stein et al., 2006). Other studies also found that knee flexor and ankle dorsiflexor strength was strongly related to walking speed, endurance and balance in people with stroke (Horstman et al., 2008; Ng et al., 2012). However, the way in which the EMG activity of the biceps femoris (BF) and tibialis anterior (TA) muscles changes during exposure to different WBV exercise protocols in individuals after a stroke remains unclear. Whether the EMG responses are related to severity of motor impairment has also never been investigated.

The objectives of this study were to examine the influence of WBV intensity on the muscle activity of the bilateral BF and TA and its interaction with exercise and the severity of leg motor impairment and spasticity among people with chronic stroke. It was hypothesized that: 1) the magnitude of the EMG activity of the bilateral BF and TA muscles would increase significantly with increasing WBV intensity; 2) the magnitude of the WBV-induced increase in leg muscle EMG activity would be exercise-dependent (i.e., WBV intensity × exercise interaction effect); 3) the WBV would exert similar effects on the EMG magnitude on the paretic side than on the non-paretic side (i.e., no WBV intensity × side interaction effect); and 4) the WBV-induced EMG activity in the BF and TA muscles on the paretic side would not be significantly associated with severity of leg motor impairment and spasticity. The findings would be crucial for guiding the design of WBV training protocols for people with stroke.

5.3 METHODS

5.3.1 Study Design

A two-way repeated measures design was adopted to investigate the bilateral TA and BF muscle activity during exposure to three different WBV protocols and eight exercise conditions.

5.3.2 Participants

Participants were recruited from local stroke self-help groups during the period between September 2012 and May 2013. The inclusion criteria were: the diagnosis of a hemispheric stroke ≥6 months, being a community dweller, the ability to perform the experimental exercises in the present study, and having some degree of paresis in the affected leg (Chedoke-McMaster Stroke Assessment (CMSA) lower limb motor score of ≤13) (Gowland et al., 1993). The exclusion criteria were: severe cardiovascular conditions (e.g., cardiac pacemaker), neoplasms, other neurologic disorders, cerebellar stroke or brainstem stroke, significant musculoskeletal conditions (e.g., amputations), or vestibular disorders.

5.3.3 Ethics Statement

All individuals gave written informed consent before enrollment. The study was approved by the Human Subjects Ethics Subcommittee of the Hong Kong Polytechnic University (approval number: HSEARS20130209001-01), and all experiments were conducted in accordance with the Declaration of Helsinki.

5.3.4 WBV Protocols

All experimental procedures were conducted in a laboratory located in the Hong Kong Polytechnic University, Hong Kong. A vibration platform that delivered synchronous vibrations (Jet-Vibe System, Danil SMC Co. Ltd., Seoul, Korea) with a frequency range of 20-55 Hz and corresponding preset amplitudes was used. The peak acceleration (a_{peak}) was calculated by the formula: $a_{peak}=(2\pi f)^2 A$, where A and f represented the amplitude and frequency of vibrations, respectively (Kiiski et al., 2008). The a_{peak} was usually represented in terms of gravity of Earth ($1g=9.81 m/s^2$) to facilitate comparisons across studies. We used synchronous WBV, as there is some evidence that it induced higher level of muscle activity than side-alternating WBV (Ritzmann et al., 2013). The Jet-Vibe vibration parameters were verified by a tri-axial accelerometer (Model 7523A5; Dytran Instruments Inc., Chatsworth, CA).

Each participant underwent three different WBV conditions in a single experimental session: (1) no WBV, (2) low-intensity WBV [frequency: 20Hz, amplitude: 0.60mm, peak acceleration: 0.96 units of gravitational constant (g), i.e. subgravity], and (3) high-intensity WBV [30Hz, 0.44mm, 1.61 g, i.e. supragravity]. The sequence of WBV protocols used was decided randomly by drawing lots. A frequency higher than 30Hz was not used, because it was shown in our pilot work to be associated with increased discomfort in this population. Frequencies lower than 20 Hz were not used due to potential resonance effects (Kiiski et al., 2008).

5.3.5 Exercise Protocols

The complete set of eight static exercises (Figure 5.1) was repeated three times. The order of the exercises performed for each WBV condition was randomized. Practice trials were given to familiarize the participants with the exercises before the collection of actual EMG data. During each WBV condition, we used a goniometer (Baseline® HiRes^{TM} plastic 360° ISOM Goniometer, Fabrication Enterprises, White Plains, NY, USA) to check that the desired knee angle was achieved for a specific exercise. The duration of the rest period between the different exercises was set at 1-min. For standardization, all participants held gently onto the handrail of the WBV device for maintaining body balance only.

A


[redacted]

B


[redacted]

C


[redacted]

D


[redacted]

E


[redacted]

F

G


[redacted]

H


[redacted]

Figure. 5.1 Exercise Protocol

A. Upright standing position (ST): Standing with their feet placed apart at shoulder width and knees slightly flexed at about 10° and holding for 10 seconds.

B. Semi-squat position (SSq): Standing with feet placed apart at shoulder width and knee flexed at30° and holding for 10 seconds.

C. Deep squat position (DSq): Standing with feet placed apart at shoulder width and knees flexed to 90° and holding for 10 seconds.

D. Weight-shifted-forward position (FWS): Starting position same as in upright standing exercise (A), then leaning body weight forward (right) as much as possible and raising heels up and holding for 10 seconds.

E. Weight-shifted-backward position (BWS): Starting position same as in upright standing exercise (A), then leaning body weight backward as much as possible and raising forefoot and holding for 10 seconds.

F. Weight-shifted-to-the-side position (WSTS): Starting position same as in upright standing exercise (A), then shifting body weight onto one leg as far as possible and holding for 10s. Repeating on the other side.

G. Forward lunge position (FL): Standing in a forward lunge position with the paretic leg placed in front of the non-paretic leg with paretic knee flexed at 10°, then leaning forward and shifting body weight onto the paretic leg as much as possible with knee flexed at 30 °, and holding for 10 seconds. Switching the positions of the two legs, with the non-paretic leg placed in front of the paretic leg.

H. Single-leg-standing position (SLS): Standing on the paretic leg with knee flexed at 10°, and holding for 10 seconds. Repeating on the non-paretic side.

5.3.6 Measurements

At the beginning of the first session, the demographic information and clinical history of all participants was obtained through interviews. Motor impairment level of the leg and foot was evaluated using the CMSA (Gowland et al., 1993). The rating for each body part (i.e. the leg and foot) was based on a 7-point ordinal scale (i.e., 1=flaccidity, 3=obligatory synergistic movements, 7=normal movement patterns). The CMSA lower extremity total score was computed by summing the leg and foot scores (minimum score: 2; maximum score: 14), with a higher score denoting less severe motor impairment. The spasticity of the paretic knee and ankle joints was examined using the Modified Ashworth Scale (MAS), which is a six-point ordinal scale (i.e., 0=no spasticity, 4=affected part rigid) (Li et al., 2014).

The activity of the bilateral BF and TA muscles was measured using surface EMG. After palpation of the muscle belly and appropriate skin preparation, the bipolar bar electrodes (Bagnoli EMG system, Delsys, Inc., Boston, MA, USA) were attached longitudinally over the middle of the belly of the bilateral BF and TA muscles (Hermens et al., 2000). In addition, the ground electrode was attached at the fibula head on the paretic side. The insulated EMG cables were secured to prevent their excessive motion.

Before measuring the EMG response during WBV exercise, participants were asked to undergo a test for maximal voluntary contraction (MVC). The participants were seated on a chair with backrest placed against a wall, with the hip and knee joint placed at 90 degrees of flexion. The participants were asked to grasp the edge of the chair on each side for further stabilization. To measure the MVC of knee flexion (i.e., BF), the tested lower leg was strapped using a non-elastic belt that was attached to a fixed structure. The tested thigh was stabilized by the researcher’s hand, and the participants were instructed to perform a maximal isometric knee flexion by pulling against the belt and sustain it for 10 seconds. To test the MVC of ankle dorsiflexion (i.e., TA), the foot was placed in a neutral dorsiflexion/plantarflexion position. One hand of the researcher stabilized the tested lower leg. The other hand was placed on the dorsal aspect of the tested foot to provide resistance, as the participants were asked to perform a maximal isometric ankle dorsiflexion by pushing against the researcher's hand, and maintain for 10 seconds. Three trials were performed for each muscle group, with a 1-minute rest interval between trials. Verbal encouragement was given by the researcher during the contractions to elicit maximal effort from the participants.

The EMG root mean square (EMG_{rms}) value was calculated at intervals of 500ms (Eckhardt et al., 2011). For each participant, the average of the peak EMG_{rms} values obtained in the three MVC trials was used to normalize the EMG_{rms} obtained during the WBV exercise trials. Therefore, the EMG magnitude measured in the three WBV conditions was expressed as a percentage of the peak EMG magnitude in the MVC trials (%MVC). We used the average of the 3 MVC trials, rather than the highest value achieved out of the 3 trials, to normalize the EMG data because the former may better reflect the typical performance of the participants. In addition, the reliability of the EMG measurements was excellent, based on the data from our three MVC trials ($ICC_{2,1}$=0.96-1.00). Therefore, using the average or the highest MVC values for normalizing the data should not create a substantial difference in the results.

The participants were required to maintain each of the eight exercises (i.e., static exercises) (Figure 5.1) for 10 seconds and repeat them three times, with a 5-second pause between each trial. During that period, the bilateral TA and BF EMG activity was recorded. A 5-minute rest period was allowed after the completion of all eight static exercises for a given WBV condition.

The EMG signals were pre-amplified (×1000) and sampled at 1.0kHz (Bagnoli-8, DelSys, Inc., Boston, MA, USA) using LabView version 7.0 (National Instruments Corp., Austin, TX, USA) and saved directly onto a hard disk for offline analysis. The EMG data were further processed using a 20-500-Hz band-pass Butterworth filter. Using the Infinite Impulse Response rejector (MyoResearch XP, Master Package version 1.06, Noraxon USA, Inc., Scottsdale, AZ, USA), the associated harmonics (20Hz, 30Hz, and 60Hz) were removed from the EMG signals (Liao et al., 2014a). Bias was calculated and eliminated from the signals, followed by full-wave rectification of the data. The EMG_{rms} was then calculated in 100-ms windows around every data point (Abercromby et al., 2007). The middle 6 seconds of each trial were selected to calculate the EMGrms (Liao et al., 2014a). For each specific WBV and exercise combination, the average of the normalized EMG_{rms} values obtained in the three trials (expressed as %MVC) was used for analysis.

5.3.7 Statistical analysis

Statistical analysis was conducted using the IBM SPSS software (version 20.0, IBM, Armonk, NY, USA) to test the four research hypotheses, using a desired power level of 0.9. The sample size estimation was based on a previous study that examined leg extensor EMG magnitude during WBV in people after stroke (Liao et al., 2014a), using the G*Power 3.1 software (Universitat Dusseldorf, Germany). It was found that WBV significantly increased EMGrms in VL and GS, yielding large effect sizes for the main effect of intensity (f=0.66-0.93) and moderate to large intensity × exercise interaction effect (f=0.23-0.44) (Liao et al., 2014a). Therefore, for addressing the main effect of WBV intensity (hypothesis 1), intensity × exercise interaction effect (hypothesis 2), and side × intensity interaction effect (hypothesis 3), a large effect size (f=0.4) was assumed. For hypothesis 1, based on ANOVA analysis (WBV intensity at 3-levels;

exercise at 8-levels), and an alpha level of 0.017 (adjusted for comparisons of 3 WBV intensities), 24 participants would be required to detect a significant difference in normalized EMG response (%MVC) between the different WBV intensities. For hypothesis 2, based on the ANOVA analysis (WBV intensity at 3-levels; exercise at 8-levels) and alpha level of 0.05, a minimum of 32 participants would be required to detect a significant intensity × exercise interaction effect. For hypothesis 3, a minimum of 16 participants would be required to detect a significant intensity × side interaction effect (WBV intensity at 3-levels; limb involvement at 2-levels) at an alpha level of 0.05. For the correlation analysis between normalized EMG responses and CMSA and MAS scores (hypothesis 4), we assumed a moderate correlation (r=0.5). A total of 34 participants would be required for this analysis.

First, two separate 3-way ANOVA with repeated measures (limb involvement at 2-levels; WBV intensity at 3-levels; exercise at 8-levels) was used to analyze the normalized EMGrms values for the TA and BF muscles respectively. The 3-way ANOVA would simultaneously yield the results regarding the main effect of WBV intensity (hypothesis 1), intensity × exercise interaction (hypothesis 2), and intensity × side interaction (hypothesis 3). If a significant intensity × exercise × side interaction was found in the 3-way ANOVA model, separate 2-way ANOVA analyses would be done for the TA and BF muscles of the paretic and non-paretic sides. The Greenhouse-Geisser epsilon adjustment was applied when the sphericity assumption was not fulfilled. When significant results were obtained, contrast analysis using the Bonferroni adjustment was performed.

To further address how the increase in WBV intensity affected the normalized EMG responses (hypothesis 1), a trend analysis was performed. For each individual exercise, the mean normalized EMGrms values for the three WBV intensities were used for trend analysis using the Microsoft Excel software (version 2007, Microsoft Corp., Redmond, WA, USA).

Next, to address hypothesis 4, the degree of association of the difference in normalized EMGrms (i.e., normalized EMGrms during WBV minus normalized EMGrms without WBV) in the paretic TA with CMSA foot motor score and ankle MAS score was assessed by Spearman's correlation coefficients. A similar correlational analysis was carried out for the paretic BF muscle, using the CMSA leg motor score and knee MAS score.

We did not formally test for order effects related either to exercise or to WBV protocol, but relied on randomization to minimize order effects.

5.4 RESULTS

5.4.1 Characteristics of the Participants

The study flow chart is shown in Figure 5.2. Thirty-six individuals (26 men, 10 women) with chronic stroke completed all the measurements (Table 5.1). Overall, the impairment level of the affected lower limb was moderate, as revealed by the CMSA lower extremity composite motor score (median: 7; first quartile: 4; third quartile: 12) All were ambulatory and 24 of them (67%) required walking aid for outdoor mobility.

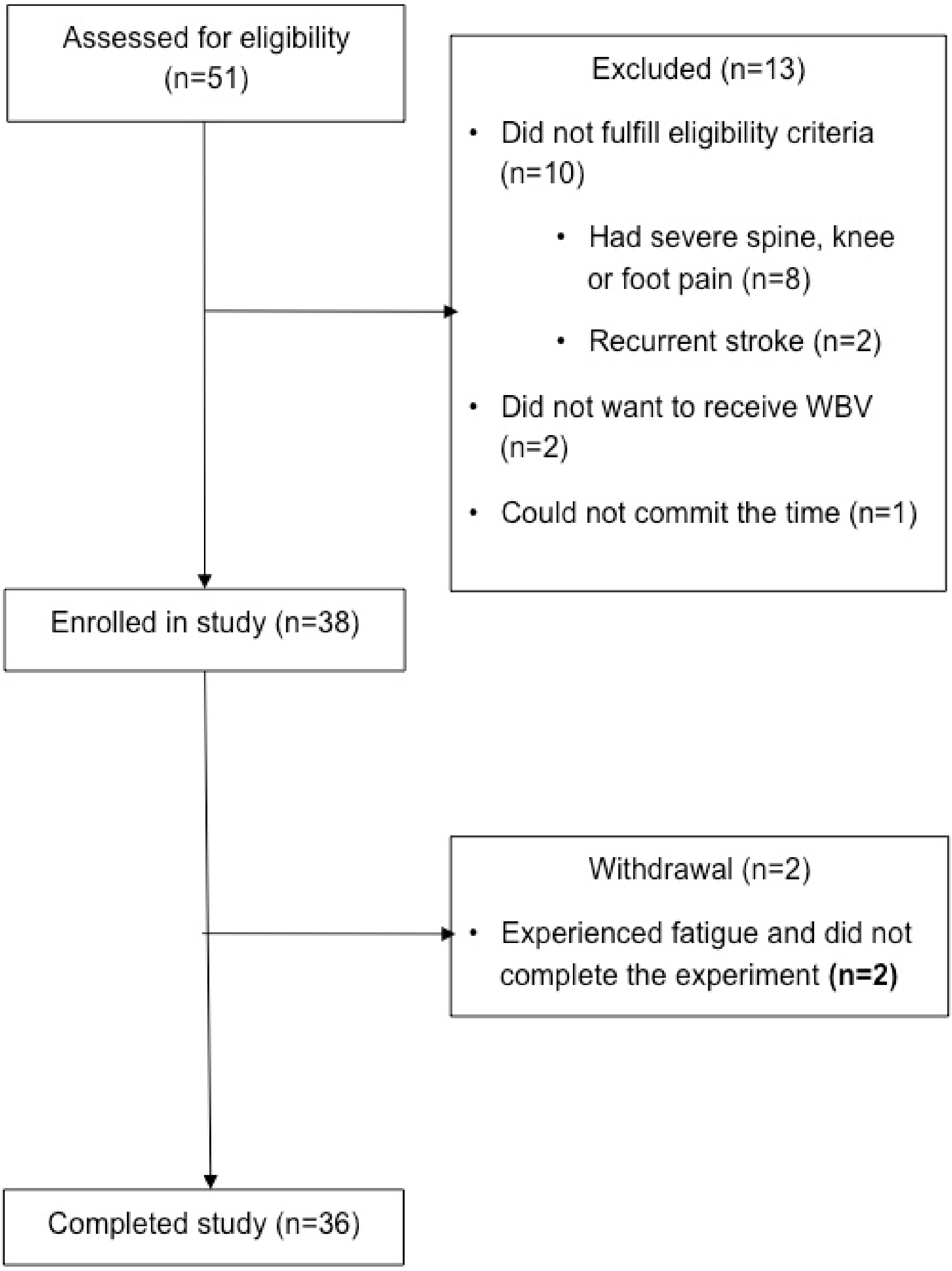

Figure 5.2 Study flow chart. A total of 36 people with stroke completed all measurements.

Table 5.1 Characteristics of the Participants (n=36)

Variable	Value[a]
Basic demographics	
Age, year	57.6 ±10.2
Gender, male/female, (n)	26/10
Body Mass Index, (kg/m^2)	24.9±2.8
Required walking aid for outdoor mobility, none/cane/quadrapod, n	12/20/4
Stroke characteristics	
Time since stroke onset, (year)	5.0±3.2
Type of stroke, ischemic/hemorrhagic/unknown, (n)	22/12/2
Side of hemiparesis, left/right, (n)	16/20
CMSA Lower Extremity Composite Score (out of 14), median (IQR)	7(8)
CMSA leg score (out of 7), median (IQR)	4(3)
CMSA foot score (out of 7), median (IQR)	3(5)
Paretic knee MAS score (0–4)[b], median (IQR)	0 (1)
Paretic ankle MAS score (0–4), median (IQR)	1.5 (1)
Co-morbid conditions	
Hypertension, (n)	23
High cholesterol, (n)	19
Diabetes mellitus, (n)	6
Knee osteoarthritis, (n)	1
Medications	
Antihypertensive agents	21
Hypolipidemic agents, (n)	19
Antidiabetic agents, (n)	6
MVC EMGrms (μV)	
Paretic leg TA	479.3±222.8
Non-paretic leg TA	700.5±302.5
Paretic leg BF	251.2±102.9
Non-paretic leg BF	377.4±183.8

[a] Mean±SD presented for continuous variables.

[b] Modified Ashworth Scale is a 6-point ordinal scale. The category 1+ was converted to 1.5 for statistical analysis.

BF=biceps femoris, CMSA = Chedoke–McMaster Stroke Assessment, EMG=electromyography, IQR= interquartile range, MAS = Modified Ashworth Scale, MVC= maximum voluntary contraction, n=number count, rms=root mean square, TA=tibialis anterior.

5.4.2 Three-way ANOVA

Our 3-way ANOVA analyses revealed a significant intensity × exercise × side interaction effect for the TA ($F_{6.42, 224.75}$=2.82, P=0.01) and BF ($F_{7.87, 275.33}$=2.34, P=0.019) muscles, indicating that the EMG responses to WBV was influenced by the interaction of all three factors. The subsequent paragraphs would address the main effect of intensity (hypothesis 1), intensity × exercise interaction (hypothesis 2), intensity × side interaction (hypothesis 3), and the associations of EMG responses with motor impairment and spasticity (hypothesis 4).

5.4.3 Main effect of intensity

Our 3-way ANOVA models revealed a significant main effect of intensity on normalized EMG responses in the TA ($F_{1.11, 38.82}$=80.58, P<0.001) and BF ($F_{1.06, 37.23}$=140.08, P<0.001), indicating that increasing WBV intensity resulted in an overall increase in EMG magnitude in these muscles tested. Further analyses using two-way ANOVA showed that the main effect of intensity remained significant if the TA and BF muscles for in the paretic and non-paretic leg were analyzed separately (Table 5.2). Post-hoc contrast analysis with Bonferroni adjustment revealed that the normalized EMG_{rms} values for the three WBV conditions all differed significantly from each other in BF muscles on both the paretic and non-paretic sides (P<0.05). In the paretic and non-paretic TA muscles, addition of low-intensity and high-intensity WBV during exercise led to significantly higher normalized EMGrms compared with the same exercises without WBV (P<0.05), but the difference between the low-intensity and high-intensity protocols did not quite reach statistical significance (P=0.06). The average increase in EMG activity was 10.8-12.1%, 19.9%-22.7%, 10.0-10.7%, and 20.6-23.1% in the paretic TA, paretic BF, non-paretic TA, and non-paretic BF, respectively, depending on the WBV intensity.

Based on the trend analysis (Figure 5.3), it is clear that adding WBV to exercise considerably increased the EMG activity in the 4 muscle groups tested, but the relationship between WBV intensity and normalized EMG response was not a linear one. The data for each muscle group were fitted with a logarithmic curve.

Table 5.2 The effect of whole-body vibration (WBV) intensity on normalized EMGrms values

	WBV Intensity × exercise interaction effect		**Main Effect of WBV intensity**		**Post-hoc contrast analysis**					
					No WBV Vs Low-intensity WBV		**No WBV Vs High-intensity WBV**		**Low-intensity WBV Vs High-intensity WBV**	
Muscle	**F_{df}**[c]	***P*-value**	**F_{df}**[c]	***P*-value**	**Mean difference**[a] **(95% CI)**	***P*-value**[b]	**Mean difference (95% CI)**	***P*-value**[b]	**Mean difference (95% CI)**	***P*-value**[b]
Paretic TA	$6.13_{6.36,222.75}$	<0.001*	$55.13_{1.20,42.03}$	<0.001*	10.8 (7.0, 14.6)	<0.001*	12.1 (8.3, 15.9)	<0.001*	1.3 (-0.1, 2.7)	0.06
Non-paretic TA	$15.64_{6.08,212.87}$	<0.001*	$63.34_{1.07,37.45}$	<0.001*	10.0 (6.9, 13.1)	<0.001*	10.7 (7.4, 14.1)	<0.001*	0.8 (0.0, 1.5)	0.06
Paretic BF	$3.00_{5.63,196.89}$	0.01*	$119.88_{1.08,37.85}$	<0.001*	19.9 (15.5, 24.3)	<0.001*	22.7 (17.5, 27.9)	<0.001*	2.8 (1.4, 4.2)	<0.001*
Non-paretic BF	$2.20_{6.56,229.47}$	0.04*	$96.84_{1.05,36.89}$	<0.001*	20.6 (15.4, 25.9)	<0.001*	23.1 (17.2, 28.9)	<0.001*	2.4 (1.2, 3.6)	<0.001*

[a] EMG magnitude expressed as percent maximal voluntary contraction (%MVC)

[b] The p-values for the contrast analysis are Bonferroni corrected values.

[c] Greenhouse-Geisser epsilon adjustment was used to generate the F-score, degrees of freedom and P-values are Greenhouse-Geisser epsilon adjustment due to violation of the sphericity assumption.

*Statistically significant (*P*<0.05)

BF=biceps femoris, df=degrees of freedom, TA=tibialis anterior, WBV=whole-body vibration

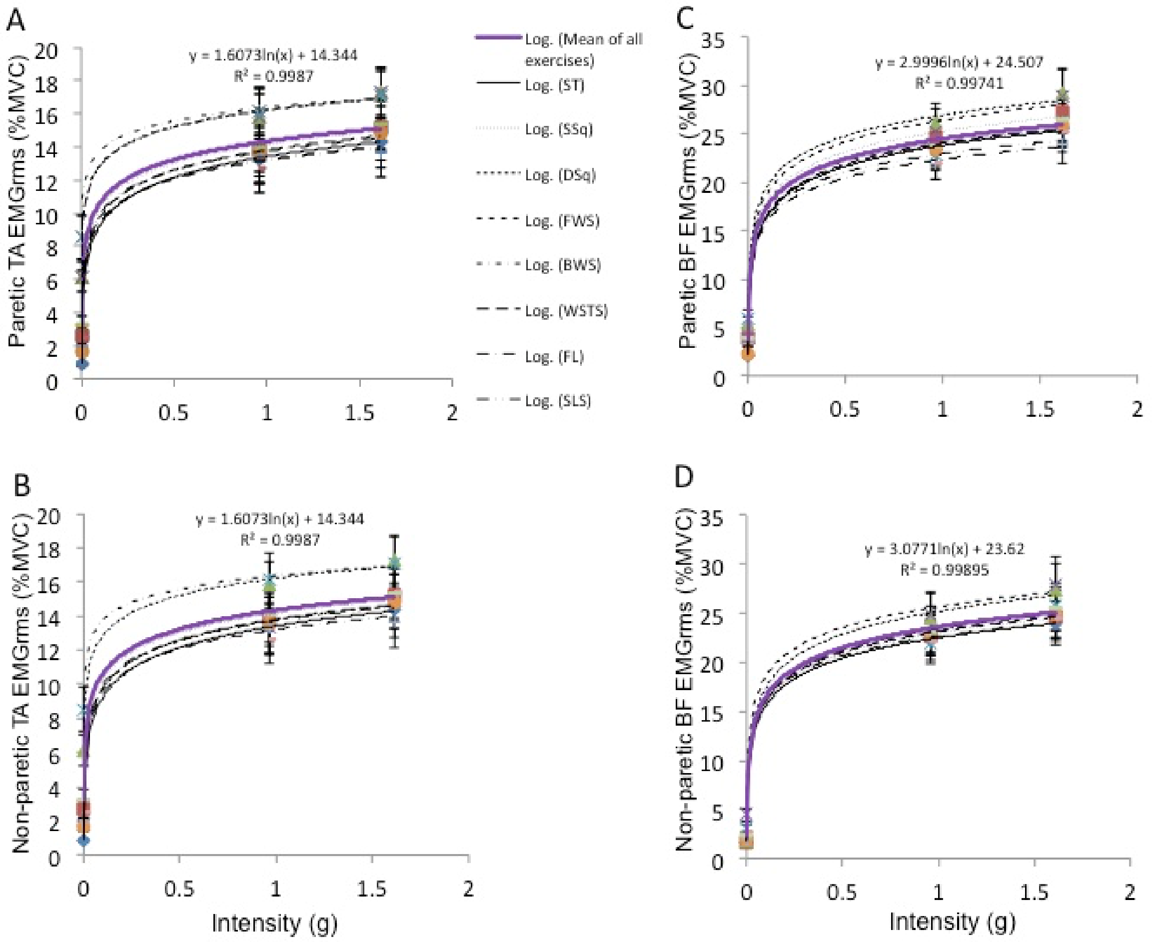

Figure 5.3 Trend analysis: illustration of the effect of WBV intensity

The relationship between normalized EMGrms and WBV intensity is shown for (A) paretic TA, (B) non-paretic TA, (C) paretic BF and non-paretic BF muscles. Each data point represents the mean value of the normalized EMGrms for a given exercise at a particular WBV intensity. The error bar represents 1 standard error of the mean. For each exercise, the 3 data points were best fitted with a logarithmic curve. The thick purple line represents the trend after pooling the data of all 8 exercises. As it is impossible to fit the data with a logarithmic curve if one of the WBV intensities is 0g, therefore, a factor of 0.001g was added to yield WBV intensities of 0.001g, 0.961g and 1.611g respectively.

5.4.4 Intensity by exercise interaction

The normalized EMG responses in the paretic and non-paretic leg during the WBV trials are displayed in Figure 5.4. The 3-way ANOVA model revealed a significant WBV intensity × exercise interaction effect in TA ($F_{6.72, 235.30}$=15.49, P<0.001) and BF muscles ($F_{5.41, 189.53}$=2.78, P=0.02), indicating that the differences in normalized EMGrms among the different WBV conditions were exercise-dependent. Further analyses using two way ANOVA showed that the WBV intensity × exercise interaction effect remained significant if the TA and BF muscles in the paretic and non-paretic legs were analyzed separately (Table 5.2).

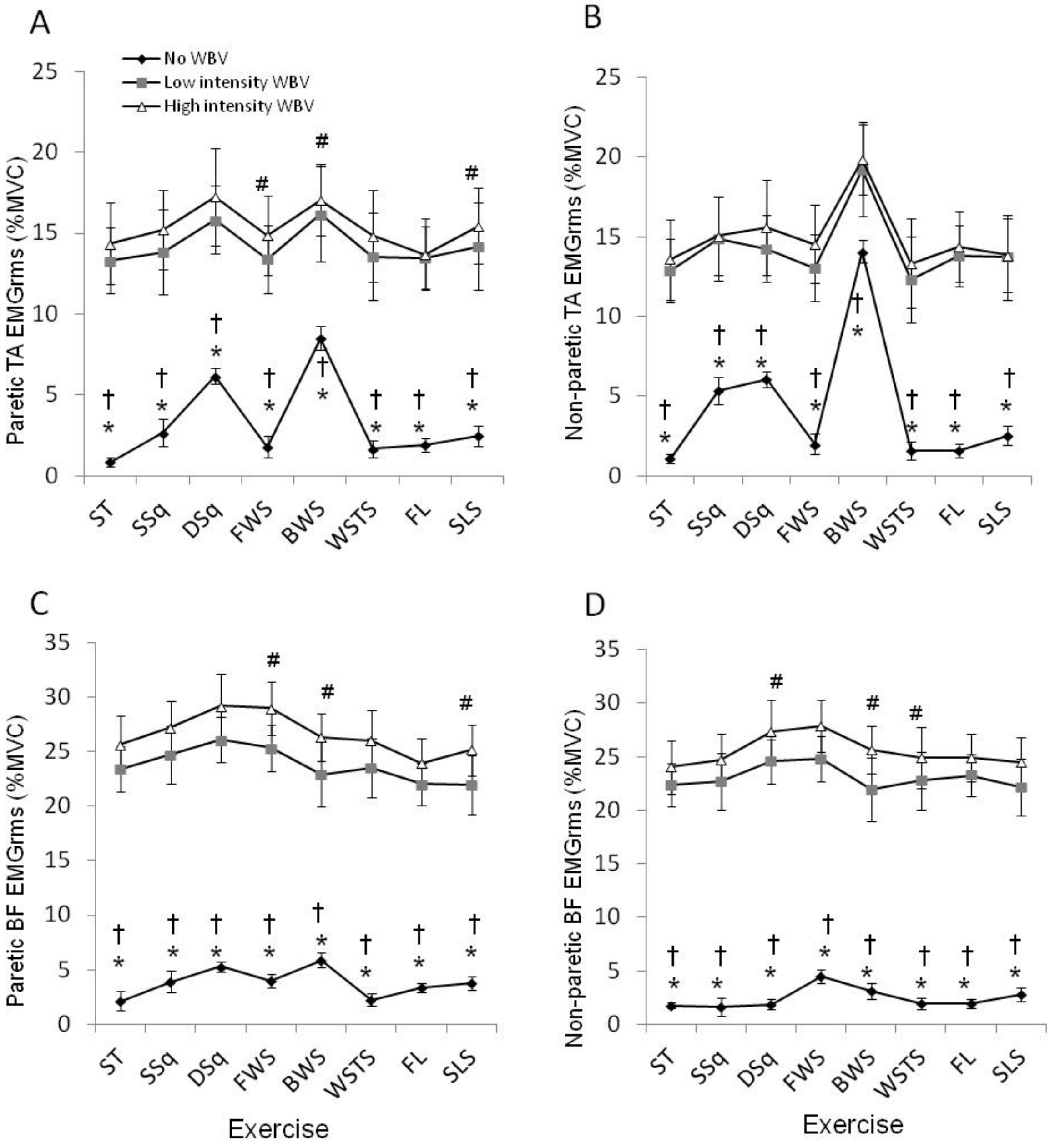

Figure 5.4 Normalized EMG magnitude under different WBV exercise conditions

The normalized EMGrms of the paretic TA (Figure 5.4A), non-paretic TA (Figure 5.4B), paretic BF (Figure 5.4C) and non-paretic BF (Figure 5.4D) in each test condition is expressed as %MVC. The white triangle (Δ), gray square (■), and black diamonds (♦) represent the mean normalized

EMGrms values recorded in the high-intensity WBV, low-intensity WBV and no-WBV conditions respectively. The error bars represent 1 standard error of the mean. Eight different static exercises were examined in each WBV condition: upright standing (ST), semi squat (SSq), deep squat (DSq), weight-shifted-forward (FWS), weight-shifted-backward (BWS), weight-shifted-to-the-side (WSTS), forward lunge (FL), and single-leg-standing (SLS). * denotes significant difference between the control condition (no WBV) and low-intensity WBV condition (P<0.002). † indicates significant difference between the control condition and high – intensity WBV protocol. # denotes significant difference between the low-intensity WBV and high-intensity protocols. Application of WBV resulted in an overall significant increase in normalized EMG magnitude of the TA and BF on both sides.

5.4.5 Intensity by side interaction

The 3-way ANOVA model revealed no significant intensity × side interaction effect for the TA ($F_{1.26, 43.93}$=0.61, P=0.48) and BF muscles ($F_{1.08, 37.71}$=0.10, P=0.91), suggesting that the normalized EMG responses to WBV did not significantly differ between the two sides.

5.4.6 Association with leg motor impairment and spasticity

Of the 24 WBV exercise conditions for the four muscles tested, no relationship was found between WBV-induced changes in EMG activity in the paretic TA and BF muscles and the CMSA motor score or MAS score (P>0.05).

5.5 DISCUSSION

Our results showed that paretic and non-paretic TA and BF muscle activity was increased significantly by adding WBV during exercise, and that the high-intensity WBV protocol (supragravity, 1.61 g) resulted in significantly higher EMG response than the lower-intensity WBV protocol (subgravity, 0.96 g) in the BF muscles among individuals with chronic stroke. The degree of WBV-induced increase in muscle activity was consistent, regardless of the severity of motor impairment and spasticity.

5.5.1 Influence of WBV intensity

The first hypothesis was supported because the results revealed that the higher WBV intensity led to a significantly greater increase of muscle activity in TA and BF in both legs. Our results generally concur with previous WBV research in healthy adults. Typically, a higher WBV intensity is associated with greater EMG responses (Cardinale & Lim, 2003; Ritzmann et al., 2013; Hazell et al., 2007, 2010; Krol et al., 2011; Lienhard et al., 2014; Marín et al., 2009; Roelants et al., 2006; Pollock et al., 2010; Abercromby et al., 2007). The increase in muscle activity with WBV varied across the various studies, and could be due to difference in characteristics of the participants (e.g., people with disability Vs people without disability), types of vibration, frequency, amplitudes, additional load, data processing methods, and exercise performed.

Liao et al. (2014a) examined the activity in the VL and GS muscles during WBV in people with stroke. Using the same WBV intensities, the EMG activity of both the paretic VL and GS muscles was significantly increased by the application of WBV, by an average of 10.0%-10.1% and 14.9-17.5% respectively, depending on the WBV intensity used (Liao et al., 2014a). However, they did not identify any significant difference in VL and GS EMG activity level induced by the low-intensity and high-intensity WBV protocols. In contrast, the effect of WBV intensity was more apparent in the TA and to a greater extent, the BF muscles as shown in this study. First, the high-intensity protocol induced significantly higher EMG magnitude than the low-intensity protocol in the paretic BF muscle during weight-shifted-forward, weight-shifted-backward, and single-standing exercises; and in the non-paretic BF muscle during deep-squat, weight-shifted-backward, and single-standing exercises. Second, the increase in BF activity reported here was somewhat greater than that in leg extensors (Table 5.2). The larger percentage increase in EMG magnitude reported in this study was partially attributable to the very low EMG activity in the BF muscle without WBV (<5%MVC for most exercises) (Figure 5.4), whereas the EMG activity was higher in the VL and GS under control conditions (>10%MVC for the majority of exercises) (Liao et al., 2014a).

The effects of WBV on muscle activation may not be entirely restricted to the peripheral mechanisms (e.g., reflex activation of muscles) (Eklund & Kramer, 1966; Ritzmann et al., 2010), but may also involve corticospinal and intracortical processes (Kipp et al., 2011; Mileva et al., 2009). Using transcranial magnetic stimulation, Mileva et al. (2009) showed that, in a sample of healthy men, the application of WBV (30Hz, 1.5mm) during static squat exercises increased the motor-evoked potential of the TA muscle, indicating an increase in excitability of the corticospinal pathway. There was also evidence of a WBV-induced alteration of the intracortical processes (increased short-interval intracortical inhibition and decreased facilitation) (Mileva et al., 2009).

5.5.2 Interaction effect between WBV intensity and exercise

The second hypothesis was also confirmed because a significant overall intensity × exercise interaction effect was found in all four muscles tested, indicating that the degree of WBV-induced increase in EMG magnitude was exercise-dependent (Figure 5.4).

Some other studies investigated intensity × exercise interaction effects (Roelants et al., 2006; Di Giminiani et al., 2013), but the results were conflicting. For example, Di Giminiani et al. (2013) showed that the EMG response recorded during different positions was not affected by different vibration frequencies. In contrast, Roelants et al. (2006) found a significantly greater increase in VL EMG activity in the one-leg-squat position (i.e., weight bearing on one leg) than in the high-squat and low-squat positions (i.e., weight bearing on both legs) when WBV was applied. In the present study, as shown in Figure 5.4, the intensity by exercise interaction effect was more apparent in the TA muscles. The WBV-induced TA EMG activity was less during weight-shifted-backward and deep squat exercises compared with the other exercises after WBV was applied (Figure 5.4A and 4B). This may have occurred because the bilateral TA muscles had the greatest pre-activation without WBV during these two exercises, and thus the further increase in EMG achieved by the application of WBV may be slighter. In addition, the vibration energy transmitted to the participants could have been affected by contact of the surface area with the vibration platform (Krol et al., 2011). In the weight-shifted-backward exercise, the contact of the surface area with the vibration platform was the smallest among all exercises. Hence, the effect of WBV may be reduced. Hazell et al. (2010) also studied the EMG responses of the TA muscle during WBV in young healthy participants. Their results showed that the EMG magnitude of the TA was significantly lower during loaded dynamic squats compared with the same exercise under the unloaded condition. During loaded dynamic squat, the TA EMG magnitude was significantly increased with the application of WBV at 45Hz, but not 25 Hz or 35 Hz, when compared with the no-WBV condition (Hazell et al., 2010). Overall, it seems that the activation of the TA muscle is highly dependent upon the exercise and the intensity of WBV stimulation.

5.5.3 Comparison of EMG responses between paretic and non-paretic legs

Our results revealed no significant intensity × side interaction, and thus supported our hypothesis that the WBV would induce similar EMG responses in the paretic and non-paretic sides. Hence, there was no evidence of preferential activation of either leg by WBV when performing the exercises described in our study.

5.5.4 Relationship with motor impairment and spasticity

Our final hypothesis was supported, because no significant relationship was found between the WBV-induced increase in EMG magnitude and the CMSA and MAS scores. The results suggested that WBV had a similar influence on leg muscle activation, regardless of the severity of motor impairment and spasticity. The lack of association of EMG responses during WBV and spasticity has also been shown by Liao et al. (2014a) in their study of VL and GS muscle responses to WBV. It is thus highly improbable that the increase in EMG activity during WBV exposure was due to muscle activity triggered by spasticity.

5.5.5 Clinical Implications

Many of the exercises chosen here have been used in previous WBV studies and stroke exercise trials (Lau et al., 2011; Pang et al., 2005a). Significant improvements in leg muscle strength have been reported after regular training using these exercises without WBV (Lau et al., 2011; Pang et al., 2005a). Our findings showed that the muscle activity of TA and BF in both paretic and non-paretic legs can be increased considerably by the application of WBV, particularly the high-intensity protocol, during exercise. Lee et al. (2015) have investigated the level of EMG activity of the TA muscle during squatting exercise, an exercise commonly used in stroke rehabilitation programs for muscle strengthening purpose. It was found that the paretic TA EMG magnitude recorded during the maintenance phase of the dynamic squat exercise was on average more than 3.4 times than that during static standing in people with stroke. In our study, we also found that the paretic TA EMG magnitude was greater during semi-squat (2.7%±2.9%MVC) than static standing (0.9%±0.8%MVC). When high-intensity WBV was added, the paretic TA EMG magnitude was further increased by an average of 12.5% MVC (SD=9.5%MVC). Only one study have examined the BF EMG activity after WBV training in people with stroke (Tihanyi et al., 2007). Tihanyi et al. (2007) showed that after one WBV session (20Hz, peak-to-peak amplitude: 5mm), the EMGrms of VL during maximal isometric contraction was significantly increased by 44.9%, but that of BF was not significantly changed.

Some studies have investigated the level of TA or BF EMG activation in leg muscles in people with stroke after different forms of exercise training (Andersen et al., 2011; Lee et al., 2013). For example, Andersen et al. (2011) showed that after 12 weeks of intervention comprising high-intensity resistance training and body weight supported treadmill training, the EMG magnitude of the paretic hamstrings muscle during concentric and eccentric knee flexion was increased by approximately 20-30% (expressed as a percentage of EMG magnitude of the corresponding muscle on the unaffected side) in a sample of people with chronic stroke. Lee et al. (2013) found that in individuals with chronic stroke, six weeks of closed kinetic chain exercises led to a significant increase in the EMG magnitude of the paretic TA and BF muscles by 7-8%, whereas open kinetic chain exercises resulted in a significant increase in the EMG magnitude of the paretic BF muscle only, by about 5-6%. In this study, the amount of WBV-induced increase in EMG magnitude was approximately 10.8%-12.1% and 19.9%-22.7% in the paretic TA and BF muscles respectively (Table 5.2), when compared with the no-WBV condition. When comparing these values with those obtained from other forms of exercise training mentioned in the above studies, it seems that the WBV protocols used here may have potential in improving muscle activation in the paretic leg, but our current study design does not allow us to determine the effects on EMG activation after sustained WBV training. Nevertheless, our results suggested that, in addition to WBV intensity, both the choice of exercise and the target muscle group should be considered when prescribing WBV because these factors also affect the muscle response to WBV.

The increase in EMG activity was similar regardless of the level of motor impairment and spasticity, suggesting that individuals with more severe impairments or spasticity may potentially benefit equally from WBV as those with less severe impairments or spasticity. This is important, because people with severe stroke with limited active movements may find it difficult to engage in other forms of exercise for muscle strengthening purposes. In contrast, WBV training involves holding simple body exercises only and may suit those who have more severe motor or even cognitive impairments.

5.5.6 Methodological considerations

Surface EMG signals can be easily disturbed by vibration artefacts. Needle electrodes would probably have been a better choice but we did not use it because of its invasive nature. As in previous studies that used surface EMG to measure muscle responses to WBV (Cardinale & Lim, 2003; Ritzmann et al., 2013; Hazell et al., 2007, 2010; Krol et al., 2011; Lienhard et al., 2014; Marín et al., 2009; Roelants et al., 2006; Pollock et al., 2010; Abercromby et al., 2007), proper processing and filtering of the EMG signals were done to minimize the effects of artifacts that may be induced by WBV. The origin of the EMG signals during WBV has been previously studied by Ritzmann et al. (2010) In their experiments, dummy electrodes were placed close to the EMG electrodes to monitor motion artifacts. Their results showed that the dummy electrodes registered almost no activity during WBV. It was also found that when the dummy electrodes showed peaks of activity, they did not systematically concur with the preset vibration frequency, and had large standard deviations. Their results thus showed that the contribution of motion artifacts to the overall EMG activity is insignificant. Taken together, we feel our data reasonably reflect the muscle activation level during WBV exercise.

5.5.7 Limitations and Future Research Directions

First, many of the participants were middle-aged adults (<65 years). More men than women were tested. The generalizability of the findings may be compromised as a result. Second, the study only measured leg muscle activity during static exercises. The muscle response to WBV during dynamic exercises should also be addressed in the future to provide a more comprehensive picture of WBV-induced muscle response. In addition, we only compared the EMG responses among 3 WBV intensities, incorporating more WBV intensities would enable us to more accurately estimate the trend of EMG responses with increasing WBV intensity, and also the EMG responses for intensities beyond 1.61g. Finally, while this study found that low- and high-intensity WBV protocols could increase leg muscle activity during different exercises, whether long term training using these protocols can bring about actual improvement in muscle strength remains unknown. Randomized controlled trials that incorporate the measurement of muscle force production and functional capacity as outcomes are needed.

5.5.8 Conclusions

We found a positive relationship between the EMG magnitude of the TA and BF in both legs using a WBV intensity of up to 1.61g. The increase in EMG activity evoked by WBV was also influenced by the specific exercise performed. Therefore, the WBV intensity and the exercise chosen are important guiding factors in designing WBV exercise protocols for the stroke population. The EMG magnitude was the greatest during exposure to the high-intensity protocol. Our results have thus provided a basis for future randomized controlled studies to test the efficacy of this protocol in modifying neuromuscular function after stroke.

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Ethical standard The experiments comply with the current laws of the country in which they were performed.

Conflict of interest The authors declare that they have no conflict of interest.

CHAPTER SIX

Effect of Whole-body Vibration on Neuromuscular Activation of Leg Muscles during Dynamic Exercises in Individuals with Stroke

Liao Lin Rong

6.1 ABSTRACT

Background: Increasing research effort has examined the application of whole-body vibration (WBV) therapy in the stroke population in the past few years. However, the extent to which leg muscle activity is enhanced by WBV during dynamic exercises in individuals with stroke has never been investigated.

Objective: This study was designed to investigate the neuromuscular activity of vastus lateralis (VL), tibialis anterior (TA), biceps femoris (BF), and gastrocnemius (GS) muscles in the paretic and non-paretic legs during exposure to different WBV intensities while performing various dynamic exercises in people with chronic stroke.

Methods: Thirty people with chronic stroke performed a series of dynamic exercises with and without WBV: (1) low-intensity WBV (LWBV) [20Hz, 0.60mm, peak acceleration: 0.96 units of gravity of Earth (g)], (2) high-intensity WBV (HWBV) (30Hz, 0.44mm, 1.61g), and (3) no WBV (NWBV). Neuromuscular activation was measured by surface electromyography (EMG) on bilateral VL, TA, BF, and GS muscles and was reported as EMG root mean square normalized to % maximal voluntary contraction (MVC).

Results: The neuromuscular activation of VL, BF, TA and GS muscles of both legs was significantly increased by adding WBV during dynamic exercise ($P<0.05$) and that EMG neuromuscular activation in the BF, TA and GS muscles during exposure to the high-intensity WBV protocol was significantly greater than the low intensity WBV protocol ($P<0.05$). The WBV induced an increase in EMG neuromuscular activation in the TA and GS muscles that was exercise-dependent ($P<0.05$). The EMG response to WBV in the GS and BF muscles, but not the VL and TA muscles, was greater on the paretic leg than the non-paretic leg.

Limitations: The neuromuscular activation of leg muscles was measured during dynamic exercises only.

Conclusions: This study found a positive relationship between the neuromuscular activation (EMGrms) of the bilateral VL, BF, TA and GS muscles and WBV intensity (up to 1.61g) in individuals with stroke. The increase in neuromuscular activation in the TA and GS muscles evoked by WBV was also influenced by the specific dynamic exercise performed. The EMG response in the BF and GS muscles was greater in the paretic than non-paretic lower extremity. The choice of WBV intensity, dynamic exercise and muscle trained should be important factors to consider when prescribing WBV exercise.

Keywords: cerebrovascular accident; muscles; electromyography; dynamic exercise; rehabilitation; whole body vibration

6.2 INTRODUCTION

A wealth of literature has investigated the effects of whole-body vibration (WBV) on neuromuscular function in young and older adults (Bosco, C., et al., 1998; Chung et al., 2013; Cardinale, et al., 2003; Cochrane. 2011; Kemertzis et al., 2008; Luo et al., 2005; Delecluse, et al., 2003). Adding WBV to exercise has been demonstrated to augment the level of neuromuscular activation as measured by surface electromyography (EMG) during static and dynamic exercise in young adults (Abercromby et al., 2007; Rittweger et al., 2001; Torvinen et al., 2002a; Cardinale & Lim. 2003; Hazell et al., 2007 & 2010; Cormie et al., 2006; Roelants et al., 2006; Pollock et al., 2010), highlighting its potential impact on neuromuscular function after long-term training. Several meta-analyses have indeed concluded that WBV has therapeutic effects on some aspects of balance, muscle strength, and functional mobility in elderly population, but the optimal WBV parameters remain unclear (Lau et al., 2011; Lam et al., 2012; Rogan et al., 2011). Individuals with stroke may beneficiaries of WBV therapy, as they also sustain similar deficits in neuromuscular function, such as muscle weakness (English et al., 2010), balance and functional mobility (Garland et al., 2003; Sommerfeld et al., 2012; Laufer et al., 2003).

Increasing research effort has investigated the application of WBV therapy in the stroke population in the past few years. A recent systematic review of WBV clinical trials in stroke (Liao et al. 2014b) concluded that there was limited evidence to support or refute the use of WBV therapy to improve neuromuscular function in people with stroke, primarily because of the conflicting results reported, the small number of available studies, and the methodological weakness of the studies reviewed (Liao et al., 2014b). It seems that more important questions have to be addressed before further large-scale randomized controlled efficacy studies are conducted (Liao et al., 2014b). One of the fundamental questions pertains to the correlation between the intensity of WBV therapy and the extent of neuromuscular activation, and how these factors (e.g., frequency, amplitude, duration of WBV stimulation) interact with the different exercises performed (i.e., static and dynamic exercises). Liao et al.

(2014a) demonstrated that neuromuscular activation in bilateral vastus lateralis (VL) and gastrocnemius (GS) muscles was significantly augmented with the addition of WBV during the static exercise in people with chronic stroke by up to 20-30%, depending on the exercise performed (Liao et al., 2014a). However, the extent to which leg EMG activity is enhanced by WBV during dynamic exercises in individuals with stroke has never been investigated. A novel aspect of the present study is that we investigated various dynamic exercises (Figure 6.1) and WBV parameters (Table 6.1) in an effort to identify the best combinations of dynamic exercises and WBV conditions that would result in the highest level of EMG activity. This may provide important insight into the design of WBV protocol regimens to improve neuromuscular function for people with stroke.

The objectives of this study were to investigate the neuromuscular activity of VL, tibialis anterior (TA), GS, biceps femoris (BF) muscles in the paretic and non-paretic legs during exposure to different WBV intensities while performing various dynamic exercises in people with chronic stroke. It was hypothesized that: 1) Increasing the WBV intensity would significantly increase the bilateral VL, GS, BF, and TA muscles EMG magnitude during different dynamic exercises in individuals with stroke; 2) The WBV-induced increase in EMG activity in the tested leg muscles was dependent on the dynamic exercise performed (WBV intensity × exercise interaction effect); 3) The WBV would have similar effects on the EMG magnitude on the paretic side and the non-paretic side (i.e., no WBV intensity × side interaction effect).

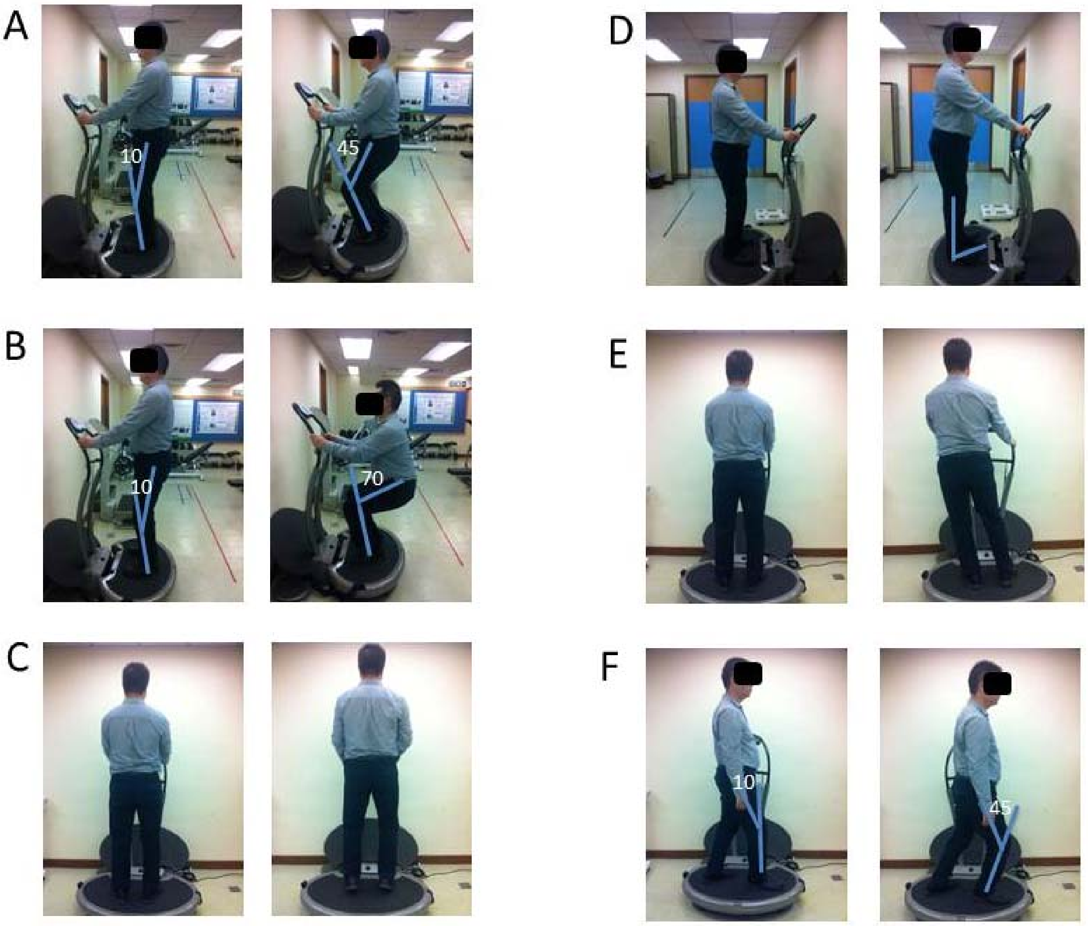


Figure 6.1 Exercise Protocol

A. Dynamic semi-squat (DSS): Feet placed apart at shoulder width, trunk upright, bilateral knees flexion and extension between the range from 10° to 45°.

B. Dynamic deep squat (DDS): Feet placed apart at shoulder width, trunk upright, bilateral knees flexion and extension between the range from 10° to 70°.

C. Dynamic forward weight shift (DFWS): Feet placed apart at shoulder width, trunk upright, bilateral knees keep at 10° flexion, body leaned forward with heels off the WBV platform as much as possible.

D. Dynamic backward weight shift (DBWS): Feet placed apart at shoulder width, trunk upright, bilateral knees keep at 10° flexion, body leaned backward with forefoot off the WBV platform as much as possible.

E. Dynamic weight shift side to side (DWSSTS): Feet placed apart at shoulder width, trunk upright, bilateral knees keep at 10° flexion, body weight shifted to the paretic leg, and then shifted to the non-paretic leg.

F. Dynamic forward lunge (DFL): Paretic leg placed in front, trunk upright, body leaned forward and weight shifted onto the paretic leg as much as possible, the paretic knee flexion and extension between the range from 10° to 45°. The same exercise was performed after the positions of the two legs were switched.

Table 6.1 WBV protocols

Group	Frequency (Hz)	Amplitude (mm)	Peak Acceleration (g)	Duration/exercise (second)
LWBV	20	0.60	0.96	45
HWBV	30	0.44	1.61	
No-WBV	0	0	0	

WBV: whole body vibration; LWBV: low-intensity WBV; HWBV: high-intensity WBV

6.3 METHODS

6.3.1 Experimental Design

An experimental study design (i.e., a single group repeated measures) was adopted to investigate the neuromuscular activation of bilateral VL, BF, TA and GS muscles in individuals with chronic stroke during different dynamic exercises and WBV conditions.

6.3.2 Subjects

All subjects were screened for contraindications to WBV exposure (see exclusion criteria below), and were recruited from a local stroke self-help group between June 2013 to March 2014. The inclusion criteria were: chronic stroke (i.e., diagnosis of hemispheric stroke > 6 months) living in community, having some degree of paresis in the paretic leg, indicated by a composite lower limb motor score ≤13 according to the Chedoke-McMaster Stroke Assessment (CMSA) (Gowland C et al., 1993), and ability to perform six dynamic exercises (Figure 6.1) in this study. The exclusion criteria were: a history of low back pain, any disease of the spine, severe cardiovascular conditions (e.g., cardiac pacemaker), peripheral vascular disease, musculoskeletal disorders (e.g. fresh fractures), kidney or bladder stones, vestibular disorders or pregnancy. Written informed consent was obtained for each participant prior to enrollment. All procedures of the present study was approved by the institutional review boards at the Hong Kong Polytechnic University (approval number: HSEARS20131125001), and all experiments were conducted in accordance with the Declaration of Helsinki.

6.3.3 Sample Size Calculation

Our research team has previously performed a study on GS and VL muscles during static WBV exercise in individuals with stroke (Liao et al., 2014a) and showed that WBV stimulation significantly augmented neuromuscular activation in paretic GS, with effect sizes (f) of 0.46-0.93 (large effect sizes).

Based on these results, we performed a power calculation to calculate the sample size required for this study. After accounting for a 10% attrition rate, a total of 27 subjects would yield a 90% power at a significance level of $P<0.05$.

6.3.4 WBV Conditions

All participants underwent a single session of WBV stimulation on a vibration platform (Jet-Vibe System, Danil SMC Co. Ltd., Seoul, Korea) that delivered uniform synchronous oscillations with frequency range from 20 to 55Hz and corresponding preset amplitudes. We used synchronous WBV in this study, as synchronous WBV tended to induce higher level of neuromuscular activation when compared with side-alternating WBV (Ritzmann R et al., 2013). All experiments were conducted in an exercise laboratory located in the Hong Kong Polytechnic University.

All participants were exposed to three WBV conditions: 1) low-intensity WBV (LWBV) [20 Hz frequency with 0.60mm amplitude, peak acceleration: 0.96 unit of Earth's gravity (g)]; 2) high-intensity WBV (HWBV) [30Hz, 0.44mm, 1.61g]; and 3) no WBV (NWBV) (Table 1). The sequence of WBV conditions used was decided randomly by drawing ballots. The parameters (i.e., amplitude, frequency) of WBV device were verified by using a tri-axial accelerometer (Model 7523A5; Dytran Instruments Inc., Chatsworth, CA). The peak acceleration (a_{peak}) was represented in units of Earth's gravity ($1g=9.81m/s^2$) to facilitate comparisons across studies, and was computed by the following formula:

$$a_{peak}=(2\pi f)^2 A$$

where f represented the frequency and A represented the amplitude of vibrations (Kiiski J et al., 2008).

6.3.5 Exercise Conditions

Within each WBV condition, participants were required to perform six dynamic exercises (Figure 1). Practice trials were given to familiarize the participants with the exercises before EMG data collection. A metronome was used in conjunction with verbal commands to guide the rhythm during each dynamic exercise (1.5-second down and 1.5-second up). Each exercise was 45 seconds in duration for each repetition, and 3 repetitions were performed (Hazell et al., 2007). A 10-second pause was given between each trial of the same exercise. In addition, a 1-minute rest period was provided after the 3 repetitions were completed. A 5-min rest period was given after the participant had completed all 6 exercises under a given WBV condition. The order of exercises performed for each WBV condition was randomized before the measurement. In addition, an electro-goniometer (Type XM180, Penny and Giles Biometric Ltd, Blackwood, Gwent, UK) was placed on the paretic knee, with one of the axis fixed along the longitudinal axis of femur and the other along the longitudinal axis of the fibula. This was done to monitor the knee angle changes in the sagittal plane during exercises. The following instructions were common during all data-collection trials: stand with head up and look forward; stand with equal body weight on each leg; and hold onto the hand bar of the WBV device gently for balance only. The details of the instructions for specific exercises are described in Figure 6.1.

6.3.6 Measurement of neuromuscular activation

Surface EMG was recorded form the VL, GS, BF and TA muscles in paretic-leg and non-paretic-leg in all subjects during all three WBV conditions. First, according to specifications of the Surface EMG for a Non-invasive Assessment of Muscles (SENIAM) project (Hermens HJ et al., 2000), the skin surface of test muscles was first carefully shaved. Sandpaper was then used to remove the dead layer of the skin, followed by cleaning the surface with alcohol to lower the level of impedance before electrode placement. Bipolar bar electrodes (Bagnoli EMG system, Delsys, Inc., Boston, MA, USA) were placed at the middle of the respective muscle belly. Second, a ground electrode was attached to the participants' fibula head of the paretic side to ensure that no muscle activity was recorded. Third, medical tape was used to secure the electrodes and wires to minimize possible power-line interferences and cable motion artifacts.

Each participant sat on a chair with backrest placed against a wall to complete maximal voluntary contraction (MVC) tests for the eight muscle groups being tested. The hip and knee joint was placed in flexion at 90°. Three trials were completed for each muscle group, with 1-min rest period between each trial. The investigator gave verbal encouragement during the testing to elicit maximal effort from the participants. To measure the EMG activity during MVC of knee extension and knee flexion (i.e., VL and BF), the tested lower limb was strapped using a non-elastic belt that was attached to an immovable object. The tested leg was stabilized by the researcher's hand, and participants were instructed to perform a maximal isometric contraction by pulling against the belt and sustain it for 10-seconds. To measure the EMG activity of GS and TA muscles during MVC of ankle dorsiflexion and plantarflexion, the ankle joint was placed in a neutral dorsiflexion/plantarflexion position. For the GS muscle, the researcher used two hands onto the tested thigh and then lean his upper body weight to the test thigh, the participants were asked to perform a maximal isometric ankle plantarflexion contraction against the floor and maintain for 10 seconds. For the TA muscle, one hand of the researcher stabilized the tested lower limb, and the other hand was placed on the distal dorsal aspect of the tested foot to provide resistance, as the participants were instructed to complete a maximal isometric ankle dorsiflexion by pushing against the researcher's hand, and sustain for 10 seconds. The peak EMG values obtained from 3 MVC trials were averaged to yield the mean, which was then used to normalize all EMG root mean square (EMG_{rms}) data during the WBV exercise trials. Based on the EMG_{rms} data of three MVC trials in the present study, the reliability of the EMG measurements was excellent ($ICC_{2,1}$=0.85-0.98).

6.3.7 EMG data analysis

The EMG signal was sampled at 1000 Hz (Bagnoli-8, DelSys, Inc., Boston, MA, USA) and stored directly to hard disk for offline analysis. The $\mathrm{EMG}_{\mathrm{rms}}$ data was post-processed using a computer with customized software (LabView version 7.0, National Instruments Corp., Austin, TX, USA) using a 20-500Hz band-pass Butterworth. The correlated harmonics at the frequency of 20Hz, 30Hz and 60Hz were excluded by implementing the Infinite Impulse Response (IIR) rejector (MyoResearch XP, Master Package version 1.06 software, Noraxon USA, Inc., Scottsdale, AZ, USA) (Liao et al., 2014a), which removed any noise caused by the frequency of the WBV platform, followed by full-wave rectification of data. The $\mathrm{EMG}_{\mathrm{rms}}$ was then calculated in 100-ms windows around every data point (Abercromby AF et al., 2007). The middle 30 seconds of each trial were selected for calculation of the $\mathrm{EMG}_{\mathrm{rms}}$ values (Hazell et al., 2007), the $\mathrm{EMG}_{\mathrm{rms}}$ values of each muscle evaluated during all WBV conditions were averaged and then divided by the MVC and multiplied by 100 for normalization. For each combination of specific exercise and WBV, the $\mathrm{EMG}_{\mathrm{rms}}$ values of the 3 trials were averaged and expressed as a percentage of the peak EMG amplitude (%MVC) collected during the maximum muscle activity.

6.3.8 Statistical Analyses

Statistical analysis was performed using the IBM SPSS software (version 20.0, IBM, Armonk, NY, USA), and $P<0.05$ was considered significant. The dependent variables in all statistical tests were $\mathrm{EMG}_{\mathrm{rms}}$, obtained from VL, GS, BF and TA muscles of paretic leg and non-paretic leg, all data are presented as means ± standard deviation (SD).

To assess neuromuscular activation among the LWBV, HWBV and NWBV groups, four separate 3-way repeated measure ANOVA models (WBV intensity at three levels; exercise at six levels; limb involvement at two levels) were used to analyze the normalized EMGrms values (i.e., %MVC) for the VL, GS, BF and TA muscles respectively. For testing hypotheses 1-3, the 3-way ANOVA would simultaneously yield the results regarding the main effect of WBV intensity (hypothesis 1), intensity ×

exercise interaction (hypothesis 2), and intensity × side interaction (hypothesis 3). If a significant intensity × exercise × side interaction was found in the 3-way ANOVA model, separate 2-way ANOVA analyses would be done for the VL, TA, GS and BF muscles of the paretic and non-paretic legs. If significant results were obtained, contrast analysis using the Bonferroni adjustment was performed. The Greenhouse-Geisser epsilon adjustment was used if sphericity assumption was violated. Effect size was denoted by partial eta-squared (partial η^2). Small, medium and large effect sizes were represented by partial η^2 values of 0.01, 0.06, and 0.14, respectively (Pallant et al., 2007).

6.4 RESULTS

6.4.1 Characteristics of Participants

The flow chart of this study is shown in Figure 6.2. Twenty-one men (mean ±SD age: 58.2±9.0 yr; mean ± SD height: 1.7±0.1m; mean ±SD weight: 68.3±11.9kg) and nine women (mean ±SD age: 53.4±12.2 yr; mean ± SD height: 1.6±0.1m; mean ±SD weight: 57.8±11.8kg) participants completed all data collection. The median lower extremity composite motor score was 7 out of 14, as measured by Chedoke-McMaster Stroke Assessment (CMSA). A total of 21 participants required an aid for outdoor mobility. The demographic data are summarized in Table 6.2.

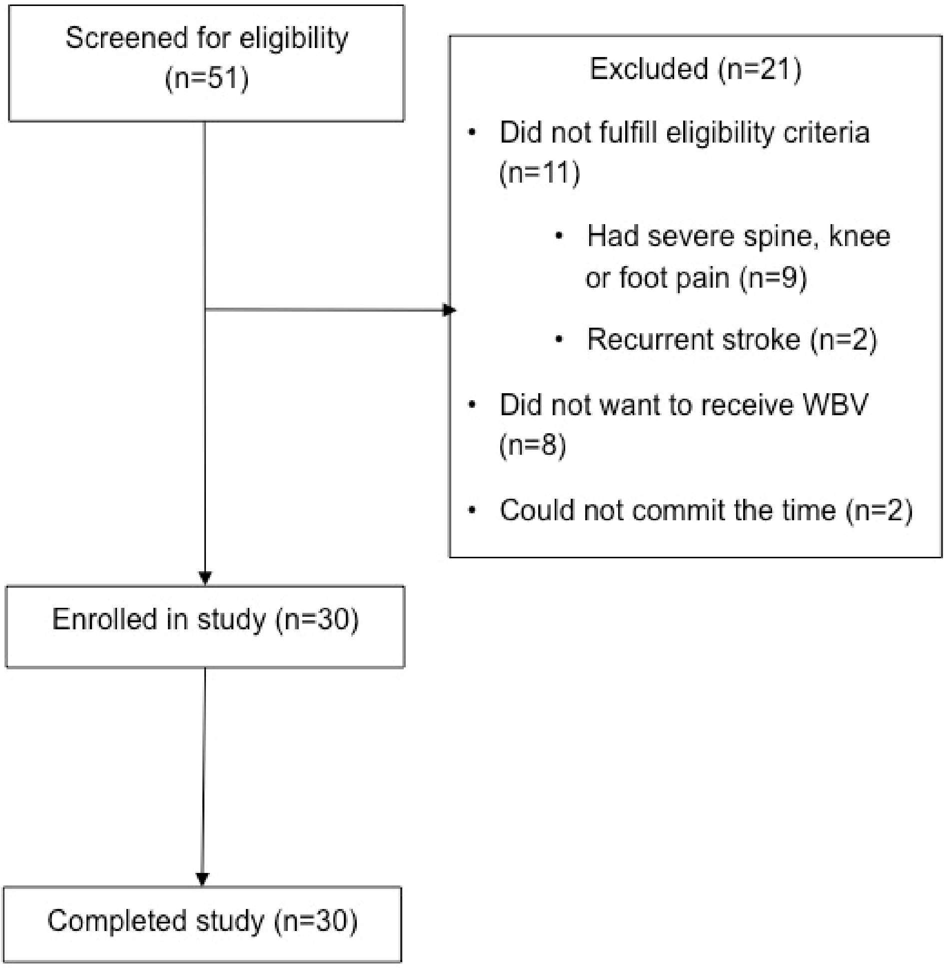


Figure 6.2 Study Flow Chart. A total of 30 individuals with stroke completed all data collection.

Table 6.2 Characteristics of Participants (n=30)

Variable	**Value**[a]
Basic demographics	
Age, year	56.8 ±10.1
Gender, male/female, n	21/9
Body Mass Index, kg/m^2	24.7±3.7
Required walking aid for outdoor mobility, none/cane/quadrupod, n	9/17/4
Stroke characteristics	
Time since stroke onset, year	5.2±3.4
Type of stroke, ischemic/hemorrhagic/unknown, n	14/12/4
Side of hemiparesis, left/right, n	10/20
CMSA Lower Extremity Composite Score (out of 14), median (IQR)	7(6.75-9)
Abbreviated Mental Test Score (out of 10)	9.2±1.0
Paretic knee Modified Ashworth Scale of spasticity score (0–4)[b]	
Median (IQR)	0 (0-1)
Paretic ankle Modified Ashworth Scale of spasticity score (0–4)	
Median (IQR)	1.5 (1-2)
Co-morbid conditions	
Hypertension, n	18
High cholesterol, n	15
Diabetes mellitus, n	4
Medications	
Antihypertensive agents	
Beta-blockers, n	18
Calcium channel blockers, n	5
Angiotensin converting enzyme inhibitors, n	4
Hypolipidemic agents, n	15
Antidiabetic agents, n	4
MVC EMGrms (µV)	
Paretic leg VL	301.8±159.8
Non-paretic leg VL	444.0±185.6
Paretic leg GS	218.5±182.0
Non-paretic leg GS	356.5±133.4
Paretic leg BF	187.3±136.6
Non-paretic leg BF	456.2±193.9
Paretic leg TA	369.2±243.2
Non-paretic leg TA	654.8±274.4

[a] Mean±SD presented for continuous variables.

[b] Modified Ashworth Scale is a 6-point ordinal scale. The category 1+ was converted to 1.5 for statistical analysis.

AFO= Ankle-foot-orthosis, BF=biceps femoris, CMSA = Chedoke–McMaster stroke assessment, EMG=electromyography, GS= gastrocnemius; IQR= interquartile range, MVC= maximum voluntary contraction, VL= vastus lateralis; rms=root mean square, TA=tibialis anterior

6.4.2 Three-way ANOVA

The 3-way ANOVA model revealed that the intensity by exercise by side interaction was not significant for the VL ($F_{5.50, 159.39}$=0.64, P=0.112), GS ($F_{48.10, 43.80}$=1.10, P=0.353), TA ($F_{3.67, 106.50}$=1.28, P=0.285), and BF muscles ($F4_{.46, 129.34}$=1.07, P=0.376), indicating that the EMG responses to WBV was not influenced by the interaction of all three factors (i.e., intensity, exercise, and side). The subsequent paragraphs would address the main effect of intensity (hypothesis 1), intensity by exercise interaction (hypothesis 2), and intensity by side interaction effects (hypothesis 3).

6.4.3 Main Effect of Intensity

The main effect of intensity on normalized EMG responses in the VL ($F_{1.63, 47.38}$=7.50, P=0.003), GS ($F_{1.28, 37.18}$=27.52, $P<0.001$), TA ($F_{1.58, 45.94}$=1.28, $P<0.001$), and BF muscles ($F_{1.35, 39.28}$=41.28, $P<0.001$) were all statistically significant, indicating that increasing the intensity of WBV resulted in an overall augmentation in EMG magnitude in these muscles measured. Further analyses based on the results from 3-way ANOVA revealed that in the paretic and non-paretic VL, GS, BF and TA muscles, addition of LWBV and HWBV during exercise led to significantly higher normalized EMG$_{rms}$ compared with the same exercises without WBV ($P<0.05$). Additionally, the difference between the low-intensity and high-intensity protocols also reached statistical significance for all muscles ($P<0.05$), with the exception of the VL muscle ($P>0.05$) (Table 6.3).

Table 6.3 The effect of whole-body vibration (WBV) intensity on neuromuscular activation

Muscle	**WBV Intensity × exercise interaction effect**		**Main Effect of WBV intensity**		**Post-hoc contrast analysis**					
					NWBV Vs LWBV		**NWBV Vs HWBV**		**LWBV Vs HWBV**	
	F_{df}[a]	***P*-value**	**F_{df}[a]**	***P*-value**	**Mean difference[b] (95% CI)**	***P*-value [c]**	**Mean difference (95% CI)**	***P*-value**	**Mean difference (95% CI)**	***P*-value**
VL	$0.72_{5.92,171.7}$	0.632	$7.50_{1.63,47.38}$	0.003*	2.4 (0.2, 4.6)	0.011*	2.9 (1.4, 4.3)	<0.001*	0.5 (-1.8, 2.7)	0.593
BF	$1.96_{3.78,109.61}$	0.110	$41.28_{1.35,39.28}$	<0.001*	2.9 (1.8, 4.0)	<0.001*	3.9 (2.4, 5.3)	<0.001*	1.0 (0.2, 1.7)	0.008*
TA	$2.79_{4.81,139.46}$	0.021*	$15.64_{1.58,45.94}$	<0.001*	1.0 (0.3, 1.7)	<0.001*	1.9 (0.8, 2.9)	<0.001*	0.8 (0.07, 1.6)	0.010*
GS	$2.64_{4.41,127.88}$	0.032*	$27.52_{1.28,37.18}$	<0.001*	4.0 (2.3, 5.6)	<0.001*	5.3 (2.8, 7.8)	<0.001*	1.3 (0.02, 2.7)	0.018*

[a] Greenhouse-Geisser epsilon adjustment was used to generate the F-score, degrees of freedom and P-values are Greenhouse-Geisser epsilon adjustment due to violation of the sphericity assumption.

[b] EMG magnitude expressed as percent maximal voluntary contraction (%MVC)

[c] The p-values for the contrast analysis are Bonferroni corrected values.

*Statistically significant (*P*<0.05)

BF=biceps femoris, CI=confidence interval, df=degrees of freedom, GS= gastrocnemius, HWBV=high intensity WBV, LWBV=low intensity WBV, NWBV=no WBV, TA=tibialis anterior, VL= vastus lateralis, WBV=whole-body vibration

6.4.4 Intensity by Exercise Interaction

The normalized EMG neuromuscular activation in the paretic and non-paretic leg during the WBV trials are displayed in Figure 6.3. The 3-way ANOVA model revealed a significant WBV intensity by exercise interaction effect in TA ($F_{4.81,\ 139.46}$=2.79, P=0.021) and GS muscles ($F_{4.41,\ 127.88}$=2.64, P=0.032), indicating that the differences in normalized EMGrms among the different WBV conditions were exercise-dependent in these two muscles. However, no significant intensity by exercise interaction effect was detected in the VL ($F_{5.92,\ 171.78}$=0.72, P=0.632) and BF muscles ($F_{3.78,\ 109.61}$=1.96, P=0.110) (Table 6.3).

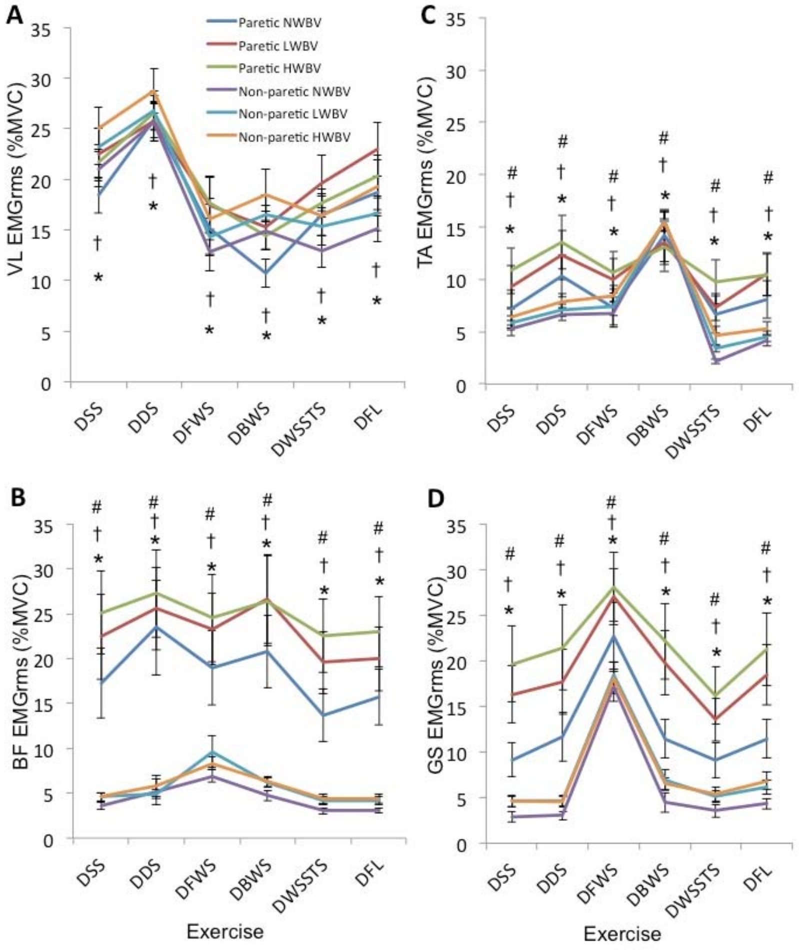


Figure 6.3 Normalized EMG Magnitude Under Different WBV Exercise Conditions

The normalized EMGrms of the VL (Figure 6.3A), BF (Figure 6.3B), TA (Figure 6.3C), and GS (Figure 6.3D) in each test condition is expressed as %MVC. The error bars represent 1 standard error of the mean. Six different dynamic exercises were examined in each WBV condition: dynamic semi-squat (DSS), dynamic deep squat (DDS), dynamic forward weight shift (DFWS), dynamic backward weight shift (DBWS), dynamic weight shift side to side (DWSSTS) and dynamic forward lunge (DFL). * denotes significant difference between the control condition (NWBV) and LWBV condition ($P<0.002$). † indicates significant difference between the control condition and HWBV protocol. $^{\#}$ denotes significant difference between the LWBV and HWBV protocols.

6.4.5 Intensity by Side Interaction

The 3-way ANOVA model revealed significant intensity × side interaction effect for the GS ($F_{1.18, 34.19}$=10.50, P=0.002) and BF muscles ($F_{1.21, 34.98}$=14.93, P<0.001), suggesting that the normalized EMG responses to WBV was significantly different between the paretic-side and non-paretic-side. However, there was no significant intensity × side interaction effect for the VL ($F_{1.37, 39.76}$=2.50, P=0.112) and TA muscles ($F_{1.76, 51.08}$=2.92, P=0.069).

6.5 DISSCUSSION

To our knowledge, this is the first study to investigate the acute effects of WBV on neuromuscular activation during different dynamic exercises with different WBV protocols in individuals with stroke. The key finding were that: 1) The neuromuscular activation (EMG_{rms}) of VL, BF, TA and GS muscles of paretic and non-paretic leg was significantly increased by adding WBV during dynamic exercise and that EMG activity in the BF, TA and GS muscles during exposure to the high-intensity WBV protocol was significantly greater than the low-intensity WBV protocol; 2) The WBV-induced increase in EMG activity in the TA and GS muscles were exercise-dependent; 3) The EMG response to WBV in the GS and BF muscles, but not the VL and TA muscles, was greater on the paretic side than the non-paretic side.

6.5.1 Influence of WBV Intensity

Adding WBV significantly increased the EMG magnitude in all muscles tested, thus confirming the first hypothesis of the study. With the exception of the VL, the high-intensity WBV protocol led to greater neuromuscular activation when compared with the low-intensity WBV protocol and no-WBV in other muscles (Table 6.3). A good number of previous studies have demonstrated that a higher WBV intensity is associated with greater neuromuscular activation (i.e., EMG responses) in healthy adults

(Lienhard et al., 2014; Pollock et al., 2010; Cardinale & Lim. 2003; Roelants et al., 2006; Ritzmann et al., 2013; Marín et al., 2009 & 2012; Krol et al., 2011; Hazell et al., 2007 &2010; Abercromby et al., 2007). Therefore, our findings generally concur with the previous WBV research finding in healthy adults. The actual extent amount of increase in neuromuscular activation with WBV varied across various studies, primarily due to difference in WBV protocols (e.g., types of vibration, frequency, and amplitudes), exercise protocols (e.g., type of exercise, additional load, and duration), the processing methods of raw EMG data, and characteristics of the participants (e.g., people with mild to moderate impairment level Vs people with severe impairment level Vs able-bodied people).

It has been proposed that mechanical WBV signals generated by the platform cause changes in the length of the extrafusal fibers, resulting in the activation of an afferent feedback response through the muscle spindle Ia afferents, a reflex response akin to the tonic vibration reflex (Hagbarth et al., 1966; Cardinale & Bosco, 2003). We have previously used the same WBV intensities as this study to examine the muscle activity of VL and GS muscles during static exercise in individuals with stroke (Liao et al., 2014a). We found that the EMG activity of both the paretic VL and GS muscles was significantly increased by an average of 10.0%-10.1% and 14.9-17.5% respectively, depending on the WBV intensity used (Liao et al., 2014a). However, the findings did not show any significant difference in GS and VL muscles EMG activity level induced by the LWBV and HWBV protocols. In contrast, the present study demonstrated that the neuromuscular activation in BF, TA and GS muscles during the high-intensity WBV protocol was significantly greater than the low-intensity WBV protocol during dynamic exercises in individuals with stroke, indicating that the relationship between increased WBV intensity and EMG response was more apparent during dynamic exercise. It should be noted that, however, the mean increase in EMG magnitude was only at 1.0-4.0% and 1.9%-5.3% respectively with addition of low-intensity and high-intensity WBV. The results thus indicated that the influence of superimposed WBV was less remarkable during dynamic exercise than static exercise (Liao et al., 2014a).

6.5.2 Interaction Effect between WBV Intensity and Exercise

In the present study, the second hypothesis was partly confirmed because a significant overall intensity by exercise interaction effect was found in TA and GS muscles, indicating that the neuromuscular activation of these two muscles were exercise-dependent (Figure 6.3). However, the intensity by exercise interaction effect in VL and BF muscles was not significant (Table 6.3). Some previous studies investigated the WBV intensity by exercise interaction effects in healthy adults (Roelants et al., 2006; Di Giminiani et al., 2013; Hazell et al., 2010) but the results were mixed. For example, Di Giminiani et al. (2013) reported that the EMG muscle activity recorded during different exercises was not affected by different WBV frequencies. In contrast, Roelants et al. (2006) demonstrated that a significantly greater augmentation in VL EMG muscle activity in the one-leg-squat exercise than in the high-squat and low-squat exercise when WBV was applied. Our recently study found that the WBV intensity by exercise interaction effect was significant for the VL and GS muscles in both legs during static exercises in individuals with stroke (Liao et al., 2014a). The greater WBV-induced enhancement of muscle activation in the TA and GS muscles compared with the VL and BF muscles in found in this study may be related to the attenuation of WBV signals as they were transmitted from the feet to the whole body. The energy of WBV signals may be attenuated by the muscles of the shank (TA and GS muscles) before reaching the thigh (VL and BF muscles), and therefore the difference in effective intensity of WBV delivered to the regions above the knee among the three WBV conditions would be less.

6.5.3 Comparison of EMG responses between paretic and non-paretic legs

Our third hypothesis was partly confirmed as there was a significant intensity by side interaction effect in the BF and GS muscles, but not the VL and TA muscles. It is clear from Figure 3 that the WBV-induced augmentation in EMG activity in the BF and GS muscles was more remarkable on the paretic side than their counterparts on the non-paretic side. The lack of significant intensity by side interaction effect in the latter two muscles could be due to inadequate statistical power. Indeed, the corresponding p-values obtained were not remote from the level of significance, at 0.112 and 0.069 respectively. Significant results might have been obtained had greater sample size been used. Overall, it seemed that there may be preferential activation of the paretic leg muscles by the WBV during dynamic exercises. Two of our previous studies revealed no preferential activation either leg by the WBV during static exercises in individuals with stroke (Liao et al., 2014a; Liao et al., in press). The reasons for the difference in results remained unclear. Perhaps during static exercises, the posture of the participants was more consistent across the different WBV intensities whereas the repetitive body movements involved in dynamic exercises may have resulted in a shift in center of gravity across trials, which in turn influenced the effective WBV intensity delivered to one side versus the other.

6.5.4 Clinical Implications

This study clearly showed that adding WBV would increase EMG activity during various dynamic exercises in people after chronic stroke. However, the degree of EMG augmentation was only around 1%-5% MVC. It was not certain whether the high-intensity WBV protocol would be effective in inducing muscle strength changes after a longer intervention period. Nevertheless, the results clearly highlighted that the choice of WBV intensity and dynamic exercise have important influence on the EMG outcomes. These factors should be carefully considered when prescribing WBV training.

6.5.5 Limitations and Future Research Directions

First, our findings may not be generalized to acute or sub-acute individuals with stroke because the participants were community dwelling people with chronic stroke in present study. Second, we only compared the neuromuscular activation among three WBV conditions. Incorporating more WBV conditions would enable us to more accurately estimate the trend of neuromuscular activation with increasing the dosage of WBV stimulation beyond the high-intensity WBV protocol used here (i.e., 1.61g). Finally, the present study only measured the immediate effect of WBV on neuromuscular activation during different dynamic exercises, and was not designed to examine whether the WBV intervention would translate into long-lasting changes in muscle activation or functional performance following a training period of longer duration (in order of weeks).

6.5.6 Conclusions

This study found a positive relationship between the neuromuscular activation (EMGrms) of the bilateral VL, BF, TA and GS muscles and WBV intensity (up to 1.61g) in individuals with stroke. The increase in neuromuscular activation in the TA and GS muscles evoked by WBV was also influenced by the specific dynamic exercise performed. Therefore, the WBV parameters (e.g., type of vibration, amplitude, frequency, and duration) and the type of exercise (i.e., dynamic or static exercise) chosen are important guiding factors in designing WBV training protocols for the stroke survivors. The high-intensity protocol here resulted in greater degree of neuromuscular activation during dynamic exercise than the other two conditions, and therefore may potentially be a useful adjunct intervention in modifying neuromuscular function in individuals with stroke.

CHAPTER SEVEN

Cardiovascular Stress Induced by Whole-Body Vibration Exercise in Individuals with Chronic Stroke

Liao Lin Rong

7.1 ABSTRACT

Background. While whole-body vibration (WBV) has sparked tremendous research interest in neurorehabilitation, the cardiovascular responses to WBV in people with stroke remains unknown.

Objective. To determine the acute effect of different WBV protocols on oxygen consumption (VO_2), heart rate (HR), rate of perceived exertion (RPE), blood pressure (BP), and rate-pressure product (RPP) during the performance of six different exercises among people with chronic stroke (time since onset ≥6 months).

Design. Repeated measures design.

Methods. Each of the 48 participants experienced all three WBV protocols in separate sessions: (1) no WBV, (2) low-intensity WBV [peak acceleration: 0.96 unit of gravitational constant (G)], and (3) high-intensity WBV (1.61G). The order in which they encountered the WBV protocols was randomized, as was the order of exercises performed during each session. VO2, HR and RPE were measured throughout. BP and RPP were measured before and after each session.

Results. Low-intensity and high-intensity WBV induced significantly higher VO_2 by an average of 0.69 and 0.79ml/kg/min respectively ($P \leq 0.001$) than the control condition. These protocols also increased HR by an average of 4 beats per minute ($P \leq 0.05$). The two WBV protocols induced higher RPE than the control condition during static standing exercise only ($P \leq 0.001$). While the diastolic and systolic BP and RPP were increased at the end of each exercise session ($P \leq 0.001$), the addition of WBV had no significant effect on these variables ($P > 0.05$).

Limitations. The results are only generalizable to ambulatory and community-dwelling people with chronic stroke.

Conclusions. Addition of high- and low-intensity WBV significantly increased the VO2 and HR, but the increase was modest. WBV thus should not pose any substantial cardiovascular hazard in people with chronic stroke.

7.2 INTRODUCTION

Stroke is one of the most common debilitating conditions worldwide. People who survived a stroke may already have poor cardiorespiratory health prior to the stroke event, as cardiovascular disease and poor cardiorespiratory fitness are known risk factors for stroke (Agabiti-Rosei & Muiesan, 2007). Additionally, individuals after stroke often sustain various physical impairments that involve multiple body systems and adversely affect mobility, thereby further encouraging a physically inactive lifestyle (Michael et al., 2005). Cardiorespiratory fitness in individuals with stroke, which is often reflected by the peak oxygen consumption rate (VO_{2peak}), has also been found to be as low as 50-80% of values reported among the age- and sex-matched physically inactive individuals (Pang et al., 2005d), and is far below the threshold for independent living (around 20 ml/kg/min) (Letombe et al., 2010). Benefits of endurance exercise training to improve cardiovascular health outcomes in patients after stroke have been reported (Pang et al., 2005a,b,c&d, 2006, 2008, 2013b). Exercising at 60-80% heart rate reserve (HRR) for 20-40 minutes per day for 3-5 days a week has been recommended for patients with mild to moderate stroke for improving cardiovascular fitness and walking endurance (Pang et al., 2013b).

Whole-body vibration (WBV) therapy has sparked tremendous research interest in the field of geriatric rehabilitation. As WBV can augment muscle activity (Liao et al., 2014a), it has been used to train different aspects of neuromuscular function, such as muscle strength/power, postural control, and mobility in the elderly (Lau et al., 2011; Lam et al., 2012). The cardiovascular responses to WBV have also been studied in young healthy adults (Hazell et al., 2008, 2012; Rittweger et al., 2000, 2001, 2002a, 2010), older adults (Cochrane et al., 2008; Bogaerts et al., 2009), women who are overweight (Vissers et al., 2009) and people with spinal cord injury (Yarar-Fisher et al., 2014). It has been demonstrated that among young healthy adults, the addition of WBV during exercise induced a significant increase in VO_2 and heart rate (HR) (Rittweger et al., 2001; Hazell et al., 2012). On the other hand, Hazell et al. (2008) demonstrated minimal cardiovascular stress (HR, blood flow, or mean arterial pressure) with the addition of WBV to a static semi-squat exercise. The choice of exercise mode (static Vs dynamic) and intensity may partially explain the discordance in results. There is also evidence that the cardiovascular response is influenced by the intensity of WBV (Rittweger et al., 2002a). The increased VO_2 and HR responses during WBV have led to its potential use as an adjunct intervention in cardiovascular exercise training. Indeed, in a randomized controlled trial involving 220 older adults, Bogaerts et al. (2009) found that a 1-year WBV training program resulted in significantly more gain in VO_{2peak}, compared with the control group without WBV.

Over the past few years, there has been an increasing interest in using WBV to improve neuromuscular function in people after stroke (Lau et al., 2012; Pang et al., 2013b). However, no studies have explored cardiovascular responses to WBV in the stroke population. As the integrity of the cardiovascular system and exercise capacity in people with stroke may be very different from the able-bodied group (Pang et al., 2005d; Hardie et al., 2004), their cardiovascular responses to WBV may also differ. Examining the effects of WBV on acute cardiovascular responses is clinically important for two reasons. First, many individuals with stroke have a positive cardiovascular history, and are at risk of recurrent stroke and cardiovascular event (Hardie et al., 2004). For safety reasons, it is essential to know the level of cardiovascular stress experienced as the patients are engaging in WBV exercises. Second, for those who are deemed safe to undergo cardiovascular exercise training, an understanding of the VO_2 and HR changes during WBV would help determine whether WBV is a useful adjunct treatment for cardiovascular exercise training. The specific objective of the current study was to determine the acute effect of different WBV protocols on the VO_2, HR, rate of perceived exertion (RPE), blood pressure (BP), and rate-pressure product (RPP) during the performance of various static and dynamic exercises among people with chronic stroke. It was hypothesized that the WBV intensity, exercises performed, and their interactions would significantly influence the above cardiovascular variables of interest.

7.3 METHODS

7.3.1 Study design

This study used a repeated measures design to compare the cardiovascular responses during exposure to different WBV conditions.

7.3.2 Participants and sample size calculation

As no study had previously investigated the cardiovascular response during WBV in individuals with stroke, research in healthy adults was used to estimate the sample size required for this study. In a study involving a sample of 8 healthy men, Hazell and Lemon (2012) reported that WBV (frequency: 45 Hz, peak-to-peak displacement: 2 mm) significantly increased VO_2 by an average of 2.08 L/min (SD=0.40), compared with the same exercises without WBV (mean difference=1.69 L/min, SD=0.27) during various static exercises. The mean difference between the two groups had translated into a large effect size (Cohen's d =1.10). A more conservative effect size, [(represented by f score in analysis of variance, ANOVA)] was estimated for this study because the WBV intensities used were lower and the study population was disabled. Based on ANOVA analysis (3 WBV conditions and 6 exercises), assuming a medium effect size (convention: f=0.25), with an alpha of 0.05, power of 0.9, an attrition rate of 10%, a minimum of 40 participants would be required.

Participants were recruited through stroke self-help groups in the local community from January 2011 to June 2012. Inclusion criteria were chronic stroke (diagnosis of a hemispheric stroke with onset ≥ 6 months), community-dwelling, Abbreviated Mental Test score ≥6 (Lam et al., 2010), and having hemiparesis in the lower extremity, as indicated by a composite leg and foot motor score of 13 or lower according to the Chedoke-McMaster Stroke Assessment (CMSA) (Gowland et al., 1993). Exclusion criteria were cerebellar or brainstem stroke, neurological conditions in addition to stroke, serious heart conditions, vestibular dysfunctions, or other serious illnesses that affected performance of daily activities, having a cardiac pacemaker or stent.

The study was approved by the Human Research Ethics Subcommittee, The Hong Kong Polytechnic University. All experimental procedures were conducted according to the Declaration of Helsinki. All participants gave written informed consent prior to data collection.

7.3.3 WBV Protocol

All experiments were conducted in a research laboratory in the Hong Kong Polytechnic University. A platform that generated vertical vibrations (Danil SMC Co. Ltd., Seoul, Korea) was used for all experiments. The device had an adjustable frequency range between 20-55Hz with corresponding preset amplitudes (Lau et al., 2012; Pang et al., 2013b). The peak acceleration (a_{peak}), which represented the WBV intensity, was related to the amplitude (A) and frequency (f), and was calculated as: $a_{peak} = (2\pi f)^2 A$ (Kiiski et al., 2008). It is usually represented in units of gravitational constant (G) for easy comparison across studies. The peak acceleration values generated by the machine were validated by a tri-axial accelerometer (Model 7523A5, Dytran Instruments Inc., CA, USA).

As WBV frequencies of lower than 20 Hz may cause destructive resonance effects to the body, and previous studies showed that frequencies higher than 30 Hz caused discomfort and fatigue in some individuals with stroke (Lau et al., 2012; Pang et al., 2013b), a frequency range of 20-30 Hz was chosen in the current study. Each participant underwent three different WBV conditions for measuring cardiovascular responses: (a) no WBV, (b) low-intensity WBV protocol (amplitude: 0.60mm, frequency: 20 Hz, peak acceleration: 0.96 G) (i.e. sub-gravity), and (c) high-intensity WBV protocol (0.44mm, 30 Hz, 1.61 G) (i.e., supra-gravity) while performing different exercises. The three WBV conditions were tested separately on three different sessions, with a minimum of one rest day in between each session. To avoid order effect, the sequence of WBV conditions was decided randomly by drawing lots once at the beginning of the first session.

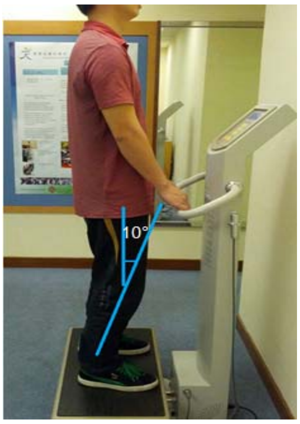
7.3.4 Exercise protocol

In each session, the participants were instructed to perform six different exercises (Figure 7.1). Three of these exercises were static: (1) Static standing exercise (SSt) (Figure 7.1A), (2) Static semi-squat (SSq) (Figure 7.1B), (3) Static standing with weight shifted to paretic leg (SWS) (Figure 7.1C). The other three were dynamic: (4) Dynamic semi-squat (DSq) (Figure 7.1D), (5) Dynamic side-to-side weight shifting (DWS)(Figure 7.1E), and (6) Dynamic forward lunge (DFL) (Figure 7.1F). The exercises chosen were commonly used in previous WBV trials in different populations (Lau et al., 2001,2012; Lam et al., 2012; Pang et al., 2013b). The sequence of exercise performed was randomized by drawing lots from a box at the beginning of each session. There were six lots in total, with each lot containing the name of one of the six exercises. Therefore, the number of possible exercise sequences was 720. Figure 2 illustrates the flow of participants and path of testing.

A steady state of VO_2 was reached in the third minute in most young healthy participants during these exercises (Rittweger et al, 2001). Most people would also feel fatigue if a longer period was used and no change in posture was allowed (Rittweger et al, 2002a). It has also been reported that VO_2 would reach a plateau within 3 minutes in people with stroke at a given workload (Tomczak et al., 2008). Thus, the duration of 3 minutes was chosen for each exercise in the current study. The dynamic exercises (Figure1D-F) were performed in cycles of 3 seconds (i.e., 20 repetitions per minute). A metronome was used to guide the people with stroke in performing the exercises at the desired rhythm. This exercise rhythm was selected based on our pilot study and was designed to balance between sufficient stimulus to increase VO_2 and HR, as well as the individual's ability to maintain the required exercise pace for 3 minutes of exercise. After each exercise, participants were instructed to sit down and rest until the VO_2 and HR returned to baseline values before the commencement of the next exercise.

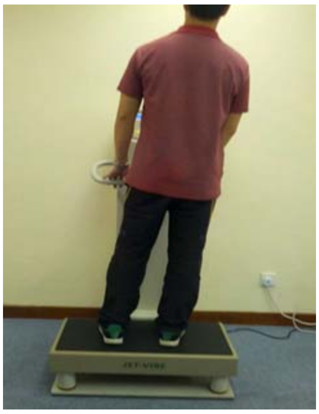
To familiarize the participants with the exercises, a practice trial was given before actual data collection. A manual goniometer (Baseline® HiRes™ plastic 360º ISOM Goniometer, Fabrication Enterprises, White Plains, New York, USA) was used to monitor the knee joint angle to ensure that each participant was performing the required exercises properly. Verbal feedback was given to the patients as necessary to ensure consistent performance of the exercises. All participants were instructed to gently hold on to the handrail of the WBV device for maintaining standing balance to ensure safety. Throughout the experimental session, the condition of each participant was monitored closely. The participants were informed of their option to terminate exercises at any time they experienced adverse symptoms. Overall, it took approximately 50-60 minutes to complete a data collection session.

A



B

C



D


[redacted] [redacted]

E


[redacted]

F


[redacted] [redacted]

Figure 7.1 Exercise protocol. (A) Static standing exercise (SSt): standing on the platform with feet placed apart at shoulder width and knees slightly flexed at 10º, and hold for 3 minutes. (B) Static semi-squat (SSq): Standing on the platform with feet placed apart at shoulder width and knees flexed at 30º, and hold for 3 minutes. (C) Static standing with weight shifted to paretic leg (SWS): Standing with body weight shifted to the paretic leg as much as possible and hold for 3 minutes. (D) Dynamic semi-squat (DSq): Starting position same as in static standing exercise (left), then bending knees to achieve the semi-squat position (right), and return to starting position, and repeat at a rate of 20 cycles per minute for 3 minutes. (E) Dynamic side-to-side weight shifting (DWS): Starting position same as in static standing exercise (left), then shifting body weight onto paretic leg (right), and return to starting position, and shifting weight onto the non-paretic leg. Repeat at a rate of 20 cycles per minute for 3 minutes. (F) Dynamic forward lunge (DFL): Standing in a forward lunge position with the paretic leg placed in front of the non-paretic leg with paretic knee flexed at 10º, then learning forward and shifting body weight onto the paretic leg as much as possible with knee flexed at 30 º, and then moving back to the starting position. Repeat at a rate of 20 cycles per minute for 3 minutes

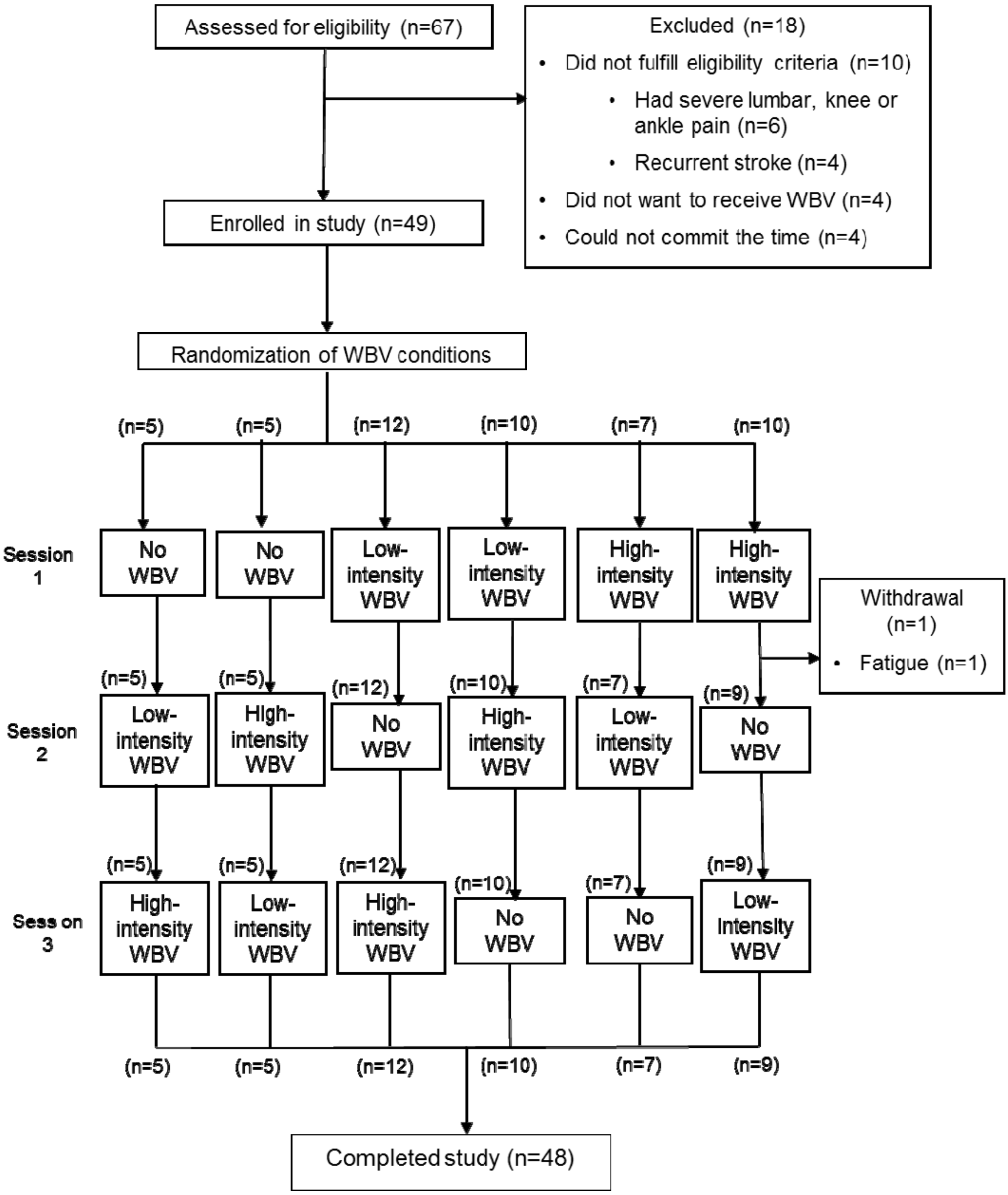

Assessed for eligibility (n=67)
Excluded (n=18)
Did not fulfill eligibility criteria (n=10)
Had severe lumbar, knee or ankle pain (n=6)
Recurrent stroke (n=4)
Did not want to receive WBV (n=4)
Could not commit the time (n=4)
Enrolled in study (n=49)
Randomization of WBV conditions
(n=5)
(n=5)
(n=12)
(n=10)
(n=7)
(n=10)
Session 1
No WBV
No WBV
Low-intensity WBV
Low-intensity WBV
High-intensity WBV
High-intensity WBV
Withdrawal (n=1)
Fatigue (n=1)
(n=5)
(n=5)
(n=12)
(n=10)
(n=7)
(n=9)
Session 2
Low-intensity WBV
High-intensity WBV
No WBV
High-intensity WBV
Low-intensity WBV
No WBV
(n=5)
(n=5)
(n=12)
(n=10)
(n=7)
(n=9)
Session 3
High-intensity WBV
Low-intensity WBV
High-intensity WBV
No WBV
No WBV
Low-intensity WBV
(n=5)
(n=5)
(n=12)
(n=10)
(n=7)
(n=9)
Completed study (n=48)

Figure 7.2 Study flow chart. Each participant underwent 3 experimental sessions. The sequence of WBV conditions was decided randomly by drawing lots once at the beginning of the first session. At the beginning of each session, the order of exercise was also randomized by drawing lots. A total of 48 participants with chronic stroke completed all assessment procedures.

7.3.5 Measurement of cardiovascular response

The primary outcome variables in this study were diastolic and systolic blood pressure (DBP and SBP, in mmHg) and rate-pressure product (RPP), rate of perceived exertion (RPE), VO_2 (ml/kg/min), and HR (beats per minute or bpm). A full-face mask and HR monitor (Polar®, Tampere, Finland) were worn by participants throughout the testing sessions, as VO_2 and HR were continuously measured by a portable metabolic system (FitMate™ Pro, Cosmed, Rome, Italy). Previous research showed that the FitMate system was a reliable and valid system for measuring VO_2 during graded exercise (Nieman et al., 2006). In addition, our pilot study found that the reliability of the FitMate system was good when used in people with stroke [intraclass correlation coefficients ($ICC_{3,1}$) = 0.80 (static exercise), and 0.91 (dynamic exercise)]. The system was also calibrated according to the manufacturer's guidelines prior to each testing session. The last 30 seconds of VO_2 (ml/kg/min) and HR (beats per minute) data during the 3-minute exercise period was averaged to obtain the mean value for analyses (Bogaerts et al., 2009; Hazell & Lemon, 2012). A similar data processing approach was also used by Cochrane et al. (2008).

SBP and DBP (in mmHg) were recorded (BPM I, Manning, Hong Kong) before and at the end of each session. The RPP was calculated as: (HR × SBP)/100 (Eng et al., 2002). Verbal RPE (from 6 to 20 according to the Borg's Scale) (Borg, 1970) was also asked at the beginning and at 1-minute intervals during each set of exercise. The highest RPE value reported in each trial was noted and used for analysis. Measures of RPP and RPE together might provide an indication of an individual's physiological tolerance to submaximal activity (Borg, 1970).

At the beginning of the second and third session, the participants were asked whether they were experiencing fatigue or other symptoms that may have resulted from the previous testing session. If the answer was positive, the assessment session was postponed until the suspected carryover effect from the previous session had subsided.

7.3.6 Statistical Analysis

Statistical analysis was performed with IBM SPSS Statistics software (version 20.0, IBM, Armonk, NY, USA). The duration of the washout period (measured in number of days) between testing session 1 and 2 was compared with that between testing session 2 and 3 using paired t-test. Two-way ANOVA with repeated measures [within-subject factors: 1. intensity (no WBV, low- and high-intensity WBV); and 2. time (before and after session)] was used to assess the difference in mean DBP, SBP, and RPP between pre- and post-session performance within each of the three sessions, and at corresponding times between the three sessions. The intensity × time interaction term determined whether changes observed between the beginning and end of each session were consistent among the three sessions, that is, whether the three WBV protocols were associated with different within-session responses.

Another two-way ANOVA with repeated measures model [within-subject factors: 1. intensity (no WBV, low- and high-intensity WBV); and 2. six exercises] was used to assess the mean VO_2 and HR between exposure to three different WBV protocols and among the six exercises. The intensity × exercise interaction effect determined whether the changes in VO_2 and HR responses induced by WBV were exercise-dependent. Greenhouse-Geisser epsilon adjustment was used if the sphericity assumption was violated. If significant results were found, contrast analysis with Bonferroni adjustment was performed. For each exercise, the comparisons of RPE (ordinal data) among the three WBV protocols were tested using the Friedman test, followed by pairwise comparisons using Wilcoxon signed-rank tests.

Additional analyses were done to examine whether the cardiovascular responses were related to the baseline values. For BP and RPP data, the within-session change score was calculated by subtracting the baseline score from the post-session score. For VO_2 and HR data, the change score (before and after each exercise) was obtained from subtracting the baseline score from the post-exercise score (i.e., average of the last 30 seconds of the trial). Pearson's product moment correlations were then used to determine the degree of association between the change score and the baseline value for each variable.

A level of significance of $P \leq .05$ was set, except for *post-hoc* analysis where the alpha was adjusted according to the number of comparisons made. We did not formally test for order effects related either to protocol or to exercise, but relied on randomization to minimize order effects.

7.4 RESULTS

7.4.1 Characteristics of participants

A total of 48 participants (36 men and 12 women; mean age: 56.3 ±10.1 years) completed all assessments (Fig.2). Participant characteristics are presented in Table 7.1. The median composite leg motor score (CMSA) was 8 out of 14 (interquartile range = 7-9), indicating moderate motor impairment. There was no significant between-session difference in baseline VO_2 (P=0.69) and HR (P=0.93). The baseline HR values of the three sessions were thus averaged to obtain the mean resting HR for each participant. It was found that 13 (27.1%) of our participants had a mean resting HR of ≥77 bpm, whereas only six (12.5%) had a mean resting HR of ≤64 bpm. A previous study in stroke found that a resting HR of ≥77 bpm was significantly associated with increased rate of vascular death, compared with those with their counterparts with resting HR of ≤64 bpm (Böhm et al., 2012).

Table 7.1 Characteristics of study participants (n=48)

Variable	Value[*]
Basic demographics	
Age, years, mean (mean±SD)	56.3 ±10.1
Sex, men/women (n)	36/12
Body mass index (kg/m^2) (mean±SD)	24.8±3.2
Required walking aid for indoor mobility, none/cane/quad (n)	43/3/2
Required walking aid for outdoor mobility, none/cane/quad (n)	17/26/5
Stroke characteristics	
Post-stroke duration, years (mean±SD)	4.7±3.2
Type of stroke, hemorrhagic/ischemic/ischemic + hemorrhage/unknown, n	16/23/3/6
Side of paresis, left/right (n)	19/29
CMSA Lower extremity composite score (out of 14) (median; IQR)[†]	8; 7-9
Abbreviated mental test score (out of 10) (mean±SD)	9.3±0.9
Co-morbid conditions	
Hypertension (n)	14
Diabetes mellitus (n)	9
High cholesterol (n)	20
Medications	
Antihypertensive agents	
Beta-blockers (n)	11
Calcium channel blockers (n)	5
Angiotensin converting enzyme inhibitors (n)	8
Angiotensin II receptor antagonists (n)	1
Adrenergic receptor blockers (n)	1
Others, n	8
Hypolipidemic agents (n)	20
Antidiabetic agents (n)	9
Baseline VO$_2$ and HR data	
Baseline VO$_2$ (ml/kg/min) (mean±SD)	
No-WBV session	4.03±0.70
Low-intensity WBV session	4.08±1.06
High-intensity WBV session	3.99±0.86
Baseline HR (beats per minute) (mean±SD)	
No-WBV session	76.3±11.7
Low-intensity WBV session	77.6±13.3
High-intensity WBV session	76.9±13.6

[*] Mean±SD presented for continues variables.

[†] CMSA: Chedoke-McMaster Stroke Assessment; HR: heart rate; IQR: interquartile range; n: number count; SD: standard deviation; VO$_2$: oxygen consumption; WBV: whole-body vibration

7.4.2 Washout period

On average, the washout period between session 1 and 2 was 1.4 days (SD=0.6 days, range =1-3 days), which was similar to that between session 2 and 3 (mean=1.3 days, SD=0.6 days, range=1-3 days) (P=0.73). None of the participants reported any carryover effects that may have resulted from the previous testing session that required postponement of testing.

7.4.3 DBP, SBP, RPP and RPE changes

The DBP ($F_{1,47}$=24.10, $P \leq 0.001$), SBP ($F_{1,47}$=29.91, $P \leq 0.001$) and RPP ($F_{1,47}$=17.19, $P \leq 0.001$) immediately after the exercise session were significantly higher than their respective values at baseline (Figure 7.3), except that in the high-intensity WBV condition, the DBP post-exercise was not significantly different from that at baseline after Bonferroni adjustment (P>0.017) (Table 7.2, Figure 7.3A). The main effect of WBV intensity, and intensity × time interaction were not statistically significant for DBP, SBP and RPP (P>0.05).

The pooled RPE data are shown in Figure 7.4A. Out of the 288 exercise trials for each WBV protocol (6 exercises × 48 participants), only 2% (2 participants, 6 trials), 6% (3 participants, 17 trials), and 5% (4 participants, 15 trials) reported a RPE >15 for no-WBV, low- and high-intensity WBV sessions, respectively. The low-intensity WBV protocols (Z =-4.43, P<0.001) and high-intensity WBV protocols (Z =-3.70, P<0.001) significant induced higher perceived effort than no WBV condition during static standing exercise. For the rest of the exercises, the RPE value demonstrated no significant differences among the three WBV protocols (P>0.05).

Other than the one participant who dropped out after the first session due to fatigue (Figure 7.2), no adverse effects were reported and none of the participants requested to stop the exercises during any of the testing sessions.

Table 7.2 The effect of whole-body vibration (WBV) intensity on outcome measurements

	WBV intensity × time interaction effect		Main Effect of WBV intensity		Main effect of time		Post-hoc analysis (within-session difference for each WBV protocol)					
							No WBV condition Pre-test Vs Post-test		Low-intensity WBV Pre-test Vs Post-test		High-intensity WBV Pre-test Vs Post-test	
Variable	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**Mean difference[‡] (95% CI)**	**p-value**	**Mean difference (95% CI)**	**p-value**	**Mean difference (95% CI)**	**p-value**
DBP[§]	0.95	0.39	0.46	0.61	24.10	≤0.001*	3.3 (1.1, 5.5)	0.01[†]	4.6 (2.0, 7.2)	≤0.001[†]	2.3 (1.1, 4.6)	0.04
SBP	0.05	0.95	0.90	0.41	29.91	≤0.001*	6.4 (2.8, 10.1)	≤0.001[†]	7.2 (3.3, 11.1)	≤0.001[†]	6.6 (3.0, 10.3)	≤0.001[†]
RPP	0.24	0.76	0.56	0.57	17.79	≤0.001*	5.9 (2.0, 9.9)	0.01[†]	7.6 (2.9, 12.3)	0.01[†]	6.8 (2.4, 11.1)	0.01[†]

	WBV Intensity × exercise interaction effect		Main Effect of WBV intensity		Main effect of exercise		Post-hoc contrast analysis (main effect of intensity)					
							No WBV Vs Low-intensity WBV		No WBV Vs High-intensity WBV		Low-intensity Vs High-intensity WBV	
Variable	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**Mean difference (95% CI)**	**p-value**	**Mean difference (95% CI)**	**p-value**	**Mean difference (95% CI)**	**p-value**
VO$_2$	0.25	0.25	16.98	≤0.001*	29.85	≤0.001*	0.7 (0.4, 1.0)	≤0.001*	0.8 (0.5, 1.2)	≤0.001*	0.1 (0.3, 0.5)	1.00
HR	2.94	0.01*	4.63	0.01*	32.67	≤0.001*	4 (1, 7)	0.01*	4 (0, 7)	0.05	0 (-4, 4)	1.00

*Statistically significant (*P*≤0.05)

[†] Statistically significant (*P*≤0.017)

[‡] A positive mean difference indicates that the mean value of the latter group is higher than that of the former group.

[§] HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; RPP: rate-pressure product; VO$_2$: oxygen consumption

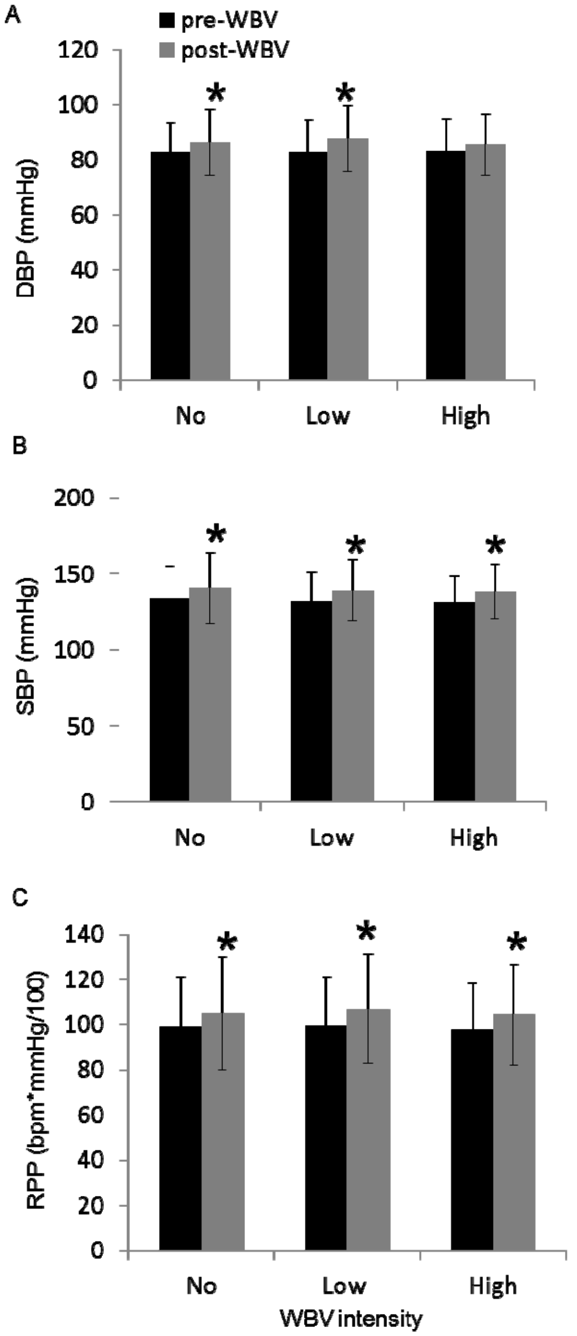


Figure 7.3 Effect of whole-body vibration on blood pressure and rate-pressure product. The average systolic blood pressure (DBP) (Fig.3A), systolic blood pressure (SBP) (Fig.3B) and rate pressure product (RPP) (Fig.3C) recorded at baseline (black bars) and immediately after each

exercise session (gray bars). The error bars represent 1 SD from the mean. Significant difference from baseline was indicated by *. The within-session differences in DBP, SBP and RPP did not themselves differ between the three WBV protocols, as evidence by the non-significant time × protocol interaction.

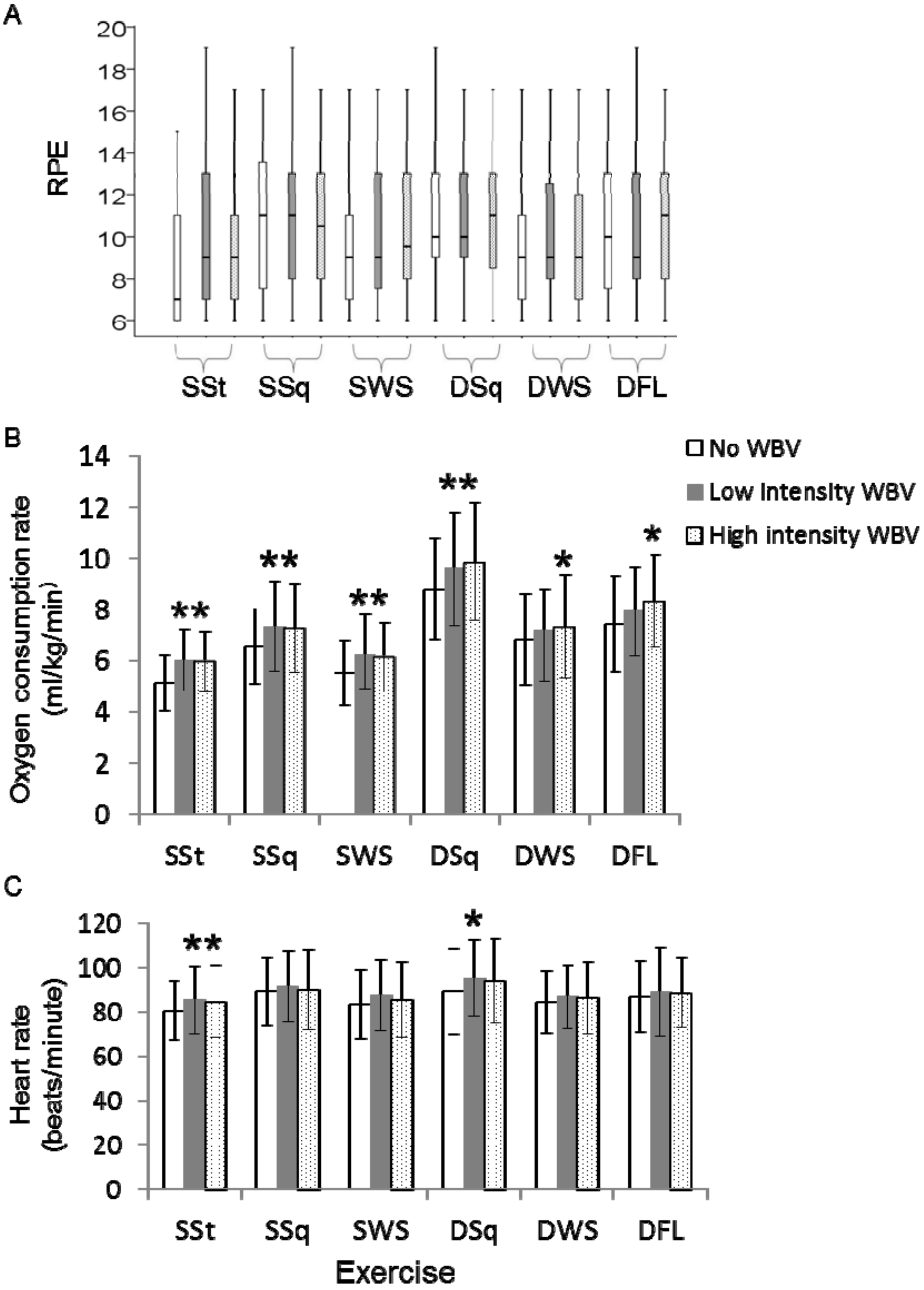


Figure 7.4 Effect of whole-body vibration on rate of perceived exertion, oxygen consumption and heart rate. Figure 7.4A shows the boxplot for the RPE data. The highest RPE value reported

in each exercise trial was used for analysis. The thick line inside each box represents the median, whereas the upper and lower borders of the box define the interquartile range. The vertical bars represent data up to 1.5 times the interquartile range extending from the upper and lower border of the box. The VO2 (Figure 7.4B) and HR (Figure 7.4C) data obtained during the last 30 seconds of each 3-minute exercise trial were averaged for subsequent analyses. The error bars represent 1 SD from the mean. The no-WBV, low-intensity WBV and high-intensity WBV exercise sessions is represented by white, gray, and dotted boxes/vertical bars, respectively. Significant difference from the no-WBV condition was indicated by *. The RPE level was significantly higher in the low-intensity and high-intensity WBV conditions than the no-WBV condition during static exercise only. WBV induced a significant increase in VO2. Adding WBV also led to significant increase in HR in static standing and dynamic semi-squat exercises.

7.4.4 VO_2 changes

An overall significant main effect of WBV intensity ($F_{2,94}$=16.98, $P \le 0.001$) and exercise ($F_{5,235}$=29.85, $P \le 0.001$) was found (Figure 7.4B). The intensity × exercise interaction effect, however, was not significant ($F_{10, 470}$=1.32, P =0.25). Contrast analysis revealed that overall, both the low-intensity and high-intensity WBV protocols induced significantly higher VO_2 than the control condition, by an average of 0.69 ml/kg/min (95%CI: 0.35, 1.03; $P \le 0.001$) and 0.79 ml/kg/min (95%CI: 0.45, 1.14; $P \le 0.001$) respectively (Table 7.2). Post-hoc analysis further showed that the increase in VO_2 induced by the two WBV protocols remained statistically significant after Bonferroni adjustment, except the dynamic weight shifting to paretic leg, and dynamic forward lunge exercises during low-intensity WBV. The difference in VO_2 value between the low- and high-intensity WBV protocols was not significant in any of the exercises after Bonferroni adjustment (P=1.00) (Table 7.2). *Post hoc* analysis of the effect of exercises showed that the static standing and static standing with weight-shifted to the paretic leg resulted in significantly lower VO_2 than that measured during other exercises ($P<0.01$). On the other hand, VO_2 during dynamic semi-squat and dynamic forward lunge was significantly higher than that during other exercises ($P<0.01$) (Figure 7.4B).

7.4.5 HR changes

There was an overall significant main effect of WBV intensity ($F_{2,94}$=4.63, P=0.01) and exercise ($F_{5,235}$=32.67, $P \le 0.001$) (Figure 7.4C). The intensity × exercise interaction effect was also significant ($F_{10, 470}$=2.94, P=0.01). Contrast analysis revealed that overall, low-intensity WBV induced significantly higher HR than the control condition by an average of 4 bpm (95%CI: 1, 7; P=0.01). The HR was also increased by the addition of high-intensity (mean difference: 4 bpm; 95%CI: 0, 7), but the result was marginally significant (*P*=0.05)(Table 7.2). The difference in HR was not significant between the low- and high-intensity WBV protocols (*P*=1.00) (Table 7.2). The increase in HR induced by low-intensity WBV remained significant for static standing (*P*≤0.001), and dynamic semi-squat (*P*≤0.001) exercises only after Bonferroni adjustment. Regarding the main effect of exercise, static standing induced significantly lower HR than other exercises (*P* <0.01) while the HR response during the dynamic semi-squat exercise was significantly higher than that during other exercises (*P* <0.01) (Figure 7.4C).

To determine the exercise intensity during different WBV conditions, the age-predicted maximal HR (HR_{max}) formula was used to estimate of the individual's HR_{max} [220 – age]; for participants on beta-blockers (n=11), the formula was modified to 70% [208 - (0.7× age)].[33] Results of this study showed that, of the 288 exercise trials for each WBV protocol, only 23%, 29%, and 25% achieved the age-predicted HR_{max} at 64% (i.e., moderate intensity) or above for the no-WBV, low-intensity WBV, and high-intensity WBV conditions respectively.

7.4.6 Association with baseline values

Baseline SBP (r=-0.57, P<0.001), DBP (r=-0.42, P=0.01) and RPP (r=-0.50, *P*<0.001) were significantly correlated with their corresponding within-session change scores for the high-intensity protocol. The baseline SBP (r=-0.43, *P*=0.01) and RPP (r=-0.39, *P*=0.01) were also correlated with their respective change scores for the low-intensity protocol.

Out of 18 different WBV intensity and exercise combinations (3 protocols × 6 exercises), baseline VO_2 was only significantly correlated with the change score during SSq (r =-0.43, P=0.01) and SWS exercises (r=-0.33, P=0.02) when receiving low-intensity WBV. No significant correlations were identified with the HR data.

7.5 DISCUSSION

This is the first study to examine the cardiovascular response to WBV in individuals with chronic stroke. The principal finding of this study was that addition of high- and low-intensity WBV significantly increased the VO_2 and HR, but the increase was modest.

7.5.1 Is WBV exercise training safe for individuals with stroke?

WBV is gaining popularity in stroke rehabilitation for enhancing neuromuscular function.[22,23] Studying the cardiovascular stress imposed by WBV during exercises can provide important information for rehabilitation practitioners to establish exercise intensity and safety. Our results showed that WBV induced only modest increase in DBP (<5mmHg) and SBP (<8mmHg) (Table 7.2). The upper bound of the 95%CI for these variables did not even exceed 8mmHg and 12mmHg respectively. This was much lower than the increase in BP after walking on a treadmill at a self-selected speed for 20 minutes previously reported in people with stroke (mean increase in SBP: 46.7 mmHg, DBP: 21.0mmHg). Our results thus generally agree with previous studies in young and older adults that WBV did not induce major changes in BP (Hazell et al., 2008; Cochrane et al., 2009).

RPP is an estimate of myocardial oxygen consumption and gives an indication of the amount of oxygen demanded by the heart (Eng et al., 2002). While the RPP was significantly increased at the end of each exercise session, the WBV intensity × time interaction effect were not significant, indicating that the myocardial oxygen demand during different exercises was similar regardless of whether WBV was added.

Rimmer et al. (2000) reported that if the RPP is higher than 200, the patient is not suited to exercise. In the current study, the mean post-exercise RPP for the low- and high-intensity

WBV sessions was 107 and 104 respectively, compared with 105 for the no-WBV session. We also recorded the RPE to monitor exercise intensity during different WBV conditions (Sage et al., 2013). Even when low- and high-intensity WBV was added, the median RPE values were below 12 for all exercise conditions (Figure 7.4A). Overall, the level of myocardial exertion (RPP) and RPE during WBV exercises did not exceed their corresponding values during the Six Minute Walk Test (RPP: mean=144, SD=33; RPE: mean=11.6, SD=3.2) in people with chronic stroke previously reported by Eng et al. (2002) With the exception of one participant who withdrew from the study due to fatigue after WBV exercise, no other adverse signs and symptoms were reported, and none of the participants requested to terminate the exercise sessions, suggesting that the WBV protocols used in the current study were safe and well tolerated.

It was found that higher baseline BP and RPP values had fair to moderate relationships (r=-0.4 -0.6) with *smaller* increase in the same variables after the WBV exercise sessions. WBV exercise thus did not pose disproportionally higher cardiovascular stress to those with higher baseline resting BP and RPP (the higher-risk group).

7.5.2 Do WBV exercises have potential to provide a positive cardiovascular training effect?

Another question pertains to whether WBV exercises have any potential in inducing a positive cardiovascular training effect. We found that WBV induced a significant but modest increase in VO_2 (by 0.7-0.8 ml/kg/min, upper bound of 95%CI=1.2ml/kg/min) and HR (by 4 bpm, upper bound of 95%CI=7 bpm), likely because of the increased exercise intensity resulting from the WBV-induced increase in skeletal muscle activity (Liao et al., 2014a). Our results thus concurred with previous studies, which also reported that the increase in VO_2 and HR during

WBV exercise was modest in younger adults (Rittweger et al., 2000, 2001; Hazell et al., 2012), and older adults (Cochrance et al., 2008; Bogaerts et al., 2009).

The WBV intensity × exercise interaction effect for VO_2 was not significant, since the WBV-induced increase in VO_2 was quite consistent across all exercises tested, regardless of whether the exercise was static or dynamic (Figure 7.4B). On the other hand, the intensity and exercise interaction effect was significant for the HR response, indicating that the WBV-induced increase in HR at various intensities was dependent upon the exercise. Adding WBV led to significant increase in HR during static standing and dynamic semi-squat but not other exercises (Figure 7.4C), thereby contributing to the interaction effect. The discordance between the results on VO_2 and HR may indicate that increase in VO_2 could not be solely explained by increase in HR. Possible mechanisms may include increase in stroke volume, muscle blood flow velocity and volume, increased utilization of oxygen by exercising muscles (Lythgo et al., 2009), and will require further investigation.

The exercise intensities of most WBV trials were generally low (<64% HRmax), and were similar to those reported during standing, stepping, basic walking and advanced walking activities in a typical physical therapy session for people with stroke (below 60%HRmax or 40% HR reserve) (Kuys et al., 2006), which were considered to be ineffective in inducing a cardiovascular training effect (Pang et al., 2013a; Kuys et al., 2006; MacKay-Lyons & Makrides, 2002; Macko et al., 2005). The training intensities, even after addition of WBV, were much lower than those reported in aerobic exercise training using a treadmill (Macko et al., 2005; Globas et al., 2012), cycle ergometer (Potempa et al., 1995; Lee et al., 2008; Lennon et al., 2008), or a combination of strengthening and aerobic activities, which often involved a training intensity of 60-80% HR reserve (Pang et al., 2005d. 2013a; Duncan et al., 2003; Mead et al., 2007). The training intensities achieved during WBV exercises were also considerably lower than that during the Six Minute Walk Test among people with chronic stroke, which could reach 80%- 85% of the VO_{2peak} (Salbach et al., 2014). Our finding is thus in accord with Cochrane et al. (2008), who found that the estimated percentage VO_{2peak} achieved during static squat exercise with WBV was only at 24%, and would not be sufficient to enhance aerobic capacity. However, it is acknowledged that using the age to predict the maximal HR may not be ideal. In fact, it has been reported that the maximal HR achieved during a symptom-limited exercise test is significantly lower than the age-predicted maximal HR in people with stroke (Tang et al., 2006).

Interestingly, Bogaerts et al. (2009) showed that their 1-year WBV training protocol had significantly improved the peak VO_2 in older adults (by 18.2%), which was comparable to that following a conventional aerobic fitness exercise program (21.0%). However, the intensity of their WBV protocol was much higher (frequency: 35-40 Hz, amplitude: high 5mm/low 2.5mm), which may partially explain why they were able to raise the HR to about 62%-80% of HRR (moderate to high aerobic exercise intensity). We did not choose a higher WBV intensity as our pilot study revealed an increased incidence of discomfort with higher WBV frequencies. Furthermore, use of WBV with high peak accelerations warrants caution for patients with stroke as they often have fragile bones (Pang et al., 2008, 2012). The fact that we did not use WBV of higher intensities may also partially explain the lack of difference in VO_2 and HR between the low-intensity and high-intensity WBV protocols (Table 7.2).

Based on the resting HR data, the cardiovascular health of 27% of our participants could be considered poor, as Bohm et al. (2012) showed that people with stroke who had a resting HR of ≥77 bpm had a significantly higher risk of vascular death compared to those with resting HR in the lowest quintile (≤64 bpm). However, we did not identify any relationship between baseline

HR and the change scores in any of the exercise trials. Of the very few significant correlations between baseline VO_2 and change in VO_2, the relationship was only fair ($r<0.5$). Taken together, the HR and VO_2 responses to our exercise protocols, with or without WBV, were generally similar regardless of the cardiovascular health status of the participants.

7.5.3 Limitations and future directions

Firstly, since all of our participants are ambulatory and community dwelling, the results are only generalizable to people with similar characteristics as our participants. Secondly, we studied the effects of the overall intensity of WBV (indicated by peak acceleration) on cardiovascular parameters. Other variables (e.g. WBV frequency, amplitude) may exert independent cardiovascular effects. We also did not measure BP before and after each individual exercise. Thirdly, only a rhythm of 20 repetitions per minute was used during the dynamic exercises. While higher movement frequencies may elicit more impressive VO_2 and HR changes, it may not be feasible for people with stroke to sustain such rhythms for prolonged periods. In addition, a substantial proportion of patients were taking long-term medications including beta-blockers for various reasons, which may attenuate the cardiovascular response to exercise. However, we feel that our sample is a good representation of the general chronic stroke population, in which administration of long-term medications is very common. Determining the cardiovascular responses during WBV exercise is important, regardless of whether the individual was on medications. A symptom-limited exercise test was not conducted, the individual's actual HR_{max} and VO_{2peak}, and thus appropriate target exercise HR (or VO_2), was not determined. Finally, the study was not designed to assess the long term effects of WBV. Whether the WBV protocols used in this study can induce long–term changes in cardiovascular fitness among people with stroke will require further investigation.

7.5.4 Conclusions

This study suggested that in individuals with chronic stroke, VO2 and HR increased modestly with addition of either low- or high-intensity WBV. The impact of WBV on BP and myocardial oxygen demand was not significant, suggesting that WBV imposes no threats to cardiovascular function for people with stroke.

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Chapter EIGHT

Different Whole-Body Vibration Intensities in Stroke: Randomized Controlled Trial

Liao Lin Rong

8.1 ABSTRACT

Purpose: A single-blinded randomized controlled study was conducted to investigate the effects of different whole-body vibration (WBV) intensities on body functions/structures, activity and participation in individuals with stroke.

Methods: Eighty four people with chronic stroke (mean age: 61.2 years, SD: 9.2) who had mild to moderate motor impairment (Chedoke McMaster Stroke Assessment lower limb motor score: median=9 out of 14, interquartile range=7-11.8) were randomly assigned to the low-intensity WBV, high-intensity WBV, or control groups. The former two groups performed various leg exercises while receiving low-intensity and high-intensity WBV respectively. The controls performed the same exercises without WBV. All individuals received 30 training sessions over an average period of 75.5 days (SD=5.2). Outcome measurements included knee muscle strength (isokinetic dynamometry), spasticity at the knee and ankle joints (Modified Ashworth Scale), balance (Mini Balance Evaluation Systems Test, Mini-BESTest), mobility (Timed-Up-and-Go test, TUG), walking endurance (6-Minute Walk Test, 6MWT), balance self-efficacy (Activities-specific Balance Confidence scale, ABC), participation in daily activities (Frenchay Activity Index), perceived environmental barriers to societal participation (Craig Hospital Inventory of Environmental Factors), and quality of life (Short-Form 12 Health Survey, SF-12). The assessments were performed at baseline and post-intervention.

Results: Intention-to-treat analysis revealed a significant time effect for muscle strength, TUG, distance and oxygen consumption rate achieved during 6MWT, Mini-BESTest, ABC, and SF-12 physical composite score domain ($P<0.05$). However, the time by group interactions effects were not significant for any of the outcome measures ($P>0.05$).

Conclusion: The addition of the 30-session WBV paradigm to the leg exercise protocol was no more effective in enhancing body functions/structures, activity and participation than leg exercises alone in people with stroke who sustained mild to moderate motor impairments.

Key Words: cerebrovascular accident; rehabilitation; exercise; hemiparesis

8.2 INTRODUCTION

Stroke is one of the most common leading causes of long-term disability and is a major public health issue (Fuentes B, et al., 2014). One of the major physical impairment experienced by individuals with stroke is muscle weakness, particularly in the paretic limbs (Flansbjer et al., 2006; Kluding P et al., 2009; Saunders DH et al., 2014). It is well documented that isometric and dynamic muscle strength are correlated to other important functions, such as walking endurance (Flansbjer et al., 2006; Kluding P et al., 2009), walking velocity (Flansbjer et al., 2006; Kluding P et al., 2009), and balance skills (Kluding P et al., 2009; Moriello C, et al., 2011). The limitations in these functional activities may lead to poor community reintegration (Chau JPC et al., 2009), triggering a vicious cycle of further deterioration of physical functioning, and reduced societal participation (DH et al., 2014). It is thus important to tackle the problems arising from muscle weakness and associated functional problems in stroke rehabilitation.

Whole-body vibration (WBV) therapy, in which vibratory signals are delivered to the human body through a vibration platform, has gained increasing attention in neurorehabilitation. A number of research studies have examined the efficacy of WBV in people with stroke, with some studies reporting positive results on neuromuscular function (Merkert J et al., 2011; Tankisheva E et al., 2014; Tihanyi J et al., 2010), while others showing negative findings (Brogårdh C et al., 2012; Machado A et al., 2010; Lau RWK et al., 2012; van Nes IJ et al., 2006). For example, out of six studies that measured leg muscle strength (Brogårdh C et al., 2012; Machado A et al., 2010; Lau RWK et al., 2012; Tankisheva E et al., 2014; Tihanyi J et al., 2010; van Nes IJ et al., 2006), only two studies reported beneficial effects induced by WBV (Tankisheva E et al., 2014; Tihanyi J et al., 2010). Five studies assessed balance (Brogårdh C et al., 2012; Machado A et al., 2010; Lau RWK et al., 2012; Merkert J et al., 2011; Tankisheva E et al., 2014; van Nes IJ et al., 2006), and only one of these reported positive results (Tankisheva E et al., 2014). A recent meta-analysis of eight stroke WBV trials also revealed that the effects of WBV on muscle strength, and mobility performance remain inconclusive (Yang X et al., 2015). Another recent systematic review of nine stroke WBV clinical trials also generated a similar conclusion (Liao LR et al., 2014a). The limited number of studies and their methodological weaknesses (only two of the trials provided level 1 evidence) could partially account for the inconclusive results (Liao LR et al., 2014a). Thus, more larger and good-quality clinical trials are warranted to study the efficacy of WBV among people with stroke.

One of the major knowledge gaps identified in these reviews is that it remains uncertain which WBV intensities are more effective in improving various health outcomes post-stroke (Liao LR et al., 2014a; Yang X et al., 2015). Another key issue identified is the relative lack of activity and participation outcomes in previous stroke WBV trials (Liao LR et al., 2014a). As mentioned, the health consequences of stroke are multi-dimensional. This factor should be taken into consideration when selecting outcome measures. Therefore, the framework of this study was constructed based on the International Classification of Functioning, Disability and Heath (ICF) model (WHO. 2001) by incorporating outcomes at the body functions/structures (e.g., muscle strength, spasticity,), activity (e.g., mobility, walking endurance, balance) and participation levels (e.g., participation in community activities). According to this model, there is dynamic interaction between body structures/functions, activity and participation, meaning that impairments in body structures/functions may influence activity and participation outcomes. Therefore, by addressing the impairments (e.g., muscle weakness) through the proposed intervention, it was postulated that activity and participation may also improve. Inclusion of outcome measures in body structures/functions, activity and participation domains would provide a more comprehensive picture of the therapeutic value of the experimental intervention.

The objective of this RCT was to investigate the effects of different WBV intensities on body functions/structures, activity and participation in community-dwelling individuals with chronic stroke. As previous WBV studies in the healthy adult (Pollock RD et al., 2010) and stroke populations (Liao LR et al., 2014b; Liao LR et al., 2015) have shown that the level of WBV-induced muscle activity, as measured by surface electromyography (EMG), was positively associated with WBV intensity, it was hypothesized that 1) adding WBV to exercise training would lead to significantly greater improvements in body functions/structures, activity and participation outcomes compared with the same exercise training without WBV; and 2) the high-intensity protocol would induce significantly more gain in the same outcomes compared with the low-intensity protocol.

8.3 METHODS

8.3.1 Design

The present investigation was a single-blinded randomized controlled trial (RCT), in which the assessor was blinded. The study was registered at ClinicalTrials.gov (NCT01822704).The reporting of this WBV clinical trial is in accordance with the recommendations of the International Society of Musculoskeletal and Neuronal Interactions (Rauch F et al., 2010).

8.3.2 Participants and sample size

The study was conducted at a research laboratory at the Hong Kong Polytechnic University. The inclusion criteria were: diagnosis of hemispheric stroke with onset more than 6 months at the time of enrolment, age ≥ 18 years, community-dwelling, a score of 6 or above on the Abbreviated Mental Test (AMT) (Antonelli Incalzi R et al., 2003), and the ability to stand with or without aid for more than 90 seconds. Patients were excluded if any of the following conditions were present: brainstem or cerebellar stroke; other neurological disorders (e.g., spinal cord injury), neoplasms, severe cardiovascular diseases (e.g., a pacemaker, uncontrolled hypertension), pain that affected the ability to participate in physical activities, pregnancy, vestibular conditions, recent fractures or metal implants in the lower limbs, or other serious medical problems.

The sample size was estimated based on evidence from previous WBV studies that investigated the leg extensor EMG activity during WBV in individuals with stroke (Liao LR et al., 2014b), using G Power 3.1 software (Universitat Dusseldorf, Germany). Liao et al. (2014b) demonstrated that WBV training induced significantly higher levels of muscle activity in the paretic leg, with effect sizes (f) of 0.46-0.93 (i.e., large effect sizes). To be more conservative, a medium effect size was assumed (convention: f=0.25). Based on a 2 × 3 analysis of variance (ANOVA) model with repeated measures, with an alpha value of 1% and power of 80%, the minimum sample size required to detect a significant group by time interaction effect would be 21 subjects in each group (total of 63 participants). We used a more stringent alpha value because of the inflated probability of making a type I errors due to multiple testing. To account for a 15% attrition rate, we aimed to recruit a minimum of 75 participants (25 subjects per group). Written informed consent was obtained from all subjects. The principles of the Declaration of Helsinki were followed, and the study was approved by the Human Research Ethics Review Subcommittee of the Hong Kong Polytechnic University.

8.3.3 Recruitment and randomization

The recruitment of participants took place from February 2013 to February 2014 in the Hong Kong Stroke Association. Those who expressed interest in participating in the study were initially screened through telephone interviews, followed by a face-to-face assessment session. After the eligibility was confirmed, the participants were then randomized into the low-intensity WBV group (LWBV), high-intensity WBV group (HWBV), or control group (CON) using a 1:1:1 allocation ratio (Figure 8.1). To ensure concealed allocation, the subjects were randomly assigned to the groups using sealed opaque envelopes distributed by an ‘off-site’ researcher who was not involved in the recruitment of participants, provision of exercise training, or measurement of outcomes. The last participant completed the post-intervention assessment on May 20, 2014.

8.3.4 Interventions

All participants were given WBV exercise training 3 times a week for a total of 30 sessions. A minimum one-day rest period was scheduled between training sessions. Extra sessions for missed appointments were arranged to ensure that all participants completed all 30 sessions. All exercise training took place in the same research laboratory of the Hong Kong Polytechnic University. The exercise sessions for the 3 groups took place at different times of the day, so that the participants from one treatment group could not observe what the other groups were engaging in. Each exercise session began with 10 minutes of warm-up exercises and ended with 10 minutes of cool-down exercises (general stretching exercises in a sitting position and exercise using a cycle ergometer).

Participants in the LWBV group (n = 28) and HWBV group (n = 28) received their exercise training on a WBV platform that delivered synchronous WBV (Gymna Fitvibe Medical System, Gymna Uniphy Pasweg, Bilzen, Belgium). The choice of WBV and exercise protocols (Table 1) was adapted from a previous study that examined muscle activity during WBV exposure among individuals with stroke (Liao LR et al., 2014b). In that study, WBV intensities similar to our LWBV protocol induced significantly higher leg muscle activity compared with the control condition (Liao LR et al., 2014b). The highest level of leg muscle activity was attained during deep-squat, semi-squat, forward and backward weight-shift exercises (Liao LR et al., 2014b). Therefore, these exercises were chosen in this study to optimize the activation of major leg muscle groups in our participants (Table 1). The erect standing posture with knee extension was avoided to minimize the transmission to WBV to the head (Pollock RD et al., 2010). In addition to dynamic exercises, static exercises were also included in the training protocol, because daily activities involve both static (isometric) and dynamic muscle work. Indeed, similar to dynamic muscle strength (Flansbjer UB et al., 2006; Moriello C et al., 2011), isometric leg muscle strength was strongly correlated with other important functions post-stroke, including walking endurance, walking velocity, and balance ability (Kluding P et al., 2009). Moreover, previous WBV trials in older adults and individuals with stroke provided no clear evidence that using a combination of static/dynamic exercises (Machado A et al., 2010; Merkert J et al., 2011) was inferior to dynamic exercises (Lau RWK et al., 2012; Tihanyi J et al., 2010) or static exercises alone (Brogårdh C et al., 2012; Furness TP et al, 2009; Tankisheva E et al., 2014; van Nes IJ et al., 2006).

The dynamic exercises (Exercises 1-3 in Table 1) were performed in cycles of 3 seconds with 20 repetitions per minute. A metronome was used to pace the participants in performing the exercises at the desired rhythm. A rhythm of 20 repetitions per minute was selected based on our pilot study, which demonstrated that most individuals were able to perform the exercises at this pace for 1.5 minutes without experiencing excessive fatigue, while finding it sufficiently challenging. For the static exercise (Exercise 4 in Table 1), the participants were asked to sustain the semi-squat position for 1.5 minutes in each repetition. The training protocol was a progressive design with a gradual increase in the duration of exercise (from 12 to 18 minutes per session) over the course of the treatment period as tolerated. We increased the exercise duration as a means of progressing the intervention, as reduced exercise endurance is often a problem post-stroke (Saunders DH et al., 2014). The exercises were progressed only if tolerated by the participants. The rate of perceived exertion (RPE) was also monitored (Borg G. 1970). If the participant reported a RPE >15, the exercise would be terminated and a longer rest period was given before proceeding to the next exercise. If the participant reported any excessive fatigue or muscle soreness or pain from the previous training session, the exercise duration would not be progressed for that session. The WBV settings were validated by a tri-axial accelerometer (Model 7523A5; Dytran Instruments Inc., Chatsworth, CA), as recommended by the International Society of Musculoskeletal and Neuronal Interactions (Rauch F et al., 2010). The frequency of the WBV signals used was 20 Hz and 30 Hz. Frequencies higher than 30 Hz and amplitudes higher than 1 mm were not used in this study, due to the very high peak acceleration values generated (Kiiski J et al., 2008). Signal distortion is more severe with high-amplitude vibration signals (Kiiski J et al., 2008). WBV frequencies below 20 Hz were not used because they may induce a considerable resonance effect, resulting in amplification of the vibration signals and possible adverse effects (Kiiski J et al., 2008). Our pilot work also showed that the high-intensity protocol demanded substantial exercise effort from the stroke participants without causing excessive fatigue.

The CON group completed the same movements while standing on the same WBV platform, but no WBV was delivered (i.e., WBV device was turned off). The treatment sessions for all three groups were supervised by a researcher (researcher: participant ratio = 1:2). The participants performed the same exercises while standing on the WBV platform (Table 8.1). The training instructions and exercise progression pattern were the same for all three groups. The participants were asked to report to the research team if there was any change in medications during the study period.

Table 8.1 Parameters of WBV and exercise protocols

Group	Frequency (Hz)	Amplitude (mm)	Peak Acceleration (g)	Duration per exercise (min)	Repetitions	Total exercise duration (min)
LWBV	20	1	1.61	1.5	2 (sessions 1-15) 3 (sessions 16-30)	12 (sessions 1-15) 18 (sessions 16-30)
HWBV	30	1	3.62			
CON	0	0	0			

Exercise protocol	Starting position	Movement
1. Dynamic weight shift side to side	Stand on the WBV platform with feet placed width apart at shoulder width, with bilateral knees flexed at 10°	A metronome was used to guide the subjects in performing the exercise at a rhythm of 20 repetitions per minute (i.e., 3 seconds per cycle). Shift body weight as much as possible onto the paretic side, then shift onto the non-paretic side
2. Dynamic deep-squat	Same as exercise 1	Follow the same rhythm as exercise 1 to flex the bilateral knees to 70° and return to the starting position
3. Dynamic forward and backward weight shift	Same as exercise 1	Follow the same rhythm as exercise 1 to shift body weight forward as much as possible with ankle in plantarflexion. Then, shift body weight backward as far as possible with ankle in dorsiflexion
4. Static semi-squat	Same as exercise 1	Flex the both knees to 30° and hold for 1.5 min and return to the starting position

CON=control; HWBV=high-intensity whole-body vibration; LWBV=low-intensity whole-body vibration.

8.3.5 Outcome measures

Outcome measurements were performed between February 2013 and May 2014. Demographics and other relevant information (i.e., medications, medical history) were collected at the baseline assessment. The level of impairment of the leg and foot was evaluated using the Impairment Inventory of the Chedoke McMaster Stroke Assessment (Gowland C et al., 1993). The rating for each body part was based on a seven-point ordinal scale, with higher scores indicating better motor recovery. The ratings for the leg and foot were summed to yield an overall CMSA motor score for the paretic lower limb. The Functional Ambulation Category (score range: 0-5; 0=non-ambulatory, 5: independent) was used to indicate walking ability (Holden MK et al., 1984). The following outcomes were measured at baseline (within one week before the commencement of the exercise training), and post-intervention (within one week after the completion of the 30 treatment sessions) by the same blinded assessor.

8.3.5.1 Primary outcome

8.3.5.1.1 Muscle strength

The knee extension and flexion muscle strength of both the paretic and the non-paretic leg were measured by a dynamometer (NUMAC® NORMTM Testing & Rehabilitation System, Computer Sports Medicine, Inc., Stoughton, MA). Isometric, isokinetic concentric and eccentric muscle strength were tested. After a practice trial, each participant performed a maximal voluntary isometric contraction of knee flexion and extension at two knee joint angles, 30° and 70° of knee flexion, respectively. The peak torque value (in Nm) was registered. Isokinetic knee concentric and eccentric flexion/extension contractions through a range of movement between 70° and 10° of knee flexion at a fixed angular velocity of 60°/s were also measured. An angular speed of 60°/s was chosen, as it has been commonly used in previous stroke studies (Brogårdh C et al., 2012; Lau RWK et al., 2012; Pang MYC et al., 2013; Tankisheva E et al., 2014). A good proportion of people with stroke could not perform at higher angular velocities due to factors such as severe spasticity, which was also noticed in our pilot testing. The peak power value (Watts, W) was recorded. For all test conditions, three trials were performed with a 2-minute rest period between trials. The data were then averaged and normalized by the participant's body weight to yield the mean isometric strength (Nm/kg), and concentric and eccentric strength (W/kg) of knee flexion and extension in each leg. Muscle strength measurements using isokinetic dynamometry have been shown to be highly reliable in individuals with chronic stroke (Brogårdh C et al., 2012; Lau RWK et al., 2012; Pang MYC et al., 2013).

8.3.5.2 Secondary outcomes

8.3.5.2.1 *Spasticity*

Spasticity in the knee extensors and ankle plantarflexors was assessed using the 6-point Modified Ashworth scale (MAS) (0 = no spasticity, 4 = affected part rigid). The MAS is a widely used tool to evaluate muscle tone in stroke research and has acceptable reliability (Kendall's tau correlation = 0.847) (Pandyan AD et al., 1999).

8.3.5.2.2 Balance

The 14-item Mini Balance Evaluation Systems Test (Mini-BESTest) was used to evaluate participant's balance performance in everyday functional activities (Tsang CSL et al., 2013). The total score on this test ranges from 0 to 28, with higher scores indicating better balance ability. The Mini-BESTest has good psychometric properties when used in individuals with stroke, with excellent internal consistency (Cronbach's alpha = 0.89-0.94), intra-rater reliability (intraclass correlation coefficient (ICC) = 0.97), and inter-rater reliability (ICC = 0.96) (Tsang CSL et al., 2013).

8.3.5.2.3 Balance self-efficacy

Balance self-efficacy was evaluated using the Activities-specific Balance Confidence (ABC) scale (Botner EM et al., 2005). The participants were instructed to rate their level of confidence in performing each activity without losing their balance using a numerical rating scale from 0 to100, with higher scores denoting better balance confidence. The scores for each item were summed and then averaged to obtain the total ABC score. The ABC scale has been demonstrated to be a reliable and valid tool for evaluating balance self-efficacy in individuals with stroke (Botner EM et al., 2005).

8.3.5.2.4 Walking endurance

The 6-Minute Walk Test (6MWT) was administered while oxygen consumption (VO_2) was continuously recorded using the FitMate™ metabolic system (Cosmed, Rome, Italy). At the beginning of each testing session, the system was calibrated according to the manufacturer's guidelines. The total distance covered (in meters) and the mean VO_2 rate (ml/kg/min) during the last 30 seconds of the 6MWT (a measure that is moderately associated with peak VO_2 in stroke) were used for subsequent analysis (Eng JJ et al., 2004). Both the VO_2 measured during the 6MWT and the distance covered have shown high test-retest reliability in individuals with stroke (ICC >0.95) (Eng JJ et al., 2004).

8.3.5.2.5 Functional mobility

Functional mobility was measured with the Timed-Up-and-Go (TUG) test (Podsiadlo D et al., 1991). Each participant was asked stand up from a chair, walk forward for 3 meters, turn around and walk back to the chair and sit down, as quickly as possible. The TUG test was carried out twice, with an interspersed 1-minute rest period. The time taken to perform the test was averaged to obtain the mean value (in seconds).

8.3.5.2.6 Participation in daily activities

The Frenchay Activity Index (FAI) was used as a measure of participation (Holbrook M et al., 1983). The FAI records the frequency of participating in social activities and performing more complex activities of daily living (e.g., domestic chores, outdoor mobility, leisure). Each of the 15 items was rated on a scale from 0 to 3, yielding a total score of 15 to 60 (15-29: inactive or restricted participation; 30-44: active; 45-60: highly active) (Holbrook M et al., 1983). The construct validity and reliability of the FAI have been established (ICC= 0.87) (Holbrook M et al., 1983).

8.3.5.2.7 Perceived environmental barriers to societal participation

The participants also rated their perception of environmental barriers to societal participation using the 25-item Craig Hospital Inventory of Environmental Factors (CHIEF) (Liao LR et al., 2012). The score for each of the 25 items was calculated by multiplying the magnitude score (small problem, 1; big problem, 2) by the frequency score (range: daily, 4; never, 0) to yield a product or overall “impact” score. Items relating to work or school, when the respondent was neither working nor in school, were considered “not applicable” and were not scored. The total CHIEF score is the mean of up to 25 overall impact scores. Liao et al. (2012) demonstrated that CHIEF is a reliable and valid tool for evaluating the perceived environmental barriers to societal participation among individuals with chronic stroke.

8.3.5.2.8 Quality of life

Quality of life (QOL) was assessed using the Short-Form 12 Health Survey, version 2 (SF-12, Chinese version) (Lam CL et al., 2005). A mental health composite score (MCS) and a physical composite score (PCS) was generated (range: 0-100), with higher scores denoting better health-related QOL.

8.3.6 Test-retest reliability of the SF-12, ABC, FAI, and isometric contraction at 30° of knee flexion

Among the various outcomes used in this study, the test-retest reliability of the SF-12 subscales (PCS and MCS) and total score, ABC total score, FAI total score, and isometric knee flexion and extension strength testing at 30° of knee flexion in the paretic and non-paretic legs of individuals with stroke had not been established by previous research. Therefore, additional experiments were carried out to examine the test-retest reliability of the above outcome measures. Thirty-seven of the participants in the clinical trial were involved in the reliability experiments. The isometric muscle strength testing was repeated by the same assessor about 1 hour after the initial evaluation. For the SF-12, ABC and FAI, the re-assessment was done within 1-2 weeks after the initial evaluation, to minimize the potential effect of memorizing the answers.

8.3.7 Statistical analysis

All statistical analyses were performed using IBM SPSS software (version 20.0, IBM, Armonk, NY, USA). A more stringent significance level at $P < 0.01$ was set due to the many outcomes involved. Descriptive statistics (e.g., mean and standard deviation) were used to indicate the central tendencies and variability of the data. One-way analysis of variance (ANOVA) (for continuous variables), Chi-square tests (for nominal variables), and Kruskal-Wallis tests (for ordinal variables) were used to compare the baseline characteristics of the three groups. Intention-to-treat analysis was performed. For those who dropped out from the study, the results of the baseline assessment were carried over to the subsequent assessments using the last observation carried forward (LOCF) method (Portney LG et al., 2009). One key assumption of LOCF is that patients who do not receive treatment maintain status quo (Portney LG et al., 2009). However, in reality, many intervention programs are designed to prevent deterioration of patients who are expected to get worse without intervention. Therefore, the LOCF method, by assuming that the past had continued unchanged, may result in over-estimating the treatment effect or under-estimating the harmful effects. However, we had decided to use LOCF, because our participants were in the chronic stage of stroke and were all ambulatory, and thus should not experience major deterioration in leg muscle strength and other health outcomes without the WBV intervention during the study period (about 75 days on average). Previous chronic stroke WBV trials also did not report substantial deterioration in health outcomes in the control group (Brogårdh C et al. 2009; Lau RWK et al, 2012). Therefore, we felt that LOCF is a reasonable imputation method given the context of this study.

The Kolmogorov-Smirnov test was used to check the normality of the data. Analysis of variance (ANOVA) (mixed design; between-subject factor: group; within-subject factor: time) was used to compare the outcome variables across the two time points (i.e. baseline and post-intervention). Contrast analysis was performed within each group post-hoc when appropriate. As the MAS was an ordinal variable, between-group comparisons of the post-intervention scores were made using the Kruskal-Wallis test (which generated H statistic that was tested using the Chi-square distribution), followed by post-hoc Mann-Whitney tests as indicated. The above analyses based on the intention-to-treat (ITT) principle were repeated after excluding the drop-outs (i.e., on-protocol analysis). Among the various outcome variables, only 6MWT and Mini-BESTest had well established minimal clinically important difference (MCID) values, at 34.4 meters (Tang A et al., 2012) and 4 points (Godi M et al., 2013) respectively. The proportion of individuals who achieved an improvement of 6MWT ≥34.4m or Mini-BESTest ≥4 points were compared across groups using the Chi-square test.

Secondary analysis was done to identify the factors that may be related to better treatment outcomes after WBV training. The change scores (post-intervention score minus the pre-intervention score) of the LWBV and HWBV groups for each outcome were correlated with the corresponding baseline scores, and relevant characteristics of the participants (e.g. age, time taken to finish the 30 sessions of exercise training, baseline outcome measure scores, etc.) using either Spearman’s rho or Pearson’s correlation, depending on whether the assumptions for parametric analysis were fulfilled.

8.4 RESULTS

8.4.1 Subjects

One hundred and thirteen individuals with stroke were screened for eligibility, and 84 of them fulfilled the exclusion and inclusion criteria (see the CONSORT flow diagram in Figure

8.1). Using a 1:1:1 assignment ratio, 28 participants were randomly allocated to each of the LWBV (8 women), HWBV (10 women) and CON (4 women) groups, respectively. One participant from the HWBV group dropped out after the initial (baseline) assessment due to other engagements, and another nine participants (five from the LWBV group, three from the HWBV group, and one from the CON group) dropped out during the period of the study, yielding an attrition rate of 11.9%. A total of 74 participants completed the training programs and post-intervention assessment. A CONSORT flow diagram of this study is presented in Figure 8.1.

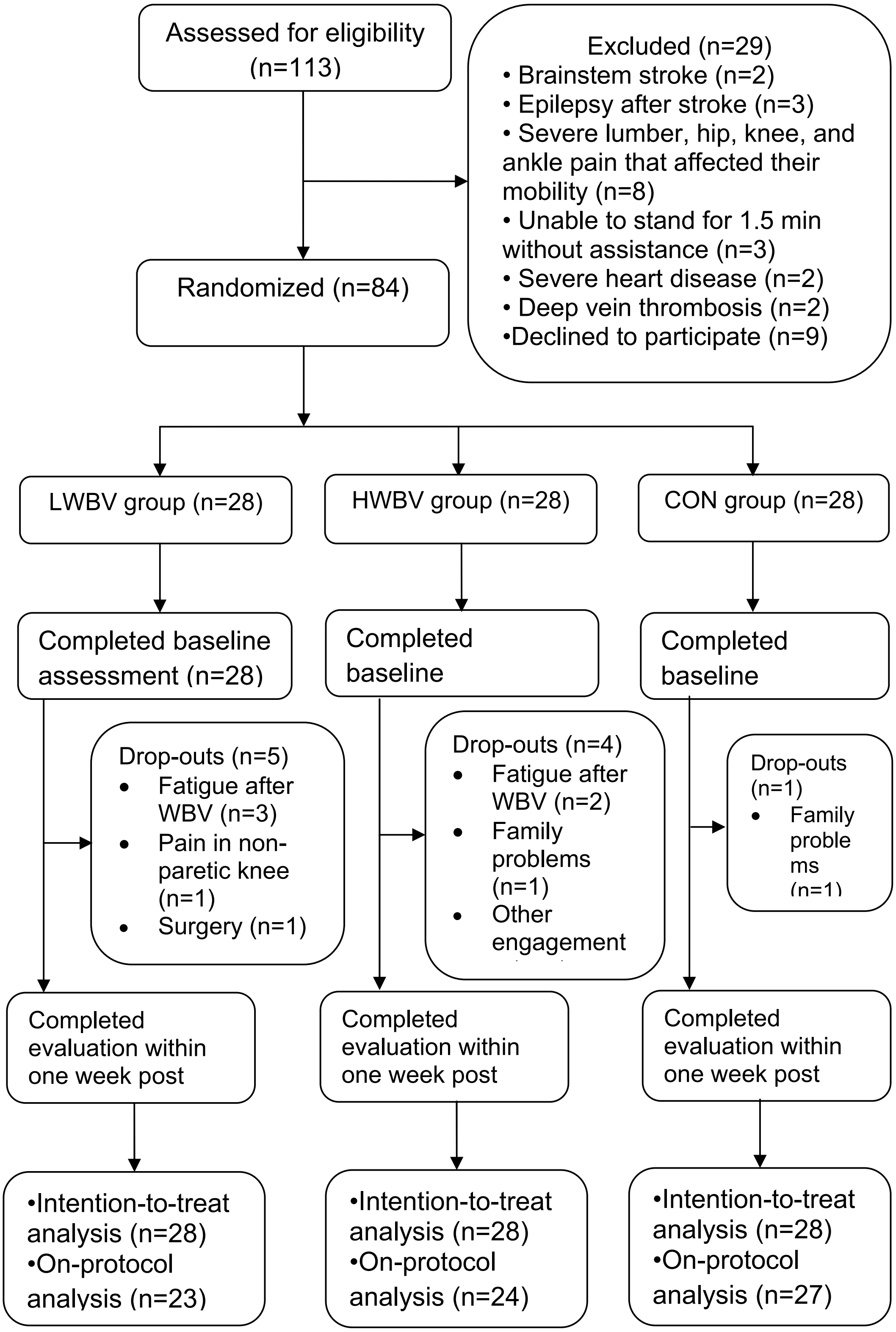


Figure 8.1 CONSORT Flow Chat

8.4.2 Demographic data

The demographic information is summarized in Table 8.2. All of the participants were ambulatory; 75 of them did not require any walking aid indoors. The CMSA motor score for the paretic lower limb (median=9 out of 14, interquartile range=7-11.8) revealed that the motor impairment level was mild to moderate. There was no significant between-group difference in any of the demographic (Table 8.2) or outcome variables at baseline ($P > 0.05$) (Table 8.3 & 8.4). The on-protocol analysis after removal of dropouts yielded similar results (see Appendix: Supplemental Digital Content 1, which shows the on-protocol analysis). None of the participants reported any changes in medications throughout the study period.

Table 8.2 Intention-to-treat analysis: Characteristics of participants

	All subjects (n=84)	LWBV (n=28)	HWBV (n=28)	CON (n=28)	*P* [a]
Basic demographics					
Age (year) [b]	61.2±9.2	60.8±8.3	62.9±10.2	59.8±9.1	0.457
Sex (men/women)	62/22	20/8	18/10	24/4	0.178
Body mass index ($kg\cdot m^{-2}$)	24.5±4.4	24.1±5.8	24.7±3.2	25.1±3.8	0.630
Stroke characteristics					
Post-stroke duration (year)	8.5±4.6	8.5±5.2	8.1±4.2	9.0±4.6	0.456
Type of stroke, hemorrhagic/ischemic, n	35/49	12/16	12/16	11/17	0.952
Hemiparetic side (right/left)	51/33	20/8	19/9	12/16	0.058
Abbreviated Mental Test score (0-10)	9.3±1.3	9.3±1	9.3±1.1	9.3±1.7	0.303
CMSA lower limb score (2-14) [c]	9(7-11.75)	8(7-11.75)	8(7-11.75)	9(7-11)	0.165
CMSA leg score (1-7)	5(4-6)	5(4-6)	4(4-6)	4.5(4-6)	0.198
CMSA foot score (1-7)	4(3-6)	4(3-5.75)	4(3-5.75)	4(3-5)	0.224
Paretic knee Modified Ashworth Scale of spasticity score (0–4)[b]					
0/1/1.5/2/3/4 (n)	24/28/23/9/0/0	7/10/6/5/0/0	7/9/9/3/0/0	10/9/8/1/0/0	0.456
Median (IQR)	1(0-2)	1(0-2)	1(0-2)	1(0-2)	
Paretic ankle Modified Ashworth Scale of spasticity score (0–4)					
0/1/1.5/2/3/4 (n)	7/10/35/24/7/1	3/4/17/4/0/0	1/3/10/11/2/1	3/3/8/9/5/0	0.254
Median (IQR)	2(2-2)	2(1-3)	1.75(0-4)	1.75(0-3)	
Mobility status					
Functional Ambulation Category (0-5)	5(4-5)	5(4-5)	5(4-5)	5(4-5)	0.794
Walking aids indoors (none/cane/quad/frame/rollators/wheelchair) (n)	75/6/3/0/0/0	26/2/0/0/0/0	23/2/3/0/0/0	26/2/0/0/0/0	0.340
Walking aids outdoors (none/cane/quad/frame/rollators/wheelchair) (n)	31/38/3/6/0/6	10/15/1/0/0/2	9/11/1/5/0/2	12/12/1/1/0/2	0.569
Ankle-foot-orthosis used (no/yes)(n)	80/4	27/1	26/2	27/1	0.403
Participants with at least one fall in the past 12 months (n)	30	8	10	12	0.537
Co-morbid conditions					
Total number of medical conditions	1.8±1.0	1.6±0.9	2.0±1.1	1.9±1.0	0.736
Hypertension, (n)	16	5	6	5	0.926
High cholesterol, (n)	50	16	17	17	0.952
Medications					
Total number of medications	4.3±1.8	4.0±1.6	4.4±1.9	4.6±1.9	0.584
Antihypertensive agents (n)	31	7	14	10	0.151
Hypolipidemic agents (n)	50	16	17	17	0.952

Antidiabetic agents (n)	14	5	5	4	0.918
Muscle relaxants (n)	6	3	1	2	0.584

[a] P values for between-group comparisons.

[b] Mean ± SD presented for continuous variables.

[c] Median (interquartile range) for ordinal variables.

CMSA = Chedoke–McMaster stroke assessment; CON = control group; HWBV=high-intensity WBV; IQR=interquartile range; LWBV=low-intensity WBV; n=number count.

Table 8.3 Intention-to-treat analysis: primary outcomes (muscle strength)

	CON (n=28) †			LWBV (n=28) †			HWBV(n=28) †			Compar-ison at baseline	Group × Time Interact-ion Effect	Time Effect
	Pre	Post	Mean change (95% CI)	Pre	Post	Mean change (95% CI)	Pre	Post	Mean change (95% CI)	*P*	*P*	*P*
Paretic side												
Isometric extension at 70° (Nm/kg)	1.41±0.58	1.48±0.59	0.07 (-0.05, 0.19)	1.33±0.38	1.42±0.44	0.09 (-0.05, 0.22)	1.31±0.52	1.49±0.55	0.19 (0.08, 0.29)	0.099	0.326	0.001*
Isometric flexion at 70° (Nm/kg)	0.42±0.25	0.47±0.26	0.05 (-0.01, 0.08)	0.29±0.21	0.35±0.21	0.05 (0.03, 0.08)	0.37±0.21	0.45±0.25	0.08 (0.03, 0.14)	0.710	0.438	<0.001*
Isometric extension at 30° (Nm/kg)	0.85±0.37	0.86±0.39	0.02 (-0.11, 0.15)	0.84±0.27	0.83±0.29	-0.01 (-0.09, 0.12)	0.85±0.35	0.86±0.37	0.01 (-0.12, 0.14)	0.997	0.931	0.881
Isometric flexion at 30° (Nm/kg)	0.62±0.32	0.63±0.35	0.01 (-0.06, 0.08)	0.52±0.20	0.56±0.24	0.04 (-0.03, 0.11)	0.61±0.26	0.63±0.29	0.19 (-0.09, 0.13)	0.272	0.890	0.359
Concentric extension (Watts/kg)	0.63±0.39	0.66±0.32	0.03 (-0.04, 0.10)	0.55±0.28	0.61±0.27	0.06 (-0.01, 0.13)	0.62±0.38	0.59±0.24	-0.03 (-0.19, 0.13)	0.622	0.482	0.517
Concentric flexion (Watts/kg)	0.19±0.19	0.27±0.24	0.08 (-0.03, -0.13)	0.18±0.19	0.20±0.19	0.02 (-0.02, 0.06)	0.21±0.19	0.24±0.18	0.03 (-0.04, 0.09)	0.856	0.258	0.006*
Eccentric extension (Watts/kg)	1.34±0.61	1.50±0.65	0.16 (-0.04, 0.35)	1.36±0.38	1.38±0.44	0.02 (-0.11, 0.15)	1.35±0.61	1.40±0.59	0.05 (-0.20, 0.30)	0.992	0.575	0.169
Eccentric flexion (Watts/kg)	0.80±0.44	0.81±0.33	0.01 (-0.11, 0.13)	0.69±0.28	0.76±0.28	0.08 (-0.03, 0.19)	0.71±0.43	0.76±0.37	0.05 (-0.08, 0.17)	0.531	0.720	0.166
Non-paretic side												
Isometric extension at 70° (Nm/kg)	1.98±0.58	2.07±0.54	0.09 (-0.07, 0.24)	1.68±0.50	1.77±0.48	0.09 (-0.05, 0.23)	1.74±0.60	1.85±0.54	0.11 (-0.05, 0.26)	0.221	0.982	0.026
Isometric flexion at 70° (Nm/kg)	0.76±0.23	0.78±0.24	0.02 (-0.02, 0.07)	0.66±0.18	0.66±0.18	-0.01 (-0.05, 0.04)	0.70±0.22	0.75±0.25	0.05 (-0.01, 0.12)	0.110	0.433	0.068
Isometric extension at 30° (Nm/kg)	1.15±0.29	1.19±0.37	0.04 (-0.09, 0.17)	1.06±2.45	1.08±0.25	0.02 (-0.06, 0.10)	1.11±0.37	1.12±0.35	0.02 (-0.11, 0.15)	0.150	0.941	0.442
Isometric flexion at 30° (Nm/kg)	0.97±0.33	0.97±0.38	0.00 (-0.09, 0.10)	0.84±0.24	0.85±0.24	0.01 (-0.06, 0.09)	0.85±0.27	0.91±0.33	0.06 (-0.05, 0.16)	0.506	0.669	0.354
Concentric extension (Watts/kg)	0.96±0.42	1.11±0.31	0.14 (-0.03, 0.31)	0.93±0.32	0.96±0.35	0.03 (-0.08, 0.14)	0.99±0.37	0.97±0.38	-0.02 (-0.11, 0.08)	0.982	0.184	0.164
Concentric flexion (Watts/kg)	0.53±0.29	0.63±0.23	0.10 (-0.00, 0.20)	0.53±0.17	0.56±0.21	0.04 (-0.04, 0.11)	0.54±0.19	0.59±0.21	0.05 (-0.04, 0.13)	0.844	0.526	0.017
Eccentric extension (Watts/kg)	1.61±0.78	1.84±0.54	0.23 (-0.10, 0.56)	1.65±0.16	1.59±0.54	-0.06 (-0.24, 0.13)	1.77±0.53	1.80±0.69	0.03 (-0.16, 0.22)	0.588	0.229	0.329
Eccentric flexion (Watts/kg)	1.03±0.51	1.11±0.31	0.07 (-0.12, 0.26)	0.93±0.31	0.98±0.32	0.05 (-0.03, 0.13)	1.00±0.40	1.03±0.43	0.02 (-0.09, 0.14)	0.614	0.874	0.196

* P < 0.01.
† Mean ± SD presented for continuous variables.
CON = control group; HWBV=high-intensity whole-body vibration; LWBV=low-intensity whole-body vibration

Table 8.4 On-protocol analysis: characteristics of participants

	All subjects (n=74)	**LWBV (n=23)**	**HWBV (n=24)**	**CON (n=27)**	***P*** [b]	**Drop out subjects (n=10)**	***P*** [c]
Basic demographics							
Age (year) [a]	60.2±9.1	59.7±8.2	61.5±10	59.6±9.2	0.701	67.9±7.2	0.302
Sex (men/women)	57/17	18/5	16/8	23/4	0.288	5/5	0.048
Body mass index ($kg\cdot m^{-2}$)	24.5±4.6	23.9±6.4	24.4±3.1	25.2±3.8	0.592	24.0±2.7	0.224
Stroke characteristics							
Poststroke duration (year)	8.1±4.4	7.2±4.5	8.2±4.2	8.85±4.6	0.256	11.5±5.2	0.981
Type of stroke, hemorrhagic/ischemic, n	30/44	8/15	11/13	11/16	0.742	5/5	0.549
Hemiparetic side (right/left)	46/28	17/6	17/7	12/15	0.057	5/5	0.436
Abbreviated Mental Test score (0-10)	9.3±1.4	9.3±1	9.2±1.2	9.3±1.8	0.264	9.5±0.5	0.206
CMSA lower limb score (2-14) [d]	9(7-12)	8(7-12)	10(8-12)	9(7-11)	0.401	9(7-10.5)	0.732
CMSA leg score (1-7)	5(4-6)	4(4-6)	5(4-6)	4(4-6)	0.611	4.5(4-6)	0.982
CMSA foot score (1-7)	4(3-6)	4(4-6)	5(4-6)	4(3-5)	0.685	4(3-5.25)	0.651
Paretic knee Modified Ashworth Scale of spasticity score (0–4) [d]							
0/1/1.5/2/3/4 (n)	21/24/29/0/0/0	6/7/10/0/0/0	8/8/8/0/0/0	7/9/11/0/0/0	0.953	3/4/3/0/0/0	0.681
Median (IQR)	1(0-2)	1(0-2)	1(0-2)	1(0-2)		1(0-2)	
Paretic ankle Modified Ashworth Scale of spasticity score (0–4)							
0/1/1.5/2/3/4 (n)	3/8/51/11/1/0	1/2/17/2/1/0	2/3/14/5/0/0	0/3/20/4/1/0	0.613	1/1/8/0/0/0	0.234
Median (IQR)	2(2-2)	2(2-2)	2(2-2)	2(2-2)		2(1.75-2)	
Mobility status							
Functional Ambulation Category (0-5)	4.5(4-5)	5(4-5)	4(4-5)	5(4-5)	0.239	5(4-5)	0.617
Walking aids indoors (none/cane/quad/frame/rollators/wheelchair) (n)	67/5/2/0/0/0	22/1/0/0/0/0	20/2/2/0/0/0	25/2/0/0/0/0	0.321	8/2/0/0/0/0	0.022
Walking aids outdoors (none/cane/quad/frame/rollators/wheelchair) (n)	28/34/2/5/0/5	9/13/0/0/0/1	8/9/1/4/0/2	11/12/1/1/0/2	0.456	3/4/2/0/0/1	0.425
Ankle-foot-orthosis used (no/yes)(n)	72/2	23/0	23/1	26/1	0.427	8/2	0.005
Participants with at least one fall in the past 12 month (n)	26	6	8	12	0.389	4	0.607
Co-morbid conditions							
Total number of medical conditions	1.9±1.0	1.7±0.9	2±1.1	1.9±1.0	0.919	1.5±1.1	0.668
Hypertension, (n)	13	3	5	5	0.626	3	0.115
High cholesterol, (n)	47	15	16	16	0.954	1	0.460
Medications							

Total number of medications	4.4±1.7	4±1.1	4.5±1.8	4.6±2.0	0.533	3.6±2.4	0.340
Antihypertensive agents (n)	28	6	12	10	0.238	3	0.250
Hypolipidemic agents (n)	46	15	15	16	0.916	6	0.948
Antidiabetic agents (n)	13	4	5	4	0.238	1	0.195
Muscle relaxants (n)	5	3	0	2	0.202	1	0.405
Compliance							
Time taken to complete 30 training sessions, (days)	75.5±5.2	74.9±4.8	74.5±4.9	76.9±5.7	0.729		
Maximum time lapse between training sessions, (days)	7.1±2.0	7.1±2.0	7.2±2.2	7.0±1.9	0.474		

[a] Mean ± SD presented for continuous variables.

[b] P values for between-group comparisons.

[c] P values for comparisons between those who completed all follow-up assessments (n=74) and dropouts (n=10)

[d] Median (interquartile range) for ordinal variables.

CMSA = Chedoke–McMaster stroke assessment; CON = control group; HWBV=high-intensity WBV; IQR=interquartile range; LWBV=low-intensity WBV; n=number count.

8.4.3 Test-retest reliability of the SF-12, ABC, FAI, and knee isometric muscle strength at 30° of knee flexion

The ABC, FAI, and knee isometric muscle strength at 30° of knee flexion revealed good to excellent test-retest reliability, with $ICC_{2,1}$ values ranging from 0.904-0.957 (Table 8.5). The SF-12, however, showed moderate reliability ($ICC_{2,1} = 0.662$-0.736). The level of agreement for all scores between the two sessions was above that expected by chance ($p < 0.001$).

Table 8.5 Test-retest reliability of SF-12, ABC, FAI, and isometric muscle strength at 30° of knee flexion (n=37)

	Time 1 Mean (SD)	Time 2 Mean (SD)	$ICC_{2,1}$	p-value
SF-12	92.7 (10.8)	94.5 (12.0)	0.662	<0.001**
PCS	41.4 (6.8)	42.4 (6.7)	0.631	<0.001**
MCS	51.4 (11.0)	52.2 (10.8)	0.736	<0.001**
ABC	80.4 (14.5)	80.6 (14.3)	0.904	<0.001**
FAI	23.0 (7.3)	22.7 (6.7)	0.957	<0.001**
Isometric contraction at 30 ° of paretic leg				
Knee flexion	39.0 (17.9)	39.6 (18.8)	0.951	<0.001**
Knee extension	58.9 (24.5)	62.1 (24.9)	0.952	<0.001**
Isometric contraction at 30 ° of non-paretic leg				
Knee flexion	61.2 (22.9)	62.5 (20.8)	0.916	<0.001**
Knee extension	76.7 (26.7)	79.4 (27.7)	0.925	<0.001**

[a] Mean ± SD presented for continuous variables.

[b] ICC: intraclass correlation coefficient

ABC= Activities-specific Balance Confidence scale; FAI= Franchay Activity Index; MCS = mental health composite score; PCS= physical composite score; SF-12= Short-Form 12 Health Survey.

**p<0.01

8.4.4 Training duration

Among those who completed all of the post-intervention assessments, the mean number of days taken to complete the 30 sessions of exercise training showed no significant difference among the three groups (P=0.729) (Table 8.2). The maximum time interval (mean number of days) between two training sessions was also similar among the three groups (P=0.474)(Table 8.2).

8.4.5 Adverse events

One participant from the LWBV group reported mild knee pain after WBV therapy and five reported fatigue (three from the LWBV and two from the HWBV groups) (Figure 8.1). These participants eventually dropped out of the study. The rest of the participants were able to increase their duration of exercise as described in our protocol (Table 8.1).

8.4.6 Outcome measures

8.4.6.1 ITT analysis

In the ITT analysis, there was a significant time effect for several muscle strength measures on the paretic side (i.e., isometric flexion and extension at 70°, and concentric flexion) ($P < 0.01$; Table 3), TUG, 6MWT distance, VO_2 during 6MWT, Mini-BESTest, ABC, and the PCS domain of the SF-12 ($P <0.01$; Table 4). However, none of the variables showed significant time × group interaction effect ($P >0.01$). Kruskal-Wallis test revealed no significant difference in the knee MAS ($\chi^2 = 0.230$; $P = 0.891$) or ankle MAS scores ($\chi^2 = 0.642$; $P = 0.725$) post-intervention among the three groups. A total of 12, 11 and 12 individuals showed an improvement of 6MWT ≥34.4m (MCID value) in the CON, LWBV and HWBV groups respectively, after the intervention period. Eighteen, 20, and 18 participants had an increase in Mini-BESTest score ≥4 points (MCID value) post-training in the CON, LWBV and HWBV groups respectively. No significant between-group difference was found in the proportion of subjects who achieved an improvement in 6MWT ($\chi^2 = 0.098$; P = 0.952) and Mini-BESTest ($\chi^2 = 0.446$; P = 0.800) that was at or beyond the respective MCID values. The above analyses were also performed after removal of the dropouts (i.e., on-protocol analysis), and similar results were found (see Appendix: Supplemental Digital Content 1, which shows the on-protocol analysis).

Table 8.6 Intention-to-treat analysis: Secondary outcomes

	CON (n=28) †			LWBV (n=28) †			HWBV (n=28) †			Between -group comparison at baseline	Group × Time Interaction Effect	Time Effect
	Pre	**Post**	**Mean change (95%CI)**	**Pre**	**Post**	**Mean change (95%CI)**	**Pre**	**Post**	**Mean change (95%CI)**	**p**	**P**	**P**
Body functions & structures												
Knee spasticity Median (IQR)	1(0.3-2)	1(0-2)		1(0.3-2)	1(0-1)		1(0-2)	1(0-2)		0.854	0.981‡	
Ankle spasticity Median (IQR)	2(2-2)	2(1-2)		2(2-2)	2(1-2)		2(2-2)	2(1-2)		0.604	0.725‡	
VO_2 during 6MWT (ml/kg/min)	10.2±2.3	11.1±2.4	-0.9 (-1.6,-0.2)	10.6±2.9	11.5±2.8	-1.0 (-1.5,-0.4)	11.6±3.3	11.7±3.1	-0.1 (-1.0,0.7)	0.186	0.197	0.002*
Activity												
TUG (Second)	22.4±24.0	18.3±23.3	4.1 (2.5, 5.7)	20.2±14.8	16.6±17.0	3.6 (1.3, 5.9)	17.9±9.0	14.0±17.2	3.8 (2.1, 5.6)	0.617	0.920	<0.001*
6MWT distance (Meter)	209.4±75.0	248.7±92.6	-39.3 (-56.8,-21.8)	203.6±82.4	253.6±90.7	-50.0 (-80.0,-20.1)	209.6±75.6	246.3±79.5	-30.6 (-46.7,-14.5)	0.839	0.446	<0.001*
Mini-BESTest	13.3±4.1	19.4±4.7	-6.1 (-7.5, -4.6)	13.0±4.4	18.0±5.3	-4.9 (-6.2,-3.7)	13.6±4.7	18.6±4.6	-5.0 (-6.6, -3.3)	0.872	0.440	<0.001*
Participation												
ABC	73.2±18.8	80.6±15.3	-7.4 (-11.2,-3.6)	76.8±14.6	81.6±16.8	-4.9 (-8.3,-1.4)	69.6±15.9	73.1±17.0	-3.5 (-7.7,0.8)	0.276	0.323	<0.001*
FAI	21.9±7.4	23.5±6.2	-1.6 (-3.4,0.2)	23.4±7.2	23.3±7.4	0.2 (-1.4,1.7)	23.9±6.2	24.1±6.4	-0.3 (-2.1,1.5)	0.526	0.296	0.239
CHIEF-C	0.6±0.5	0.6±0.4	0.03 (-0.08,0.1)	0.7±0.6	0.7±0.5	0.1 (-0.1, 0.2)	0.7±0.6	0.6±0.5	0.1 (-0.1, 0.2)	0.718	0.895	0.106
SF-12	87.3±13.2	90.7±12.4	-3.4 (-0.3,-6.5)	101.2±74.1	92.1±10.9	9.1 (-20.1, 38.3)	86.1±13.2	92.5±13.2	-6.4 (-11.2, -1.6)	0.368	0.386	0.964
PCS	38.0±7.4	41.7±8.0	-3.7 (-6.1,-1.3)	39.6±8.6	42.4±6.2	-2.8 (-5.8,0.2)	36.3±7.9	40.1±9.4	-3.8 (-7.1,-0.5)	0.303	0.865	<0.001*
MCS	49.3±11.7	48.9±10.7	0.3 (-3.2, 3.7)	61.6±74.5	49.6±10.4	12.0 (-17.3, 41.3)	49.9±13.7	52.4±9.6	-2.5 (-8.0,3.0)	0.503	0.440	0.507

* $P < 0.05$.

† Mean ± SD presented for continuous variables.

‡ p-value for comparison of MAS post-intervention score (Kruskall-Wallis test).

6MWT= Six Minute Walk Test; ABC= activities specific balance confidence scale; CHIEF-C= Chinese version of the Craig Hospital Inventory of Environmental Factors; CMSA = Chedoke–McMaster Stroke Assessment; CON = control group; FAI= Franchay Activity Index; HWBV=high-intensity WBV; IQR=interquartile range; LWBV=low-intensity WBV; MCS = mental health composite score; Mini-BESTest= Mini Balance Evaluation Systems Test; n=number count; PCS= physical composite score; SF-12= Short-Form 12 Health Survey; TUG= Timed-Up-and-Go test; VO_2= oxygen consumption rate.

8.4.6.2 On-protocol analysis

The foregoing statistical analyses were repeated after excluding the data for the dropouts. No significant differences were observed in the demographic data or stroke-specific characteristics at baseline (Table 8.4). The results of the on-protocol analyses were similar to those derived from the ITT analysis reported above. MANOVA revealed significant main effects of time for the muscle strength of the paretic leg (i.e. knee isometric flexion and extension at 70°, and concentric flexion) and non-paretic leg (i.e. knee isometric extension at 70°, concentric flexion) ($P < 0.05$; Table 8.7). Significant main effects of time were also detected for the TUG, 6MWT, VO_2 during the 6MWT, Mini-BESTest, ABC, and the PCS domain of the SF-12 ($P < 0.05$; Table 8). No significant time × group interaction ($P > 0.05$) effect was found for any of the outcome measures (Tables 8.7 and 8.8). No significant difference was identified in the knee MAS post-intervention scores ($\chi^2 = 0.853$; $P = 0.653$) or ankle MAS post-intervention scores ($\chi^2 = 1.019$; $P = 0.601$) between the three groups post-intervention.

Table 8.7 On-protocol analysis (primary outcomes): muscle strength

	CON (n=27)[b]			LWBV (n=23)[b]			HWBV (n=24)[b]			Comparison at baseline	Group × Time Interaction Effect		Time Effect	
	Pre	Post	Mean change (95%CI)	P	Post	Mean change (95%CI)	Pre	Post	Mean change (95%CI)	*P*	Effect Size[a]	*P*	Effect Size	*P*
Paretic side[c]														
Isometric extension at 70° (Nm/kg)	1.40± 0.59	1.48± 0.60	0.07 (-0.05, 0.20)	1.40± 0.38	1.51± 0.43	0.11 (-0.06, 0.27)	1.34± 0.54	1.56± 0.55	0.22 (0.10, 0.33)	0.898	0.271	0.001*	1.40± 0.59	1.48± 0.60
Isometric flexion at 70° (Nm/kg)	0.42± 0.25	0.47± 0.26	0.05 (0.01, 0.09)	0.31± 0.21	0.37± 0.20	0.07 (0.03, 0.10)	0.38± 0.22	0.48± 0.26	-0.10 (-0.16,-0.03)	0.200	0.323	<0.001*	0.42± 0.25	0.47± 0.26
Isometric extension at 30° (Nm/kg)	0.83± 0.37	0.85± 0.39	0.02 (-0.12, 0.16)	0.89± 0.28	0.87± 0.30	-0.02 (-0.15, 0.12)	0.86± 0.36	0.87± 0.39	0.01 (-0.14, 0.17)	0.839	0.933	0.898	0.83± 0.37	0.85± 0.39
Isometric flexion at 30° (Nm/kg)	0.62± 0.32	0.63± 0.36	0.01 (-0.06, 0.09)	0.53± 0.22	0.57± 0.26	0.05 (-0.04,0.14)	0.64± 0.26	0.66± 0.30	0.02 (-0.11, 0.15)	0.333	0.863	0.344	0.62± 0.32	0.63± 0.36
Concentric extension (Watts/kg)	0.62± 0.40	0.65± 0.32	0.03 (-0.04,0.10)	0.57± 0.30	0.65± 0.28	0.08 (-0.11,0.16)	0.61± 0.40	0.58± 0.25	-0.03 (-0.23, 0.15)	0.885	0.464	0.510	0.62± 0.40	0.65± 0.32
Concentric flexion (Watts/kg)	0.19± 0.19	0.27± 0.24	0.08 (0.03, 0.13)	0.20± 0.20	0.22± 0.20	0.02 (-0.02,0.07)	0.22± 0.20	0.25± 0.18	0.03 (-0.04, 0.11)	0.837	0.358	0.008*	0.19± 0.19	0.27± 0.24
Eccentric extension (Watts/kg)	1.35± 0.62	1.52± 0.66	0.16 (-0.04, 0.36)	1.39± 0.41	1.42± 0.47	0.03 (-0.04,0.10)	1.36± 0.66	1.42± 0.64	0.06 (-0.23,0.35)	0.968	0.643	0.150	1.35± 0.62	1.52± 0.66
Eccentric flexion (Watts/kg)	0.81± 0.44	0.82± 0.33	-0.01 (-0.14,0.11)	0.73± 0.29	0.82± 0.27	0.10 (-0.04, 0.23)	0.72± 0.47	0.77± 0.40	0.06 (-0.09,0.22)	0.668	0.669	0.191	0.81± 0.44	0.82± 0.33
Non-paretic side[c]														
Isometric extension at 70° (Nm/kg)	1.98± 0.59	2.07± 0.55	-0.09 (-0.25,0.07)	1.75± 0.48	1.86±0.43	-0.11 (-0.29, 0.06)	1.79± 0.57	1.92± 0.48	0.12 (-0.06, 0.31)	0.290	0.025*	0.025*	1.98± 0.59	2.07± 0.55
Isometric	0.75±	0.77±	0.02	0.69±	0.70±0.	0.01	0.72±	0.78±	0.06	0.570	0.069	0.069	0.75±	0.77± 0.25

flexion at 70° (Nm/kg)	0.23	0.25	(-0.02,0.07)	0.18	17	(-0.05, 0.06)	0.20	0.24	(-0.01, 0.14)				0.23	
Isometric extension at 30° (Nm/kg)	1.14± 0.28	1.18±0.37	0.04 (-0.09, 0.18)	1.09± 2.25	1.12±0.26	0.02 (-0.08, 0.12)	1.14± 0.36	1.16± 0.34	0.02 (-0.13, 0.17)	0.824	0.455	0.455	1.14± 0.28	1.18±0.37
Isometric flexion at 30° (Nm/kg)	0.96± 0.33	0.96± 0.38	0.00 (-0.10,0.10)	0.86± 0.25	0.88±0.26	0.02 (-0.08, 0.11)	0.88± 0.25	0.95± 0.31	0.07 (-0.06, 0.19)	0.416	0.340	0.340	0.96± 0.33	0.96± 0.38
Concentric extension (Watts/kg)	0.96± 0.43	1.11± 0.32	0.15 (-0.03,0.32)	0.96± 0.33	0.10±0.36	0.04 (-0.10, 0.17)	1.03± 0.34	1.00± 0.36	-0.02 (-0.13, 0.09)	0.798	0.197	0.197	0.96± 0.43	1.11± 0.32
Concentric flexion (Watts/kg)	0.53± 0.29	0.63± 0.24	0.10 (0.00, 0.21)	0.53± 0.17	0.57±0.21	0.04 (-0.06, 0.14)	0.56± 0.18	0.61± 0.20	0.06 (-0.05, 0.16)	0.851	0.021*	0.021*	0.53± 0.29	0.63± 0.24
Eccentric extension (Watts/kg)	1.62± 0.79	1.85± 0.55	0.24 (-0.10, 0.58)	1.72± 0.44	1.66±0.55	-0.07 (-0.29, 0.16)	1.77± 0.51	1.80± 0.70	0.03 (-0.19, 0.26)	0.656	0.389	0.389	1.62± 0.79	1.85± 0.55
Eccentric flexion (Watts/kg)	1.04± 0.52	1.12± 0.31	0.08 (-0.12, 0.27)	0.95± 0.32	1.01±0.31	0.06 (-0.34, 0.16)	1.02± 0.40	1.05± 0.43	0.03 (-0.10, 0.16)	0.730	0.204	0.204	1.04± 0.52	1.12± 0.31

[a] Effect sizes are η_P^2.

[b] Mean ± SD presented for continuous variables.

[c] Isometric strength in Nm/kg, and concentric and eccentric strength in W/kg.

* P < 0.05.

Table 8.8 On-protocol analysis: secondary outcomes

	CON (n=27)[a]			LWBV (n=23)[a]			HWBV (n=24)[a]			Compar-ison at baseline	Group × Time Inter-action Effect	Time Effect
	Pre	Post	Mean change (95%CI)	Pre	Post	Mean change (95%CI)	Pre	Post	Mean change (95%CI)	P	P	P
Body functions & structures												
Knee spasticity Median (IQR)	1 (0.3-2)	1 (0-2)		1 (0.3-2)	1 (0-1)		1 (0-2)	1 (0-2)		0.589	0.653‡	
Ankle spasticity Median (IQR)	2 (2-2)	2 (1-2)		2 (2-2)	2 (1-2)		2 (2-2)	2 (1-2)		0.479	0.601‡	
VO_2 during 6MWT (ml/kg/min)	10.1±2.2	11.0±2.4	0.9	10.4±2.9	11.6±2.9	1.2	11.7±3.2	11.8±2.9	0.2	0.128	0.193	0.002*
			(0.19, 1.66)			(-0.5, 1.8)			(-0.9, 1.2)			
Activity												
TUG (Second)	22.5± 24.4	18.3±23.8	-4.3	19.8±15.9	15.4±18.2	-4.3	17.8±9.6	13.3±8.6	-4.5	0.640	0.990	<0.001*
			(-5.9, -2.6)			(-7.1,-1.6)			(-6.4, -2.5)			
6MWT distance (Meter)	209.5±76.5	250.2±94.0	40.7	210.1±80.1	271.0±81.6	60.9	219.0±75.1	254.8±81.8	35.7	0.889	0.299	<0.001*
			(22.8, 58.7)			(25.7, 96.2)			(17.6, 53.8)			
Mini-BESTest	13.3±4.1	19.6±4.7	6.3	13.6±4.2	19.6±3.8	6.0	14.0±4.7	19.8±3.5	5.8	0.845	<0.001*	<0.001*
			(4.9, 7.7)			(4.9, 7.1)			(4.1, 7.5)			
Participation												
ABC	72.6±18.9	80.3±15.5	7.7	77.8±14.4	83.7±16.5	5.9	72.0±14.6	76.0±15.5	4.0	0.412	<0.001*	<0.001*
			(3.8, 11.6)			(1.8, 10.0)			(-1.0, 9.0)			

FAI	21.9±7.5	23.6±6.3	1.7	22.6±6.7	22.4±7.0	-0.2	24.0±6.2	24.3±6.5	0.3	0.570	0.282	0.282
			(-0.2, 3.5)			(-2.1, 1.7)			(-1.8, 2.5)			
CHIEF-C	0.6±0.5	0.6±0.4	-0.04	0.7±0.6	0.7±0.5	-0.1	0.6±0.4	0.5±0.3	-0.1	0.732	0.100	0.100
			(-0.15, 0.08)			(-0.2,0.1)			(-0.2,0.1)			
SF-12	87.1±13.5	90.7±12.6	3.5	104.2±81.6	93.1±10.7	-11.1	87.6±13.3	95.0±12.2	7.4	0.361	0.993	0.993
			(0.3, 6.7)			(-47.1, 24.9)			(1.9, 12.9)			
PCS	37.9±7.5	41.7±8.1	3.8	40.2±9.3	43.6±6.0	3.4	36.7±8.1	41.1±9.5	4.4	0.345	<0.001*	<0.001*
			(1.3, 6.3)			(-0.2, 7.0)			(0.6, 8.3)			
MCS	49.2±11.9	48.9±10.9	-0.3	64.1±82.3	49.5±11.0	-14.6	51.0±14.4	53.9±9.3	2.9	0.493	0.475	0.475
			(-3.9, 3.3)			(-50.7, 21.5)			(-3.5, 9.3)			

[a] Mean ± SD presented for continuous variables.
[b] p-value for comparison of MAS post-intervention score.
6MWT= Six Minute Walk Test; ABC= activities specific balance confidence scale; CHIEF-C= Chinese version of the Craig Hospital Inventory of Environmental Factors; CMSA = Chedoke–McMaster stroke assessment; CON = control group; FAI= franchay activity index; HWBV=high-intensity WBV; IQR=interquartile range; LWBV=low-intensity WBV; MCS = mental health composite score; MiniBEST= Mini Balance Evaluation Systems Test; n=number count; PCS= physical composite score; SF-12= Short-Form 12 Health Survey; TUG= Timed-Up-and-Go test; VO2= oxygen consumption.
* P < 0.05.

8.4.6.3 Secondary analysis

In the secondary analysis, an attempted was made to determine whether there was any significant association between the change score of each outcome measure and their respective baseline values and other relevant factors (e.g., training duration).

8.4.6.3.1 LWBV group

A significant negative correlation was found between the baseline scores and change scores for knee flexion eccentric strength (r = -0.509, P = 0.006) in the paretic leg, indicating that the participants with poorer neuromuscular function tended to have greater improvement in this outcome.

8.4.6.3.2 HWBV group

There were significant negative correlations between the change scores and their respective baseline scores for concentric flexion (r = -0.510, P = 0.006) and extension strength (r = -0.832, P < 0.001), eccentric flexion (r = -0.554, P = 0.002) and extension strength (r = -0.554, P = 0.002) of the paretic knee, and isometric extension strength at 30° (r = -0.500, P = 0.007) and flexion concentric strength (r = -0.490, P = 0.008) of the non-paretic knee. Thus, the participants with poorer neuromuscular function tended to have greater improvements in these outcomes.

8.5 DISCUSSION

The key finding of this study was that the addition of the LWBV or HWBV protocols to the leg exercise protocol was no more effective in enhancing body functions/structures, activity and participation than leg exercises alone (i.e., the CON protocol).

8.5.1 Does WBV stimulation alone confer any additional benefits?

Both hypotheses of the present study were not supported. The findings of this study revealed that certain leg muscle strength variables showed significant time effects, indicating significant improvement after the training period. However, the group × time interaction effects were not significant, indicating that adding either LWBV or HWBV to the leg exercise protocol did not confer additional therapeutic effects on the strength outcomes.

There are contrasting results related to the efficacy of WBV training on muscle strength in individuals with stroke (Liao LR et al., 2014b). While a number of studies reported no significant effects (Brogårdh C et al., 2012; Lau RWK et al., 2012; Marín PJ et al. 2013; van Nes IJ et al., 2006), Tankisheva et al. (2014) and Tihanyi et al. (2010) found positive effects of WBV on muscle strength outcomes. Although there may be many reasons for the discrepancies in results between the current report and these two studies, one key issue may be related to the design of the control group. In the current study and previous research that reported no significant between-group differences in muscle strength outcomes after the intervention period (5,18,24,38), the control group performed exactly the same exercises as the WBV group. In contrast, Tankisheva et al. (2014) and Tihanyi et al. (2010) involved a comparison group that engaged in different activities. Specifically, Tankisheva et al. (2014) found a significantly greater increase in isometric and isokinetic knee extension torque (240°/s) in the paretic leg for the WBV group than the comparison group that engaged in habitual physical activities. It is thus possible that the better outcomes in the WBV group were related to the leg exercises performed while standing on the WBV device rather than the WBV stimulation. In Tihanyi et al. (2010), the WBV group (WBV plus conventional rehabilitation) experienced a significantly greater improvement in eccentric and isometric knee extension torque in both legs compared with the comparison group that received conventional rehabilitative treatment only. The better improvement in muscle strength reported in the WBV group could be attributable to the leg exercises and the longer total treatment time rather than the WBV stimulation. Considering the overall available evidence, no study has convincingly demonstrated any positive effect of WBV alone on muscle strength in individuals with stroke. A recent meta-analysis also revealed that WBV induced no significant effect on isometric and eccentric knee extension strength among individuals with stroke (Yang X et al., 2015). The results of this study thus further consolidate the current body of evidence in showing that WBV had no effect on leg muscle strength post-stroke.

An alternative explanation of the lack of significant effects on muscle strength is that the intensity of the WBV stimulation may not be high enough. Higher intensities were not used in this study, as the high peak accelerations generated may pose potential hazards, such as damage to fragile bones and back pain (Bovenzi M. 2009; Kiiski J et al., 2008). A previous RCT has shown that WBV at an intensity of 0.96-1.61g was not effective in improving muscle strength in people with chronic stroke (Lau RWK et al., 2012; Pang MYC et al., 2013). Adding WBV at an intensity of 1.61g has been shown to augment the EMG activity of major leg muscle groups during exercise by approximately 10-25% (Liao LR et al., 2014b; Liao LR et al., 2015). The intensity used here in the HWBV group (3.62g) was even higher and would presumably have induced greater muscle responses (Lau RWK et al., 2012; Liao LR et al., 2014b; Liao LR et al., 2015). However, a recent study on people with chronic stroke (Liao LR et al., 2015) showed that the relationship between WBV intensity and muscle activation level was non-linear. Increasing the WBV intensity from 0.96g to 1.61g only led to an additional 3-5% increase in leg muscle EMG amplitude. Thus, further increasing the WBV intensity beyond a certain point may no longer effectively increase EMG activity. Therefore, despite the use of higher WBV intensities in this study, it may not necessarily translate into substantially higher muscle activation level, compared with no WBV or lower WBV intensities.

Finally, the overall non-significant results may be related to the heterogeneity of the sample, and to the observation that WBV may be beneficial only for a highly select group of individuals. The secondary analysis indeed revealed that those with more severe deficits tended to gain more improvement from WBV training.

Significant time effects were also detected for body functions/structures (VO_2 rate), activity (TUG, 6MWT distance, Mini-BESTest), and participation levels (ABC, physical health domain of SF-12), indicating that all three groups experienced improvement in these outcomes after the training period. However, the lack of a group × time interaction effect on these outcomes indicated that the WBV stimulation itself did not confer any additional effects. As WBV did not pose any significant effect on the muscle strength and spasticity variables (body functions/structures), a significant treatment effect on the related outcomes at the activity and participation levels, which often have multiple determinants, would not be expected. Another possible explanation of the non-significant treatment effect on the mobility outcomes may be that the WBV therapy did not involve any walking-related activities.

Nevertheless, our results generally concurred with the available body of evidence. Only four studies have previously investigated the influence of WBV on mobility function post-stroke (Brogårdh C et al., 2012; Lau RWK et al., 2012; Merkert J et al., 2011; van Nes IJ et al., 2006), and only Merkert et al. (2011) reported better performance in the TUG test in the WBV group. However, their control group engaged in conventional rehabilitation whereas the WBV group received additional WBV training on top of conventional rehabilitation. Thus, their WBV group had more total treatment time than the control group. This factor, rather than WBV stimulation, may explain the better outcomes in the WBV group. Five studies assessed balance (Brogårdh C et al., 2012; Lau RWK et al., 2012; Merkert J et al., 2011; van Nes IJ et al., 2006), and only one of these reported positive results (Tankisheva E et al., 2014). Only one study investigated the effect of WBV therapy on social participation, using the Stroke Impact Scale, and found no significant effect compared with sham vibration (Brogårdh C et al., 2012). Taken together, the present results are generally in line with previous studies in showing that WBV does not induce improvement in activity and participation outcomes. A similar conclusion was also made in a recent meta-analysis by Yang et al. (Yang X et al., 2015).

8.5.2 Limitations

This study has several limitations. First, the findings should not be generalized to patients who are in the acute/subacute stage of recovery or who have severe motor impairments, because the participants in the present study were all in the chronic stage (onset more than 6 months) and had mild to moderate impairments post-stroke. Second, the participants and the trainer were not blinded to the group allocation, but it was difficult to achieve these in exercise trials. However, all efforts were made to minimize any possible bias (e.g., assessor blinding, separate exercise periods for the three groups, etc.). Third, no long-term follow-up assessment was performed. The potential long-term beneficial or harmful effects of WBV remain uncertain.

8.5.3 Future directions

Based on the results of the current study, and the body of evidence accumulated from previous trials (Liao LR et al., 2014a; Yang X et al., 2015), the clinical use of WBV in stroke rehabilitation could not be recommended at this point. Further research should be performed in this area. As revealed in our secondary analysis, WBV may benefit more for those who were more severely impaired. Future research should test the feasibility and efficacy of using WBV in a more homogeneous sample of people with more severe stroke-induced motor impairment. It would be interesting also to assess the effects of WBV in more acute stages of stroke recovery, when the impairment level was often more severe. We only compared the effects of different WBV intensities, further research is required to compare different WBV parameters (type of vibration stimulus, duration of WBV). For example, there is some preliminary evidence from a meta-analysis that vertical (synchronous) WBV is more beneficial than side-alternating WBV in improving mobility post-stroke (Yang X et al., 2015). Further studies are also needed to investigate some fundamental questions, such as the transmissibility of WBV signals, and how it varies with different WBV parameters and exercises performed. Finally, electrophysiological studies should be done to address the physiological mechanisms associated with applications of WBV post-stroke.

8.5.4. Conclusion

In summary, while WBV therapy is safe and feasible for individuals with chronic stroke, the addition of the WBV paradigm used here (LWBV and HWBV protocols) to the leg exercise protocol was no more effective in enhancing body functions/structures, activity and participation than leg exercise training alone in community-dwelling individuals with mild to moderate chronic stroke impairments.

ACKNOWLEDGMENT

This study was supported by the General Research Fund provided by the Research Grants Council (PolyU 5245/11E). The whole-body vibration device was provided by SOOST Limited. The results of the present study do not constitute endorsement by the American College of Sports Medicine. All authors declare no conflict of interest.

CHAPTER NINE

Summary and Conclusion

Liao Lin Rong

9.1 Chapter 2 entitled: Effects of Whole-body Vibration Therapy on Body Functions and Structures, Activity and Participation Post-stroke: A Systematic Review

No solid evidence was found to confirm the beneficial effects of WBV after a single treatment session or an intervention period of 3-12 weeks among people with stroke, compared with either no WBV under the same exercise condition, or other types of physical activities. This is partially due to the limited number of studies investigating the topic of WBV in stroke, lack of identification of the main impairment of the participants, poor methodological quality and heterogeneity of samples used. In summary, based on the evidence available in the literature, clinical use of WBV in stroke rehabilitation is not supported.

9.2 Chapter 3 entitled: Measuring the Environmental Barriers Faced by Individuals Living with Stroke: Development and Validation of the Chinese version of the Craig Hospital Inventory of Environmental Factors

In conclusion, the CHIEF-C is a reliable and valid tool for evaluating the environmental barriers experienced by people with chronic stroke. The CHIEF-C short form is a reasonable alternative if administering the long form is not feasible due to time constraints.

9.3 Chapter 4 entitled: Leg Muscle Activity during Whole-body Vibration in Individuals with Chronic Stroke

In conclusion, the present study suggested that leg muscle activity on both the paretic and non-paretic sides was increased significantly by adding the low-intensity and high-intensity WBV. The added WBV induced a similar increase in EMG activity in the paretic and non-paretic legs, except in weight-shifted-to-the-side and single-leg-standing exercises, where the VL muscle on the non-paretic leg was more responsive to the added WBV than that on the paretic VL side. A randomized controlled trial is warranted to determine whether these two protocols could induce any gain in muscle strength in stroke patients following long-term WBV exercise training, and whether the high-intensity protocol could lead to better muscle strength than the low-intensity one.

9.4 Chapter 5 entitled: Effect of Vibration Intensity, Exercise and Motor Impairment on Leg Muscle Activity Induced by Whole-Body Vibration in People with Stroke

A positive relationship between the EMG magnitude of the TA and BF in both legs using a WBV intensity of up to 1.61g during static exercises was found in people with stroke. The increase in EMG activity evoked by WBV was also influenced by the specific exercise performed. Therefore, the WBV intensity and the exercise chosen are important guiding factors in designing WBV exercise protocols for the stroke population. The EMG magnitude was the greatest during exposure to the high-intensity protocol. These results have thus provided a basis for future randomized controlled studies to test the efficacy of this protocol in modifying neuromuscular function after stroke.

9.5 Chapter 6 entitled: Effect of Whole-body Vibration on Neuromuscular Activation of Leg Muscles during Dynamic Exercises in Individuals with Stroke

This study found a positive relationship between the neuromuscular activation (EMGrms) of the bilateral VL, BF, TA and GS muscles and WBV intensity (up to 1.61g) during dynamic exercise performance in individuals with stroke. The increase in neuromuscular activation in the TA and GS muscles evoked by WBV was also influenced by the specific dynamic exercise performed. The BF and GS muscles on the paretic side tended to show a greater EMG response to WBV when compared with the non-paretic side. Overall, the WBV intensity and the type of dynamic exercise chosen are important guiding factors in designing WBV exercise protocols for the stroke population.

9.6 Chapter 7 entitled: Cardiovascular Stress Induced by Whole-Body Vibration Exercise in Individuals with Chronic Stroke

This study suggested that in individuals with chronic stroke, the VO_2 and HR increased modestly with addition of either low- or high-intensity WBV. The impact of WBV on BP and myocardial oxygen demand was not significant, suggesting that WBV imposes no threats to cardiovascular function for people with stroke.

9.7 Chapter 8 entitled: Different Whole-Body Vibration Intensities in Stroke: Randomized Controlled Trial

The addition of the 30-session WBV paradigm to the leg exercise protocol was no more effective in enhancing body functions/structures, activity and participation than leg exercises alone in people with stroke who sustained mild to moderate motor impairments.

APPENDICES

APPENDIX I Consent Form for Chapter 3

The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project entitled: **Determinants of Activity and Participation in Individuals with Stroke**

Investigators: **Dr. Marco Pang (Assistant Professor, Department of Rehabilitation Sciences, Hong Kong Polytechnic University)**

Mr. Linrong Liao (MPT), MPhil Student, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Purpose

To identify the factors related to successful activity participation.

Design of the Study

Subjects with a diagnosis of stroke are included in this study. But those are institutionalized, unable to carry out simple conversation, having other neurological disease or other severe diseases that preclude the individuals from participating will be excluded.

All subjects will complete the measurement protocol at a random order. They have to complete a few questionnaires and physical assessments.

Questionnaires:

The questionnaires will assess your activity level, mood, quality of life, balance confidence, and how well you are integrated into the community.

Walking performance:

We will ask to you to do the following walking tasks:

(1) You will be required to stand up from the chair and then walk for 3 meters and then return to the chair and sit down. You will do this safely at your natural speed.
(2) We will measure the distance you walk in 6 minutes. You will be required to cover as much distance as you can within 6 minutes at comfortable speed.

Motor examination:

You will conduct a few simple tests to assess your arm and leg movements.

Leg Muscle Strength:

We will measure how strong your leg muscles are. Muscle strength is measured by an instrument called dynamometer. We will measure your hip, knee and ankle muscle strength. You will be required to sit comfortably in a chair and you will be asked to maximally contract your muscles for 5 seconds. Three trials will be performed with a 1-minute rest between trials. Both sides will be tested.

Balance and mobility:

We will ask you to perform a few tasks to assess your balance and mobility (e.g. stand with eyes closed, pick up an object from the floor, etc.).

Subjects are required to complete the tests in experiment laboratory in The Hong Kong Polytechnic University. Each session will last for about 2 hours.

Benefits and Risks:

There are no known risks associated with these measurements. The major benefit from participating in this study is that you will have the opportunity to know your degree of recovery in physical function. You may feel a little bit tired during the test and rests can be taken when necessary.

Confidentiality:

All information and data collected from this study will be treated in strict confidence. Your name and personal data will not be disclosed to anyone except the project investigators.

Consent:

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

I can contact the chief investigator, Dr Marco Pang at telephone 27667156 for any questions about this study. If I have complaints related to the investigator(s), I can contact Mrs Michelle Leung, secretary of Departmental Research Committee, at 27665397. I know I will be given a signed copy of this consent form.

Signature (subject):___________ Date:_________

Signature (witness):___________ Date:_________

香港理工大學康復治療科學系科研同意書

科研題目：中風病人融入社區研究

科研人員：彭耀宗博士（香港理工大學康復治療科學系助理教授）

廖麟榮先生(香港理工大學康復治療科學系碩士研究生)

科研內容：

本科研的目的是研究影響中風病人成功重新融入社區的因素。

參與研究的對象必須為已確診的中風病人、不需住院、能進行簡單的交談，以及沒有其他神經科疾病或阻礙其參與研究的嚴重疾病。

參加者需按隨機的次序完成所有測量程序。他們需要完成數份問卷及身體測量。

問卷:

問卷將會對你的活動程度、情緒、生活質素、平衡能力信心及融入社區的程度進行評估。

步行表現:

我們將要求你做以下的步行測試：

1. 從椅子站起，步行 3 米然後轉身回到椅子坐下。你將安全地以你的自然速度完成。
2. 閣下需要以最快及舒適的速度來回步行六分鐘，我們會記錄閣下的最多步行距離。

運動測量:

你需要做幾個簡單的測試來評估你的手及腳的動作。

腳部肌肉力量：

我們將會用測力計量度你的腳部肌肉力量。我們會量度你的臂部、膝蓋及腳腕的肌肉力量。你需要舒適地坐在椅子上並用最大的力量收縮肌肉 5 秒。此測試將會進行 3 次，在每次測試之間會有 1 分鐘的休息時間。左右腳都會被測試。

平衡及活動能力：

我們將要求你進行幾個測試來評估你的平衡及活動能力（例如：閉眼站立、拾起地上的物品等）。

參加者需親臨香港理工大學康復治療科學系之研究實驗室接受測試，所需時間約 2 小時。

<u>對項目參與人仕和社會的益處</u>：

參加者可透過此次研究了解自己身體活動能力的康復程度。

<u>潛在危險性</u>：

所有測試並沒有任何已知的潛在危險。測試期間你可能會感到少許疲倦，並可按需要作適量的休息。

<u>個人資料保密</u>：

所有有關此項研究的資料及數據將會絕對保密。你的名字及個人資料將不會洩露給與此研究無關的人員。

同意書：

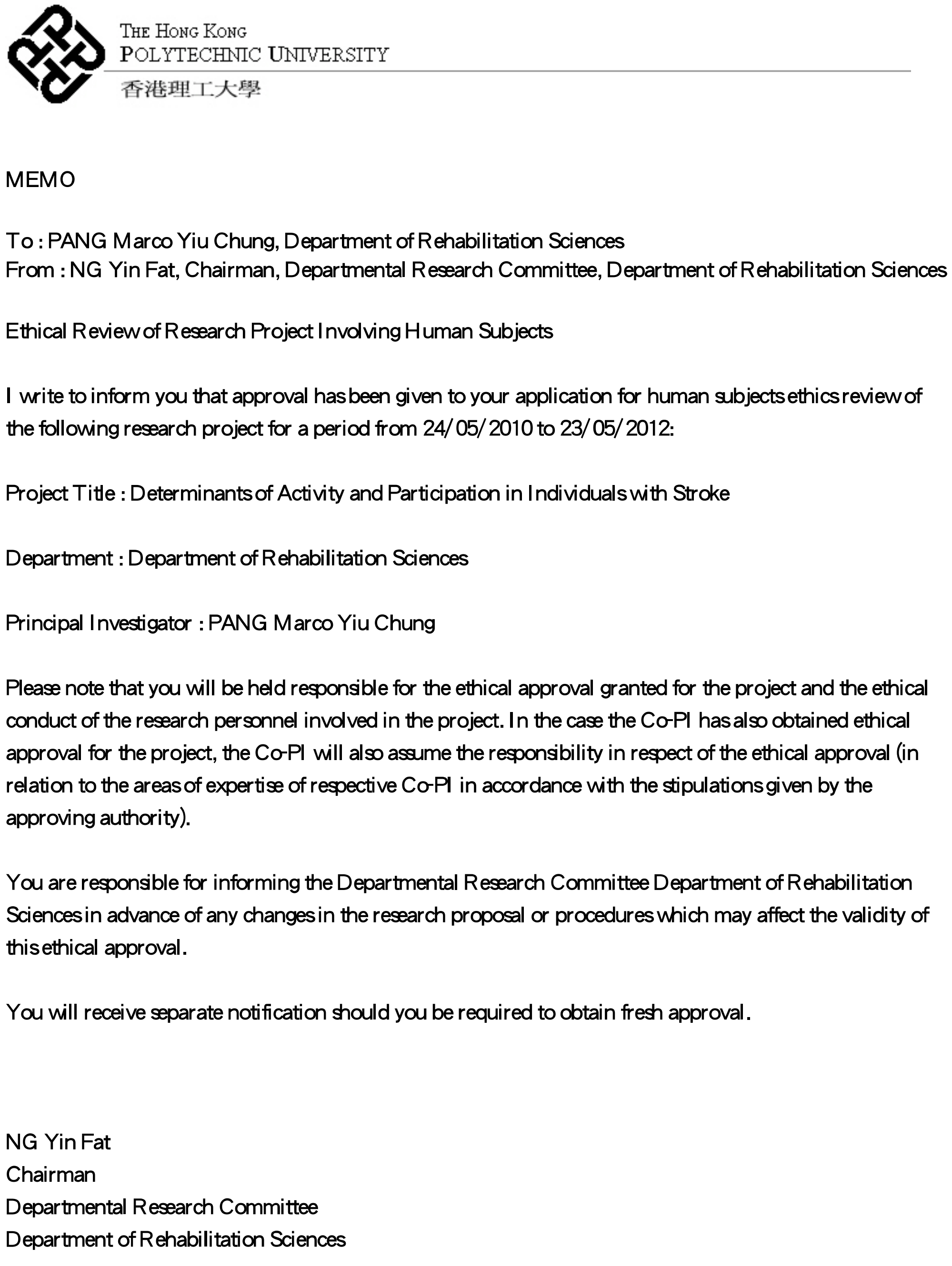
本人______________已瞭解此次研究的具體情況。本人願意參加此次研究, 本人有權在任何時候、無任何原因放棄參與此次研究, 而此舉不會導致我受到任何懲罰或不公平對待。本人明白參加此研究課題的潛在危險性以及本人的資料將不會洩露給與此研究無關的人員，我的名字或相片不會出現在任何出版物上。

本人可以用電話 27667156 來聯繫此次研究課題負責人，彭耀宗博士。若本人對此研究人員有任何投訴，可以聯繫梁女士（部門科研委員會秘書），電話：27665397。本人亦明白，參與此研究課題需要本人簽署一份同意書。

簽名（參與者）：____________ 日期：

簽名（證人）：____________ 日期：

APPENDIX II Approval Letter for Chapter 3



THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

MEMO

To : PANG Marco Yiu Chung, Department of Rehabilitation Sciences
From : NG Yin Fat, Chairman, Departmental Research Committee, Department of Rehabilitation Sciences

Ethical Review of Research Project Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following research project for a period from 24/05/2010 to 23/05/2012:

Project Title : Determinants of Activity and Participation in Individuals with Stroke

Department : Department of Rehabilitation Sciences

Principal Investigator : PANG Marco Yiu Chung

Please note that you will be held responsible for the ethical approval granted for the project and the ethical conduct of the research personnel involved in the project. In the case the Co-PI has also obtained ethical approval for the project, the Co-PI will also assume the responsibility in respect of the ethical approval (in relation to the areas of expertise of respective Co-PI in accordance with the stipulations given by the approving authority).

You are responsible for informing the Departmental Research Committee Department of Rehabilitation Sciences in advance of any changes in the research proposal or procedures which may affect the validity of this ethical approval.

You will receive separate notification should you be required to obtain fresh approval.

NG Yin Fat
Chairman
Departmental Research Committee
Department of Rehabilitation Sciences

APPENDIX III Consent Form for Chapter 4, 5, 6, and 7

The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project title: Neuromuscular and cardiovascular response during whole body vibration exercise in Individuals with stroke

Investigator(s):

Dr. Marco Yiu Chung Pang (PhD), Associate Professor, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Prof. Alice Jones (PhD), Professor, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Prof. Gabriel Ng (PhD), Chair Professor, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Mr. Ricky Wai Kin Lau (MSc), PhD Student, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Mr. Linrong Liao (MPT), MPhil Student, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Project information: Whole body vibration has been found to be useful in promoting bone health, balance, and muscle performance in older adults. The overall aim of the proposed study is to determine the neuromuscular and cardiovascular response during whole body vibration exercise in Individuals with stroke.

Training Protocol

You will undergo four sessions of training and measurement. In the first three sessions, you will be instructed to perform some exercises while standing on the vibration platform with different vibration frequencies. Your oxygen consumption and hear rate will be monitored throughout. To achieve this, you will be required to wear a mask, and a strap will be placed across your chest. Two sets of electrodes will be attached to your thigh and calf muscles to measure tissue oxygenation. We will use soap water, sandpaper and alcohol to clean the skin surface of the area before attaching the electrodes.

In the last session, you will perform the same exercises on the vibration platform. Two sets of electrodes will be attached to your thigh and calf muscles in order to record the electrical activity of your tested muscles.

Side-effects associated with the WBV are extremely rare (e.g. dizziness). The symptoms should subside following a brief rest period. If you experience some discomfort during therapy, you can request the exercise be terminated.

All of the evaluation procedures will take place in the Hong Kong Polytechnic University. The total duration for each session is about 2-3 hours.

Benefits and risks of undertaking this study:

The major benefit from participating in this study is that you will have the opportunity to receive vibration therapy. The results of this study will provide important information which assists the formulation of clinical guidelines for exercise prescription.

Confidentiality:

All information and data collected from this study will be treated in strict confidence. Your name and personal data will not be disclosed to anyone except the project investigators.

Consent:

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

I can contact the chief investigator, Dr Marco Pang at telephone 2766 7156 for any questions about this study. If I have complaints related to the investigator(s), I can contact Mrs Michelle Leung, secretary of Departmental Research Committee, at 2766 5397. I know I will be given a signed copy of this consent form.

Signature (subject): __________ **Date:**_________

Signature (witness): __________ **Date:** _________

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

香港理工大學康復治療科學系科研同意書

科研題目: 全身震盪訓練對中風病患者的神經肌肉及心肺功能所產生效應的研究。

科研人員: 彭耀宗博士 (香港理工大學康復治療科學系副教授）

鍾斯何綺文教授 (香港理工大學康復治療科學系教授)

吳賢發教授(香港理工大學康復治療科學系講座教授)

廖麟榮先生(香港理工大學康復治療科學系碩士研究生)

科研內容： 過往研究顯示全身震盪訓練對長者的骨骼健康、平衡能力、及肌肉功能有益處。是項研究在於探討不同頻率的全身震盪訓練對中風病患者的神經運動表現及心肺功能所產生的效應。

訓練詳情

閣下會進行四次的訓練。閣下會接受不同頻率的全身震盪訓練，並在震盪平臺上作一系列輕巧的運動。首三次的訓練時，我們會用一部儀器測試您的氧氣與心跳指數。您須在運動時戴上面罩及在胸口系上扣子。另外，兩個電極會分別貼在您兩側大腿的肌肉上，以測量肌肉的組織氧合指數。在最後一次訓練時，我們亦會用肌電圖機及放置在閣下大腿及小腿上放兩組電極，紀錄閣下在運動時的肌肉活動。放置電極前，我們會以梘液、酒精及砂紙等清潔放置電極的位置。大部分人進行震盪訓練均沒有出現不適情況，但有很少部分人士可能會出現頭暈等不適現象，一般經休息後不適現象就會減退。若在訓練過程中感到不適，閣下可隨時要求訓練終止。

每次訓練前及訓練後，我們均會為閣下進行檢查，所有檢查將會在香港理工大學進行，每次約兩至三小時。

對項目參與人仕和社會的益處：

參與是項研究主要能讓閣下有機會接受三次的震盪治療及得知自己的肌肉活動狀況。研究的結果，將會提供重要的資料，有助於設計臨床上的運動處方。

潛在危險性:

沒有任何其他已知的危險性存在於是項研究之中。參與是次研究乃自願性質。此項研究收集所得的個人資料及數據絶對保密；除相關研究人員之外，閣下的姓名或個人資料將不會被公開。

參加者同意書

本人＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿已瞭解此次研究的具體情況。本人願意參加是項計劃，並有權在任何時候、不論任何原因放棄參與此項計劃，而此舉不會導致我受到任何懲罰或不公平對待。本人明白參與此項計劃的潛在危險性以及本人的資料將不會洩露給與此計劃無關的人員，我的名字不會出現在任何影帶或出版物上。本人亦明白製作人員可剪輯本人之訪問或錄音或錄影片段，而片段將製作成教學用具，作為教學用途或於學術會議中播放。

本人可以用電話 2766 7156 來聯絡此計劃負責人彭耀宗博士。若本人對此計劃之研究人員有任何投訴，可以聯絡部門科研委員會秘書梁女士(電話：2766 5397)。本人亦明白，參與此計劃需要本人簽署一份同意書。

簽名（參與者）：＿＿＿＿＿＿　　日期：＿＿＿＿

簽名（證人）：＿＿＿＿＿＿　　日期：＿＿＿＿

APPENDIX IV Approval Letter for Chapter 4, 5, 6, and 7

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

To Pang Marco Yiu Chung (Department of Rehabilitation Sciences)

From TSANG Wing Hong Hector, Chair, Departmental Research Committee

Email rshtsang@ Date 28-Nov-2013

Application for Ethical Review for Teaching/Research Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following project for a period from 29-Nov-2013 to 28-Nov-2015:

Project Title: Neuromuscular response during whole body vibration exercise in individuals with stroke

Department: Department of Rehabilitation Sciences

Principal Investigator: Pang Marco Yiu Chung

Reference Number: HSEARS20131125001

Please note that you will be held responsible for the ethical approval granted for the project and the ethical conduct of the personnel involved in the project. In the case of the Co-PI, if any, has also obtained ethical approval for the project, the Co-PI will also assume the responsibility in respect of the ethical approval (in relation to the areas of expertise of respective Co-PI in accordance with the stipulations given by the approving authority).

You are responsible for informing the Departmental Research Committee in advance of any changes in the proposal or procedures which may affect the validity of this ethical approval.

You will receive separate email notification should you be required to obtain fresh approval.

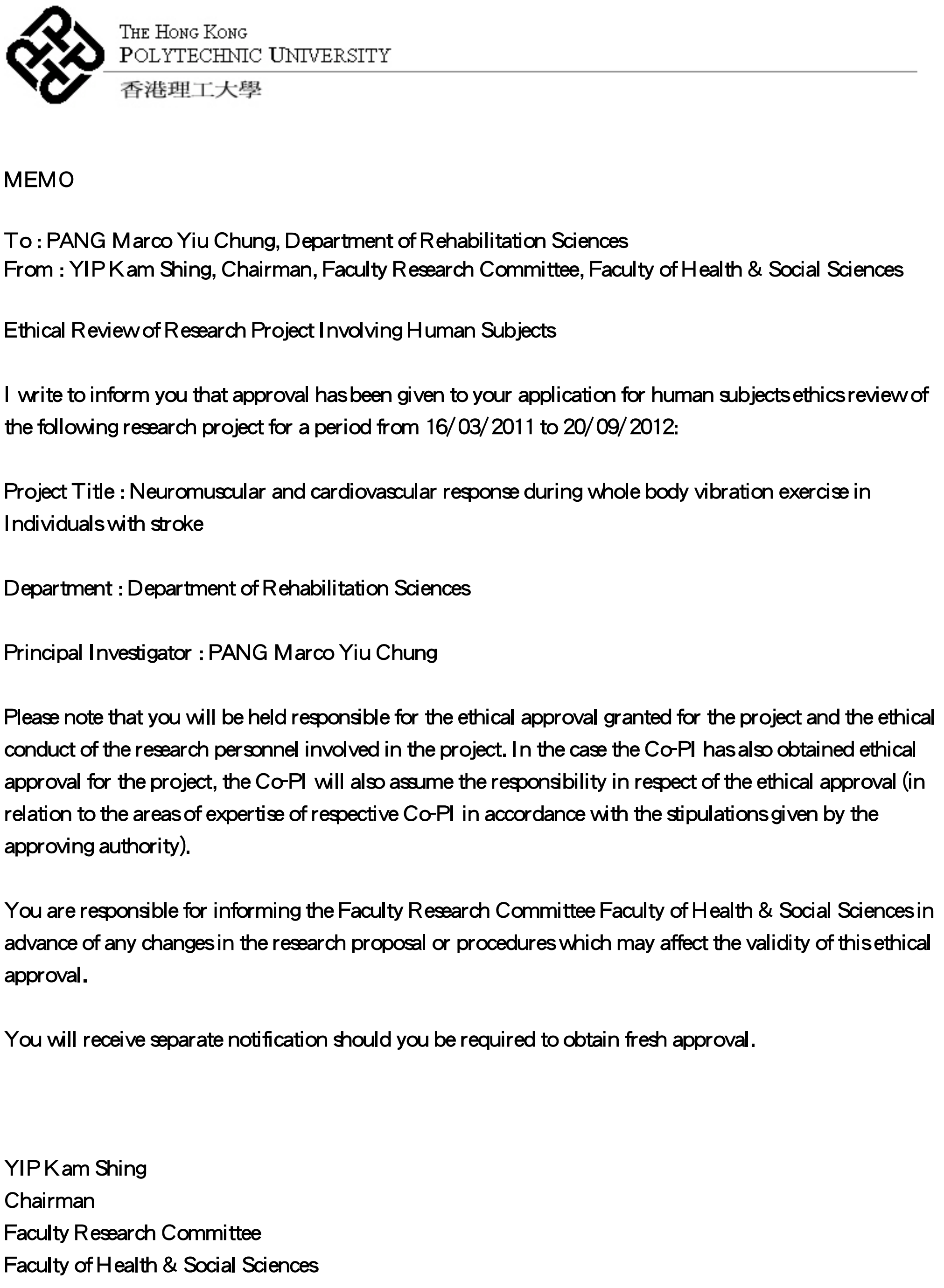
TSANG Wing Hong Hector

Chair

Departmental Research Committee

Page 1 of 1

APPENDIX IV Approval Letter for Chapter 4, 5, 6, and 7



THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

MEMO

To : PANG Marco Yiu Chung, Department of Rehabilitation Sciences
From : YIP Kam Shing, Chairman, Faculty Research Committee, Faculty of Health & Social Sciences

Ethical Review of Research Project Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following research project for a period from 16/03/2011 to 20/09/2012:

Project Title : Neuromuscular and cardiovascular response during whole body vibration exercise in Individuals with stroke

Department : Department of Rehabilitation Sciences

Principal Investigator : PANG Marco Yiu Chung

Please note that you will be held responsible for the ethical approval granted for the project and the ethical conduct of the research personnel involved in the project. In the case the Co-PI has also obtained ethical approval for the project, the Co-PI will also assume the responsibility in respect of the ethical approval (in relation to the areas of expertise of respective Co-PI in accordance with the stipulations given by the approving authority).

You are responsible for informing the Faculty Research Committee Faculty of Health & Social Sciences in advance of any changes in the research proposal or procedures which may affect the validity of this ethical approval.

You will receive separate notification should you be required to obtain fresh approval.

YIP Kam Shing
Chairman
Faculty Research Committee
Faculty of Health & Social Sciences

APPENDIX V Consent Form for Chapter 8

The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project title: Effects of different whole body vibration protocols in chronic stroke patients

Investigator(s):

Dr. Marco Yiu Chung Pang (PhD), Associate Professor, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Prof. Alice Jones (PhD), Professor, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Prof. Gabriel Ng (PhD), Chair Professor, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Mr. Lin-Rong Liao (MPT), PhD Student, Department of Rehabilitation Sciences, Hong Kong Polytechnic University.

Project information: Whole body vibration (WBV) has been found to be useful in promoting bone health, balance, and muscle performance in older adults. The overall aim of the study is to examine the effect of different WBV training protocols on leg muscle strength, balance, activity and participation in subjects with stroke.

Training Protocol

You will be randomly assigned to either the low- or high intensity vibration groups, or the exercise group. If you are allocated to the low- or high intensity vibration groups, you will receive WBV (total 12 to 18 minutes of vibration and 15 minutes stretching exercises, 1 session per day, and 3 session per week) for 10 weeks. You will be instructed to perform some exercises while standing on the vibration platform. Side-effects associated with the WBV are extremely rare (e.g. dizziness). The symptoms should subside following a brief rest period. If you experience some discomfort during therapy, you can request the exercise be terminated. You will be informed of whether you had actually received the low-intensity or high-intensity vibration at the end of the study.

If you are allocated to the exercise group, you will perform the same exercises on the platform and 15 minutes of stretching exercises, but no vibration will be given.

You will undergo the following assessments at 2 different times, ⑴ before the initiation of WBV treatment, ⑵ after 10 weeks of treatment. All of the evaluation procedures will take place in the Hong Kong Polytechnic University.

Each assessment will take approximately a total of 2 – 3 hours in the Hong Kong Polytechnic University, and will include the following:

Motor impairment: We will ask you to do some specific leg and foot movements, in order to evaluate the severity of impairment in your lower extremity.

Leg Muscle Strength: We will measure how strong your muscles are. We will measure your knee muscle strength using an isokinetic dynamometer. You will then be asked to maximally contract your knee muscles and hold for 5 seconds. We will test your isometric and concentric condition. Three trials will be performed on each side with a brief rest in between trials.

Oxygen consumption during 6-minute walk test: You will be asked to cover as much distance as you can in a 6-minute time period. Your oxygen consumption and hear rate will be monitored throughout.

Balance: We will ask you to do some specific movements and activities, in order to test the balance ability.

Questionnaires: We will ask you to complete a few questionnaires to assess your participation in daily activities, and quality of life.

Benefits and risks of undertaking this study:

The major benefit from participating in this study is that you will have the opportunity to receive exercise training. The results of this study will provide important information which assists the formulation of clinical guidelines for exercise prescription.

Confidentiality:

All information and data collected from this study will be treated in strict confidence. Your name and personal data will not be disclosed to anyone except the project investigators.

Consent:

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

I can contact the chief investigator, Dr Marco Pang at telephone 2766 7156 for any questions about this study. If I have complaints related to the investigator(s), I can contact Mrs Michelle Leung, secretary of Departmental Research Committee, at 2766 5397. I know I will be given a signed copy of this consent form.

Signature (subject): __________ **Date:**_________

Signature (witness): _________ **Date:** ________

THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

香港理工大學康復治療科學系科研同意書

科研題目: 不同的全身震盪訓練處方對中風病患者的臨床效應的研究。

科研人員: 彭耀宗博士 (香港理工大學康復治療科學系副教授）

鍾斯何綺文教授 (香港理工大學康復治療科學系教授)

吳賢發教授(香港理工大學康復治療科學系講座教授)

廖麟榮先生(香港理工大學康復治療科學系博士研究生)

科研內容:過往研究顯示全身震盪訓練對長者的平衡能力、及肌肉功能有益處。是項研究在於探討為期 10 周不同的全身震盪訓練對中風病患者在神經肌肉功能、平衡及步行等運動表現的長期效應。

訓練詳情

研究人員將會以隨機抽樣方式安排閣下進入低強度、高強度震盪訓練組或運動訓練組，閣下會連續十星期，每星期接受三天約 45 分鐘的訓練，若被抽中安排入運動訓練組，閣下會做一系列的重心轉移及伸展運動訓練。若被抽中安排入震盪訓練組，閣下會接受全身震盪訓練及伸展運動。大部分人進行震盪訓練均沒有出現不適情況，但有很少部分人士可能會出現頭暈等不適現象，一般經休息後不適現象就會減退。若在訓練過程中感到不適，閣下可隨時要求訓練終止。在研究結束時，將通知閣下是進行了低強度震盪訓練，或者是高強度震盪訓練。

參加者需要完成二次身體檢查，檢查分別安排在接受全身震盪訓練前和訓練十星期後進行。所有檢查將會在香港理工大學進行，每次約兩小時。

下肢機能測試：我們會要求閣下進行一系列指定的動作，以評估下肢受中風影響的嚴重程度。

下肢肌肉力量測試：我們將會用儀器測試閣下雙側膝部肌肉的等長收縮和向心性收縮的力量。測試時，以舒適的姿勢坐在儀器上，然後以最大的力量收縮膝部的肌肉，並維持 5 秒，重複進行 3 次。每次測試之間會休息 1 分鐘。

耐力測試：閣下需要以最快及舒適的速度來回步行六分鐘，我們會記錄閣下的最大步行距離、耗氧量及心率。

平衡：我們會為閣下測試平衡的能力。

問卷:閣下需要完成一系列的量表以評估閣下日常生活及生活質素。

對項目參與人仕和社會的益處：
參與是項研究主要能讓閣下有機會接受三次的震盪治療及得知自己的肌肉活動狀況。研究的結果，將會提供重要的資料，有助於設計臨床上的運動處方。

潛在危險性:

沒有任何其他已知的危險性存在於是項研究之中。參與是次研究乃自願性質。此項研究收集所得的個人資料及數據絕對保密；除相關研究人員之外，閣下的姓名或個人資料將不會被公開。

參加者同意書

本人____已瞭解此次研究的具體情況。本人願意參加是項計劃，並有權在任何時候、不論任何原因放棄參與此項計劃，

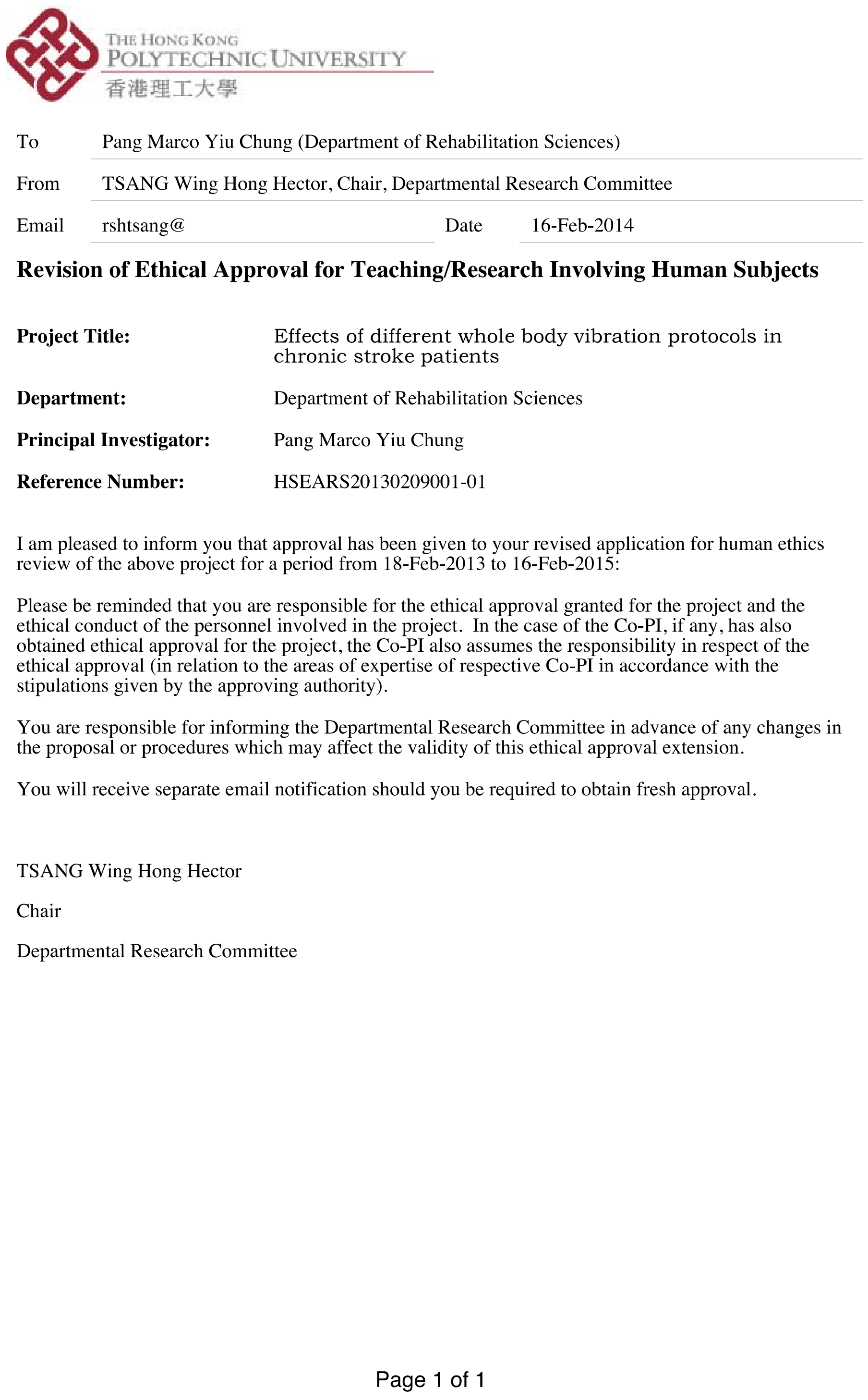
而此舉不會導致我受到任何懲罰或不公平對待。本人明白參與此項計劃的潛在危險性以及本人的資料將不會洩露給與此計劃無關的人員，我的名字不會出現在任何影帶或出版物上。本人亦明白製作人員可剪輯本人之訪問或錄音或錄影片段，而片段將製作成教學用具，作為教學用途或於學術會議中播放。

本人可以用電話 2766 7156 來聯絡此計劃負責人彭耀宗博士。若本人對此計劃之研究人員有任何投訴，可以聯絡部門科研委員會秘書梁女士(電話：2766 5397)。本人亦明白，參與此計劃需要本人簽署一份同意書。

簽名（參與者）：__________　　　　日期：_______

簽名（證人）：__________　　　　日期：_______

APPENDIX VI Approval Letter for Chapter 8



THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

To	Pang Marco Yiu Chung (Department of Rehabilitation Sciences)		
From	TSANG Wing Hong Hector, Chair, Departmental Research Committee		
Email	rshtsang@	Date	16-Feb-2014

Revision of Ethical Approval for Teaching/Research Involving Human Subjects

Project Title:	Effects of different whole body vibration protocols in chronic stroke patients
Department:	Department of Rehabilitation Sciences
Principal Investigator:	Pang Marco Yiu Chung
Reference Number:	HSEARS20130209001-01

I am pleased to inform you that approval has been given to your revised application for human ethics review of the above project for a period from 18-Feb-2013 to 16-Feb-2015:

Please be reminded that you are responsible for the ethical approval granted for the project and the ethical conduct of the personnel involved in the project. In the case of the Co-PI, if any, has also obtained ethical approval for the project, the Co-PI also assumes the responsibility in respect of the ethical approval (in relation to the areas of expertise of respective Co-PI in accordance with the stipulations given by the approving authority).

You are responsible for informing the Departmental Research Committee in advance of any changes in the proposal or procedures which may affect the validity of this ethical approval extension.

You will receive separate email notification should you be required to obtain fresh approval.

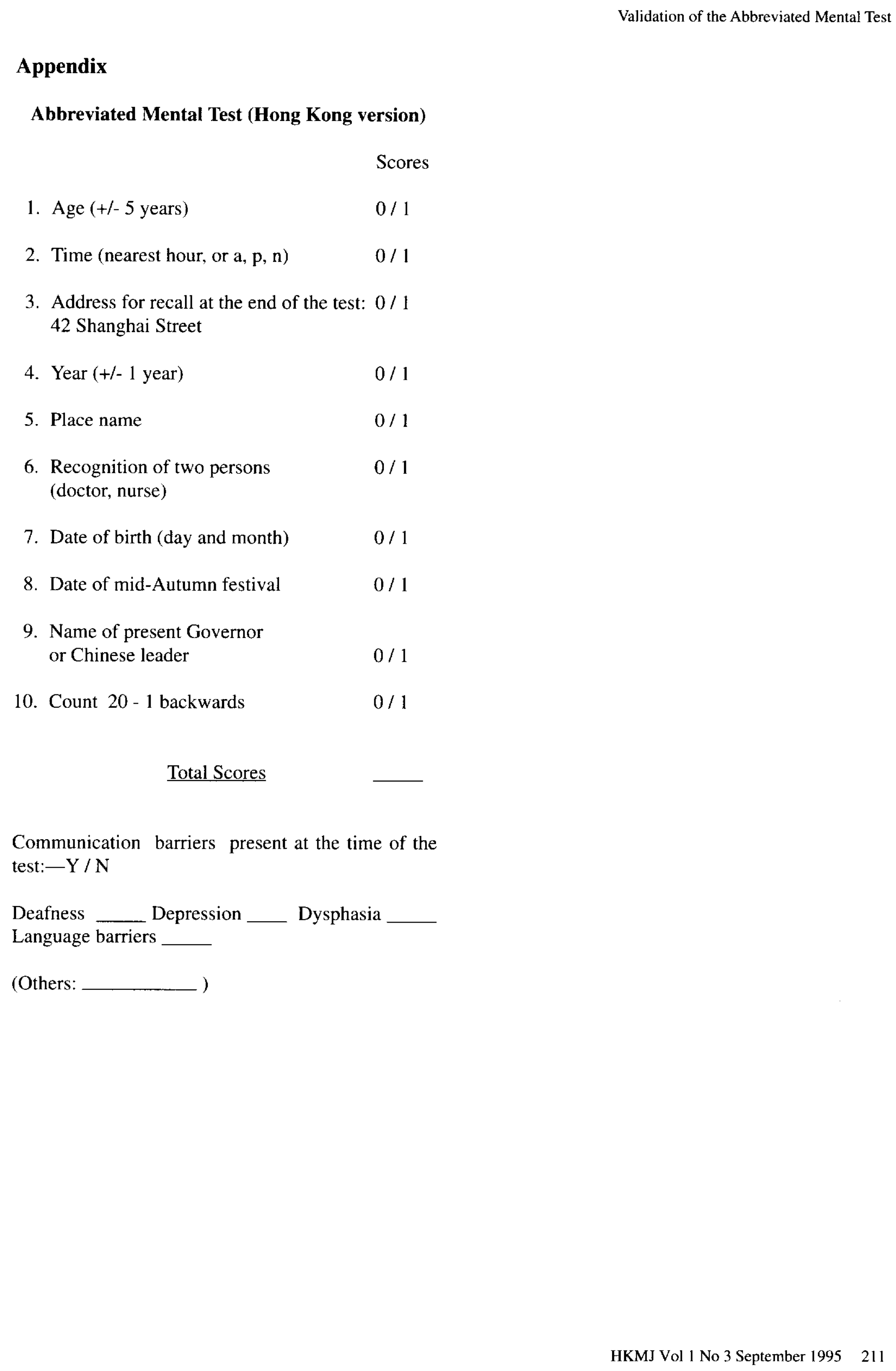
TSANG Wing Hong Hector

Chair

Departmental Research Committee

Page 1 of 1

APPENDIX VII Abbreviated Mental Test (Hong Kong Version)



Appendix

Abbreviated Mental Test (Hong Kong version)

	Scores
1. Age (+/- 5 years)	0 / 1
2. Time (nearest hour, or a, p, n)	0 / 1
3. Address for recall at the end of the test: 42 Shanghai Street	0 / 1
4. Year (+/- 1 year)	0 / 1
5. Place name	0 / 1
6. Recognition of two persons (doctor, nurse)	0 / 1
7. Date of birth (day and month)	0 / 1
8. Date of mid-Autumn festival	0 / 1
9. Name of present Governor or Chinese leader	0 / 1
10. Count 20 - 1 backwards	0 / 1
<u>Total Scores</u>	_____

Communication barriers present at the time of the test:—Y / N

Deafness _____ Depression ____ Dysphasia _____
Language barriers _____

(Others: ___________)

APPENDIX VIII Chedoke McMaster Stroke Assessment Form (Leg and Foot)

Chedoke-McMaster Stroke Assessment
SCORE FORM Page 3 of 4
IMPAIRMENT INVENTORY: STAGE OF RECOVERY OF LEG AND FOOT

LEG: Start at Stage 4 with the client in lying on back with knees bent and feet flat. FOOT: Start at Stage 3 with the client in supine. Test position is beside the item or underlined. If not indicated, the position has not changed. Place an X in the box of each task accomplished. Score the highest stage in which the client achieves at least two Xs. For "standing" test items, light support may be provided but weight bearing through the hand is not allowed. Shoes and socks off.

LEG

1		☐	not yet Stage 2
2	Crook lying	☐	resistance to passive hip or knee flexion
		☐	facilitated hip flexion
		☐	facilitated extension
3		☐	abduction: adduction to neutral
		☐	hip flexion to 90°
		☐	full extension
4		☐	hip flexion to 90° then extension synergy
		☐	bridging hips with equal weightbearing
	Sit	☐	knee flexion beyond 100°
5	Crook lying	☐	extension synergy, then flexion synergy
	Sit	☐	raise thigh off bed
	Stand	☐	hip extension with knee flexion
6	Sit	☐	lift foot off floor 5X in 5 sec
		☐	full range internal rotation
		☐	trace a pattern: forward, side, back, return
7	Stand	☐	unsupported: rapid high stepping 10X in 5 sec
		☐	unsupported: trace a pattern quickly: forward, side, back; reverse pattern
		☐	on weak keg with support: hop on weak leg
		☐	**STAGE OF LEG**

FOOT

1		☐	not yet Stage 2
2	Crook	☐	resistance to passive dorsiflexion
	lying	☐	facilitated dorsiflexion or toe extension
		☐	facilitated plantarflexion
3	Supine	☐	plantarflexion > ½ range
	Sit	☐	some dorsiflexion
		☐	extension of toes
4		☐	some eversion
		☐	full inversion
		☐	legs crossed: dorsiflexion, then plantarflexion
5		☐	legs crossed: toe extension with ankle plantarflexion
		☐	sitting with knee extended: ankle plantarflexion, then dorsiflexion
	Stand	☐	heel on floor: eversion
6		☐	heel on floor: tap foot 5X in 5 sec
		☐	foot off floor: foot circumduction
		☐	knee straight, heel off floor: eversion
7		☐	heel touching forward, then toe touching behind, repeat 5X in 10 sec
		☐	foot off floor: circumduction quickly, reverse
		☐	up on toes then back on heels 5X
		☐	**STAGE OF FOOT**

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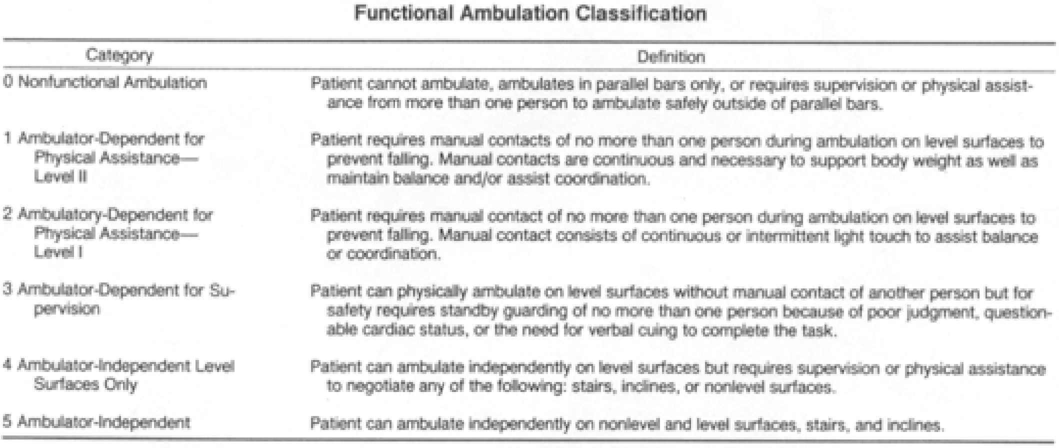
08/2007

APPENDIX IX Functional Ambulatory Category



Functional Ambulation Classification

Category	Definition
0 Nonfunctional Ambulation	Patient cannot ambulate, ambulates in parallel bars only, or requires supervision or physical assistance from more than one person to ambulate safely outside of parallel bars.
1 Ambulator-Dependent for Physical Assistance—Level II	Patient requires manual contacts of no more than one person during ambulation on level surfaces to prevent falling. Manual contacts are continuous and necessary to support body weight as well as maintain balance and/or assist coordination.
2 Ambulatory-Dependent for Physical Assistance—Level I	Patient requires manual contact of no more than one person during ambulation on level surfaces to prevent falling. Manual contact consists of continuous or intermittent light touch to assist balance or coordination.
3 Ambulator-Dependent for Supervision	Patient can physically ambulate on level surfaces without manual contact of another person but for safety requires standby guarding of no more than one person because of poor judgment, questionable cardiac status, or the need for verbal cuing to complete the task.
4 Ambulator-Independent Level Surfaces Only	Patient can ambulate independently on level surfaces but requires supervision or physical assistance to negotiate any of the following: stairs, inclines, or nonlevel surfaces.
5 Ambulator-Independent	Patient can ambulate independently on nonlevel and level surfaces, stairs, and inclines.

APPENDIX X Mini Balance Evaluation Systems Test

Examiner: ________________ Date:___________
Subject: __________________

MINI BESTest- of DYNAMIC BALANCE
Balance Evaluation – Systems Test
Copyright 2009

Subjects should be tested with flat-heeled shoes OR shoes and socks off.
If subject must use an assistive device for an item, score that item one category lower. If subject requires physical assistance to perform an item, score the lowest category (0) for that item.

1. SIT TO STAND
(2) Normal: Comes to stand without use of hands and stabilizes independently.
(1) Moderate: Comes to stand WITH use of hands on first attempt.
(0) Severe: Impossible to stand up from chair without assistance –OR- several attempts with use of hands.

2. RISE TO TOES
(2) Normal: Stable for 3 sec with maximum height
(1) Moderate: Heels up, but not full range (smaller than when holding hands)-OR-noticeable instability for 3 s
(0) Severe: ≤ 3 sec

3. STAND ON ONE LEG

Left *Time in sec Trial 1:________Trial 2:________*	Right *Time in sec Trial 1: _______Trial 2:_________*
(2) Normal: 20 s	(2) Normal: 20 s
(1) Moderate: < 20 sec	(1) Moderate: < 20 sec
(0) Severe: Unable	(0) Severe: Unable

4. COMPENSATORY STEPPING CORRECTION- FORWARD
(2) Normal: Recovers independently a single, large step (second realignment step is allowed)
(1) Moderate: More than one step used to recover equilibrium
(0) Severe: No step, OR would fall if not caught, OR falls spontaneously

5. COMPENSATORY STEPPING CORRECTION- BACKWARD
(2) Normal: Recovers independently a single, large step
(1) Moderate: More than one step used to recover equilibrium
(0) Severe: No step, OR would fall if not caught, OR falls spontaneously

6. COMPENSATORY STEPPING CORRECTION- LATERAL

Left	Right
(2) Normal: Recovers independently with 1 step (crossover or lateral OK)	(2) Normal: Recovers independently with 1 step (crossover or lateral OK)
(1) Moderate: Several steps to recovers equilibrium	(1) Moderate: Several steps to recovers equilibrium
(0) Severe: Falls, or cannot step	(0) Severe: Falls, or cannot step

7. EYES OPEN, FIRM SURFACE (FEET TOGETHER)
Time in sec:________
(2) Normal: 30s
(1) Moderate: < 30s
(0) Severe: Unable

8. EYES CLOSED, FOAM SURFACE (FEET TOGETHER)
Time in Sec:________
(2) Normal: 30s
(1) Moderate: < 30s
(0) Severe: Unable

Examiner: ________________ Date:___________
Subject: __________________

9. INCLINE- EYES CLOSED

Time in sec:________

(2) Normal: Stands independently 30 sec and aligns with gravity
(1) Moderate: Stands independently <30 SEC -OR- aligns with surface
(0) Severe: Unable to stand >10 sec -OR- will not attempt independent stance

10. CHANGE IN GAIT SPEED

(2) Normal: Significantly changes walking speed without imbalance
(1) Moderate: Unable to change walking speed or imbalance
(0) Severe: Unable to achieve significant change in speed AND signs of imbalance

11. WALK WITH HEAD TURNS – HORIZONTAL

(2) Normal: performs head turns with no change in gait speed and good balance
(1) Moderate: performs head turns with reduction in gait speed
(0) Severe: performs head turns with imbalance

12. WALK WITH PIVOT TURNS

(2) Normal: Turns with feet close, FAST ($\leq$ 3 steps) with good balance
(1) Moderate: Turns with feet close SLOW ($\geq$4 steps) with good balance
(0) Severe: Cannot turn with feet close at any speed without imbalance

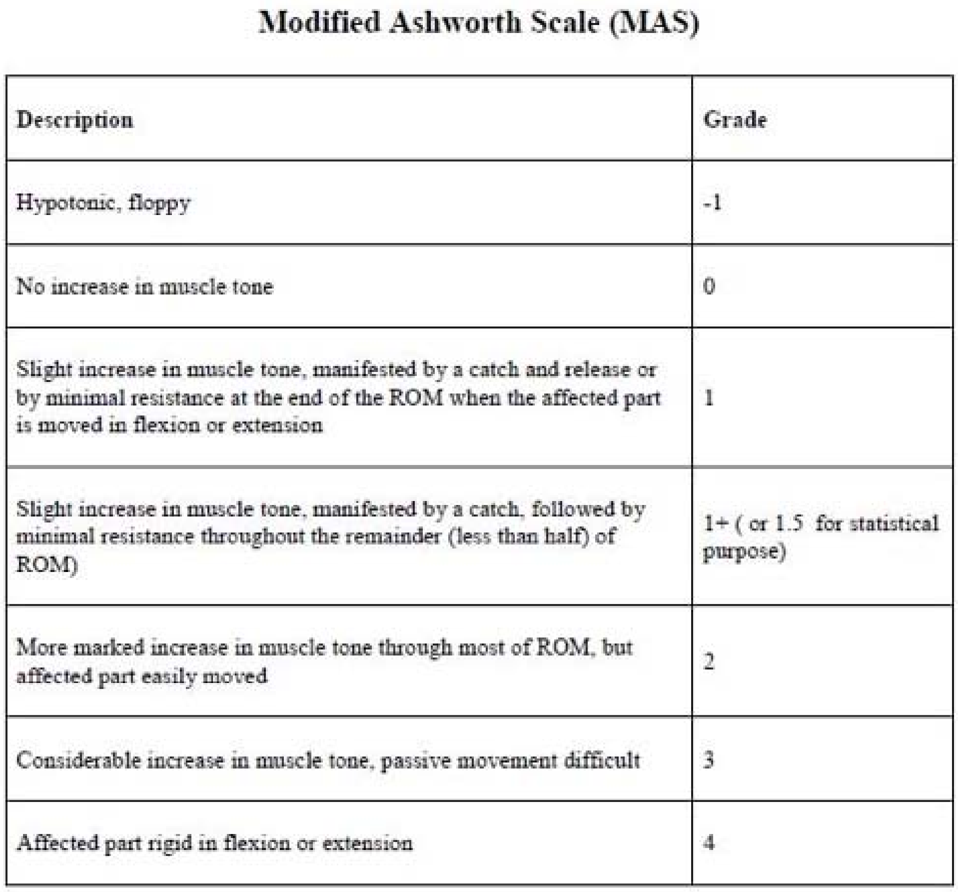
13. STEP OVER OBSTACLES

(2) Normal: able to step over box with minimal change of speed and with good balance
(1) Moderate: steps over shoe boxes but touches box OR displays cautious behavior by slowing gait.
(0) Severe: cannot step over shoe boxes OR hesitates OR steps around box

14. TIMED UP & GO (ITUG) WITH DUAL TASK *TUG: ________sec; Dual Task TUG: ________sec*

(2) Normal: No noticeable change between sitting & standing in backward counting & no change in gait speed for TUG.
(1) Moderate: Dual task affects either counting OR walking.
(0) Severe: Stops counting while walking OR stops walking while counting.

APPENDIX XI Modified Ashworth scale



Modified Ashworth Scale (MAS)

Description	Grade
Hypotonic, floppy	-1
No increase in muscle tone	0
Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the ROM when the affected part is moved in flexion or extension	1
Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of ROM)	1+ (or 1.5 for statistical purpose)
More marked increase in muscle tone through most of ROM, but affected part easily moved	2
Considerable increase in muscle tone, passive movement difficult	3
Affected part rigid in flexion or extension	4

APPENDIX XII Activities-specific Balance Confidence (Chinese Version)

Stroke WBV Study (RCT)

ABC 活動平衡信心評分表

0%	10	20	30	40	50	60	70	80	90	100%
無信心										絕對信心

ABC 計分表

當你做下面嗰啲活動既時候, 你有幾多信心你可以保持平衡同埋穩定

	活動項目	分數
1.	喺屋裡面行嚟行去	
2.	上落樓梯	
3.	“踎”低身係地下度執起隻拖鞋	
4.	喺個架到, 攞一個擺喺你頭咁高嘅罐頭	
5.	趷高腳, 去攞高過你頭頂 D 嘢	
6.	企喺櫈上面攞野	
7.	掃地	
8.	行出屋企, 去附近搭車	
9.	上落你搭慣既交通工具	
10.	穿過停車場去商場	
11.	行上或者行落條短斜坡	
12.	喺一個好迫, 同埋周圍D 人又行得好快既商場裡面行	
13.	喺商場度行嘅時候, 俾人撞落你度	
14.	捉住條扶手, 踏入或者踏出扶手電梯	
15.	拎住D 嘢, 手又冇得扶住, 踏入或者踏出扶手電梯	
16.	行出出便, 濕滑嘅地面	
	總分	
	訪問員	

APPENDIX XIII Frenchay Activity Index

芙蘭切活動量表 Frenchay Activity Index

項目及評分標準**(0~45)**；

最近三個月內		頻率及評分			
項目	無	每週少於一次	每週一至二次	每週至少三次	
1 煮飯燒菜	0	1	2	3	□
2 洗碗	0	1	2	3	□
	無	一至二次	三至十二次	每週至少一次	
3 洗衣服	0	1	2	3	□
4 簡單家務	0	1	2	3	□
5 複雜家務	0	1	2	3	□
6 購物	0	1	2	3	□
7 社交活動	0	1	2	3	□
8 戶外走路	0	1	2	3	□
9 嗜好或興趣	0	1	2	3	□
10 開車或搭車	0	1	2	3	□
最近半年內		**頻率及評分**			
項目	無	一至二次	三次以上，每週少於一次	每週至少一次	
11 旅遊	0	1	2	3	□
	無	偶而	固定	全部	
12 園藝、照顧花木	0	1(除草)	2(修剪)	3(挖掘)	□
13 維修汽車或房屋	0	1	2	3	□
	無	六個月內一本	兩週內不到一本	兩週內超過一本	
14 讀書	0	1	2	3	□
	無	每週少於十小時	每週十至三十小時	每週超過三十小時	
15 工作	0	1	2	3	□

APPENDIX XIV Craig Hospital Inventory of Environmental Factors

佳格醫院環境因素一覽表

C (若有查詢，請電郵 charison-felix@ 或 dmelick@ 聯絡)

作為社會中一個活躍及有生產力的成員，在日常生活中會參與不同範疇的活動，包括工作、上學、照顧家庭，及與家人和朋友在社區參與社交、康樂及公民活動。有很多因素能夠幫助或改進個人對這些活動的參與，另一方面，亦有其他因素會成為參與這些活動的阻礙及限制。首先，你是否認為你曾經如其他人般有一樣的機會參與以下項目並從中得到益處：

教育	是 _____	否 _____
就業	是 _____	否 _____
康樂及消閒活動	是 _____	否 _____

首先，請你告訴我在參與以下你認為重要的活動時遇到阻礙的次數有多頻密。請回想過去一年並告訴我下列項目是否每天、每星期、每個月、少於每月一次或從不對你構成問題。如果參與你認為重要的項目遇到問題時，請回答你認為問題有多大。

(備註：如果問題是指明關於上學或工作，而你並不需上學或工作的話，請剔“不適用”。)

	每天	每星期	每個月	少於每月一次	從不	**不適用**	大問題	小問題
1. 在過去十二個月內，在尋找合適的交通工具方面，你遇到問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (5: Transportation)							□	□
2. 在過去十二個月內，你家中的設計及格局，對辦理你想做或需要做的事情，構成困難的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (2: design home)							□	□
3. 在過去十二個月內，上學或工作的建築物和地方，它們的設計及格局，對辦理你想做或需要做的事情，構成困難的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (2: design work/school)							□	□
4. 在過去十二個月內，社區中的建築物和地方，它們的設計及格局，對辦理你想做或需要做的事情，構成困難的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (2: design community)							□	□
5. 在過去十二個月內，自然環境—氣溫、地理環境，及氣候，對辦理你想做或需要做的事情，構成困難的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (2: natural environment)							□	□

	每天	每星期	每個月	少於每月一次	從不	**不適用**	大問題	小問題
6. 在過去十二個月內，你四周的其他方面—光線、噪音、人群等，對辦理你想做或需要做的事情，構成困難的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (2: surroundings)							□	□
7. 在過去十二個月內，你想要或需要的資料，並沒有以你能使用或理解的形式出現，這情況出現的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (5: information)							□	□
8. 在過去十二個月內，在尋找合適的教育及培訓方面，你遇到問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (5: education/training)							□	□
9. 在過去十二個月內，在尋找合適的保健服務及醫療護理方面，你遇到問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (5: medical care)							□	□
10. 在過去十二個月內，缺乏個人裝備或特別設備 (例如：助聽器、眼鏡或輪椅)，這情況出現的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (5: personal equipment)							□	□

	每天	每星期	每個月	少於每月一次	從不	**不適用**	大問題	小問題
11. 在過去十二個月內，缺乏電腦科技的情況，出現的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (2: technology)							□	□
12. 在過去十二個月內，當你在家中需要別人幫忙時，並不能輕易找到，這情況出現的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (5: help home)							□	□
13. 在過去十二個月內，當你在學校或工作間需要別人幫忙時，並不能輕易找到，這情況出現的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (3: help work/school)							□	□
14. 在過去十二個月內，當你在社區中需要別人幫忙時，並不能輕易找到，這情況出現的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (5: help community)							□	□
15. 在過去十二個月內，家人對你的態度，在家中構成問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (4: attitudes home)							□	□

	每天	每星期	每個月	少於每月一次	從不	**不適用**	大問題	小問題
16. 在過去十二個月內，別人對你的態度，對你在學校或工作間構成問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (3: attitudes work/school)							□	□
17. 在過去十二個月內，別人對你的態度，對你在社區中構成問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (4: attitudes community)							□	□
18. 在過去十二個月內，缺乏別人在家中給你支持和鼓勵，對你構成問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (4: support home)							□	□
19. 在過去十二個月內，缺乏別人在學校或工作間給你支持和鼓勵，對你構成問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (3: support work/school)							□	□
20. 在過去十二個月內，缺乏別人在社區中給你支持和鼓勵，對你構成問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (4: support community)							□	□

	每天	每星期	每個月	少於每月一次	從不	不適用	大問題	小問題
21. 在過去十二個月內，你遇到偏見或歧視的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (4: discrimination)							□	□
22. 在過去十二個月內，缺乏社區活動及服務，對你構成問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (1: services community)							□	□
23. 在過去十二個月內，商界和機構的政策及規則，對你構成問題的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？(1: policies businesses)							□	□
24. 在過去十二個月內，教育和就業的活動及政策，對辦理你想做或需要做的事情，構成困難的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？(1: policies employment/ education)							□	□
25. 在過去十二個月內，政府推行的項目及政策，對辦理你想做或需要做的事情，構成困難的次數有多頻密？	□	□	□	□	□	□		
若問題出現時，這是一個大問題或是小問題？ (1: policies government)							□	□

APPENDIX XV Short-Form 12 Health Survey, version 2

參加者姓名：＿＿＿＿＿＿＿＿＿＿＿＿　　日期：＿＿＿＿＿＿＿＿＿＿＿＿

『健康生活質素調查問卷(SF-12)』(II)

這份問卷調查的目的是希望透過多方面的問題內容，包括：整體健康、體能、日常活動、精力、身體痛楚、心理健康、和社交活動等，加深我們對您健康狀況及日常生活質素的了解，故請您儘量回答問卷內的所有問題，並且圈出最合適的答案，每一問題只可選擇一個答案。如對某一問題不能肯定或不太清楚的話，就選出最近似的一個答案。多謝合作！

此欄由研究員填寫

1. 總括來說，您認為您現時的健康狀況是 □
   （1）非常好　（2）很好
   （3）好　（4）一般（不過不失）
   （5）差

1a. 在過去一年，您有否患上一些長期疾病？（註：長期疾病是指某一疾病已影響您已有一段很長的時間或您因某一疾病而有一段很長的時間已受困擾） □
（1）有 ⟶ （轉至問題1b）
（2）沒有 ⟶ （跳至問題2）

1b. 如有，您有否因這些疾病而限制了您的日常活動？ □
（1）有　（2）沒有

以下各項是您日常生活中可能進行的活動。以您目前的健康狀況，您在進行這些活動時，有沒有受到限制？如果有的話，程度如何？

2. 中等強度的活動，例如搬桌子，用吸塵機吸塵或清潔地板，打保齡球，或打太極拳？ □
   （1）有好大限制　（2）有一點限制
   （3）沒有任何限制

3. 上幾層樓梯？ □
   （1）有好大限制　（2）有一點限制
   （3）沒有任何限制

以下問題是關於您身體健康狀況和日常活動的關係。

4. 在過去四個星期裡，您會否因為身體健康的原因而令您在工作或日常活動中實際做完/完成的比想做的少？ □
   （1）會　（2）不會

5. 在過去四個星期裡的工作或日常活動中，您會否因為身體健康的原因而令您的工作或活動受到限制？ □

（1） 會　　（2） 不會

6. 在過去四個星期裡，您會否因為情緒方面的原因(比如感到沮喪或焦慮)而令您在工作或日常活動中實際做完/完成的比想做的少？ □

（1） 會　　（2） 不會

7. 在過去四個星期裡的工作或日常活動中，您會否因為情緒方面的原因(比如感到沮喪或焦慮)而令您的工作或活動受到限制？ □

（1） 會　　（2） 不會

8. 在過去四個星期裡，您身體上的疼痛對您的日常工作（包括上班和家務）有多大影響？ □

（1） 完全沒有影響　　（2） 有很少影響
（3） 有一些影響　　（4） 有較大影響
（5） 有非常大的影響　　（6） 不適用

以下問題是有關您在過去四個星期裡您覺得怎樣和您其他的情況。針對每一個問題，請選擇一個最接近您的感覺的答案。

9. 在過去四個星期裡，您有多少時間感到心平氣和？ □

（1） 常常　　（2） 大部份時間
（3） 很多時間　　（4） 間中
（5） 只有好少時間　　（6） 從來沒有

10. 在過去四個星期裡，您有多少時間感到精力充足？ □

（1） 常常　　（2） 大部份時間
（3） 很多時間　　（4） 間中
（5） 偶然一次半次　　（6） 從來沒有

11. 在過去四個星期裡，您有多少時間覺得心情不好，悶悶不樂或沮喪？ □

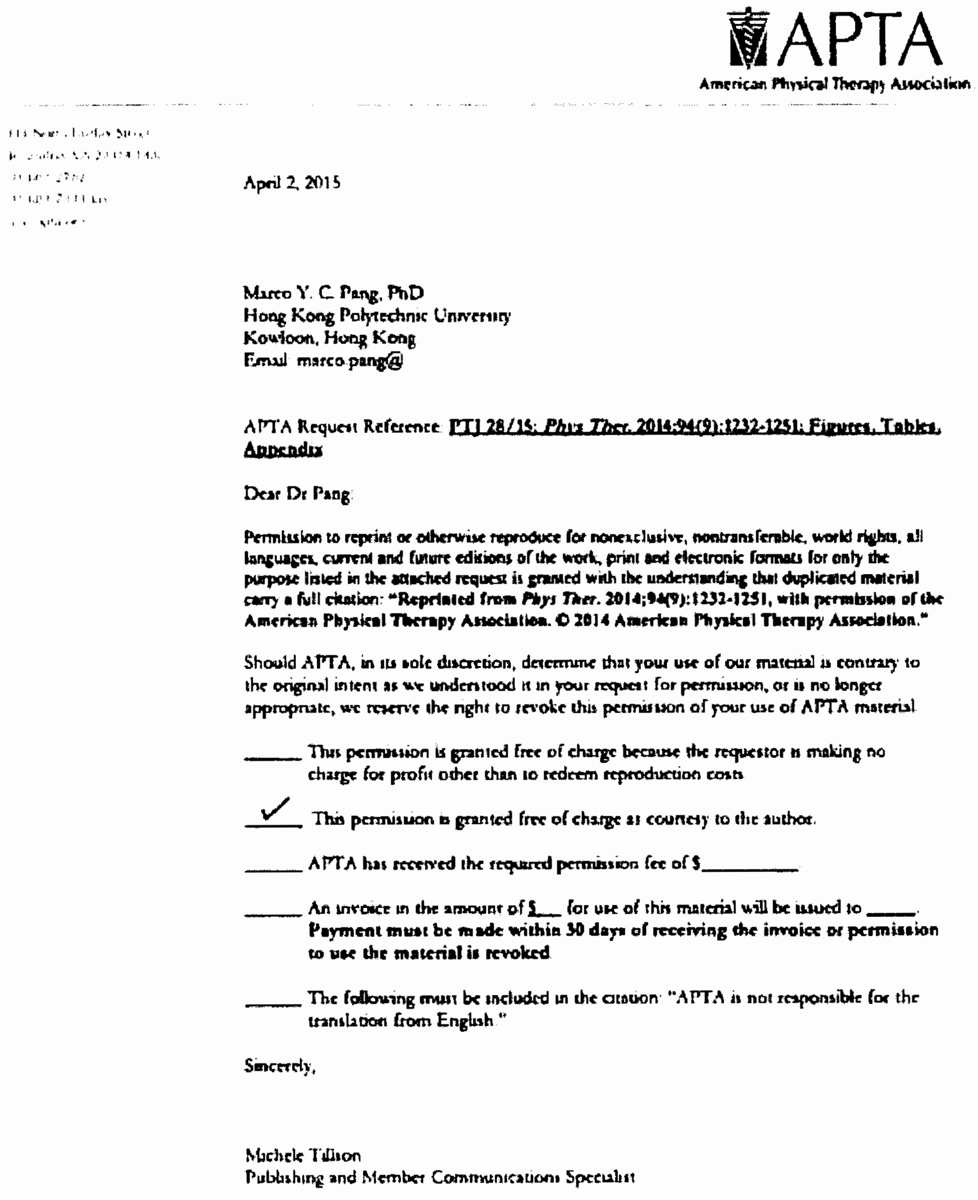
（1） 常常　　（2） 大部份時間
（3） 很多時間　　（4） 間中
（5） 偶然一次半次　　（6） 從來沒有

12. 在過去四個星期裡，有多少時間由於您身體健康或情緒問題而妨礙了您的社交活動（比如探親、訪友等）？ □

（1） 常常都有　　（2） 大部份時間有
（3） 有時有　　（4） 偶然有一次半次
（5） 完全沒有

～ 全卷完 ～

APPENDIX XVI Permission for Chapter 2 Effects of Whole-body Vibration Therapy on Body Functions and Structures, Activity and Participation Post-stroke: A Systematic Review



APTA
American Physical Therapy Association

April 2, 2015

Marco Y. C. Pang, PhD
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Email marco.pang@

APTA Request Reference: PTJ 28/15: *Phys Ther.* 2014;94(9):1232-1251; Figures, Tables, Appendix

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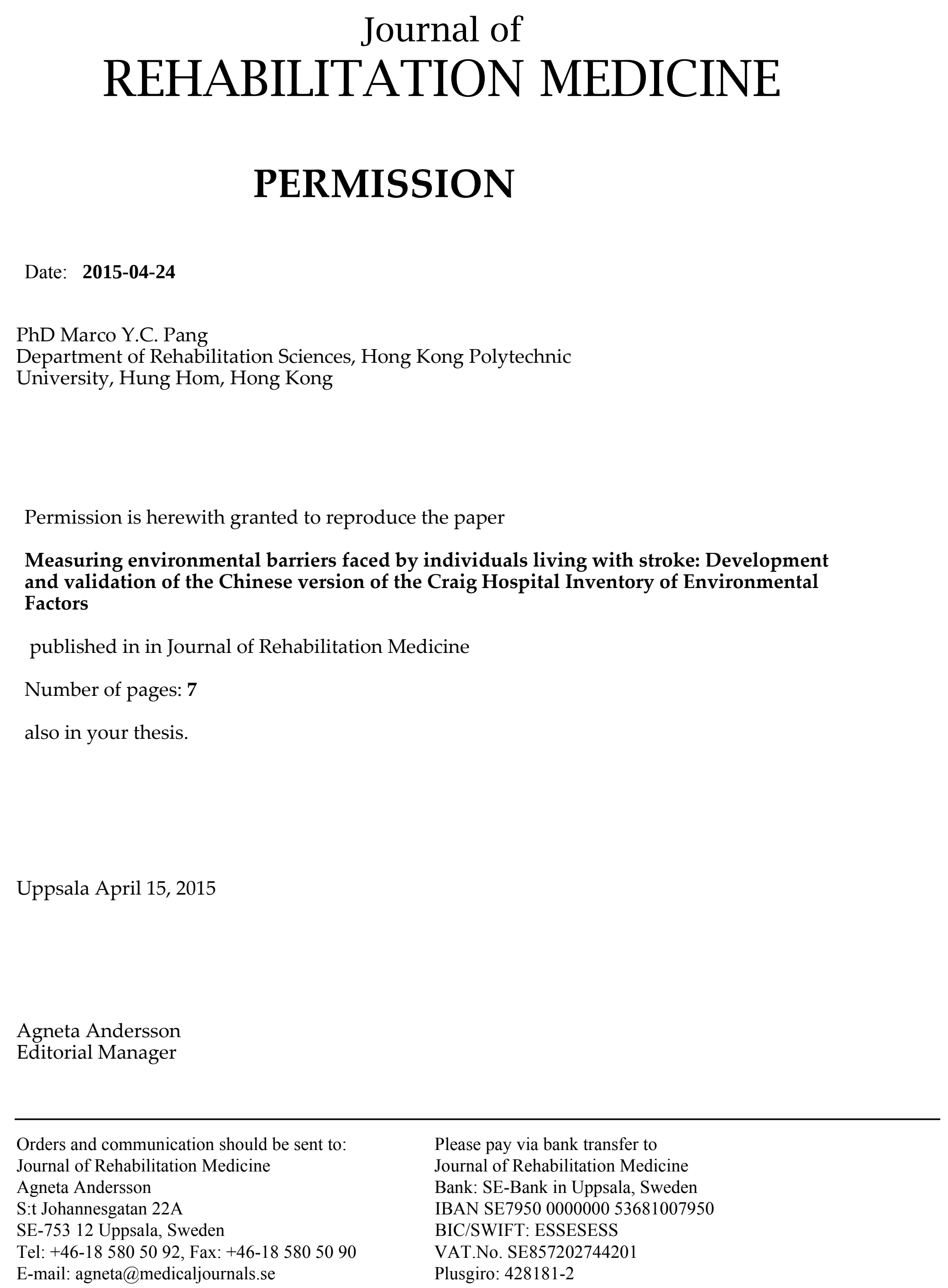

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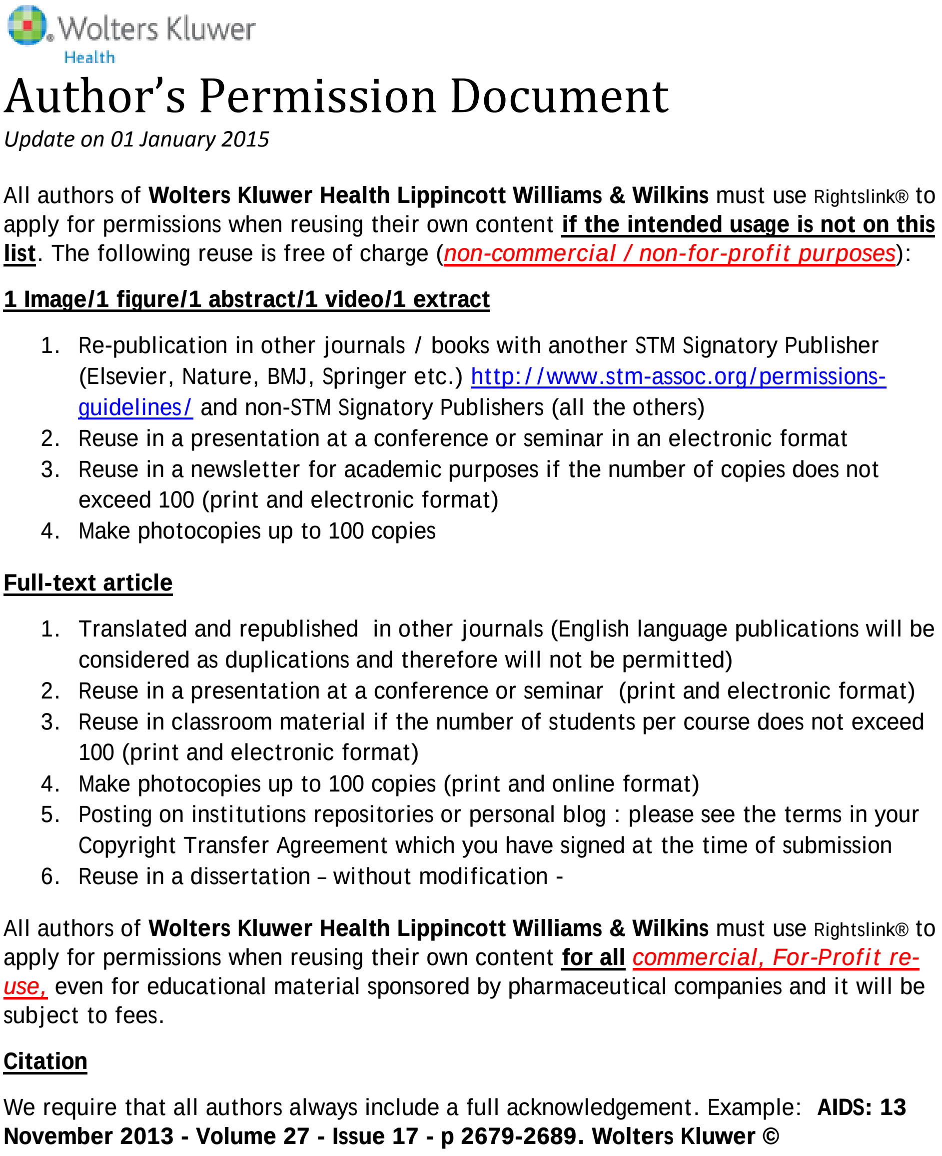

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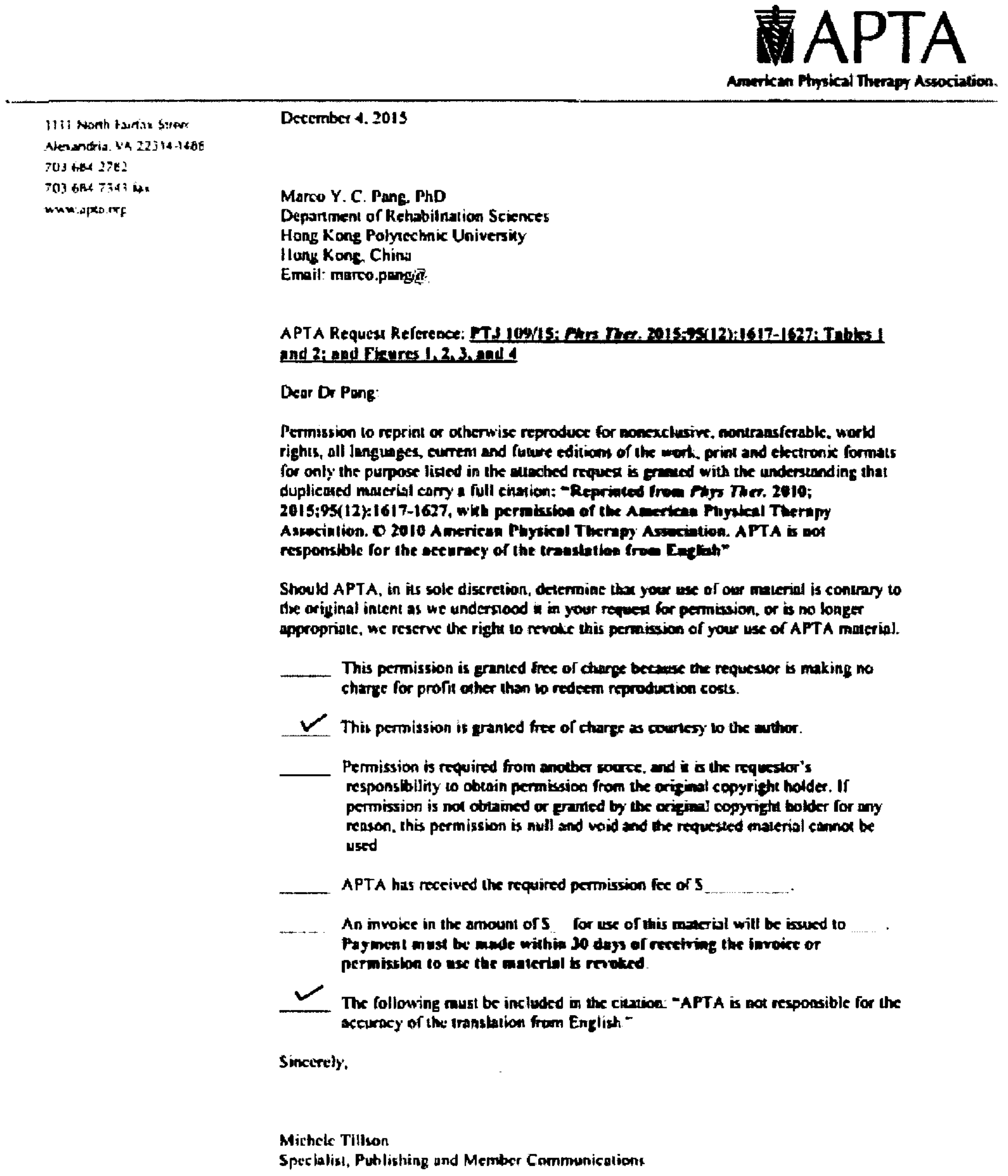

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December 4, 2015

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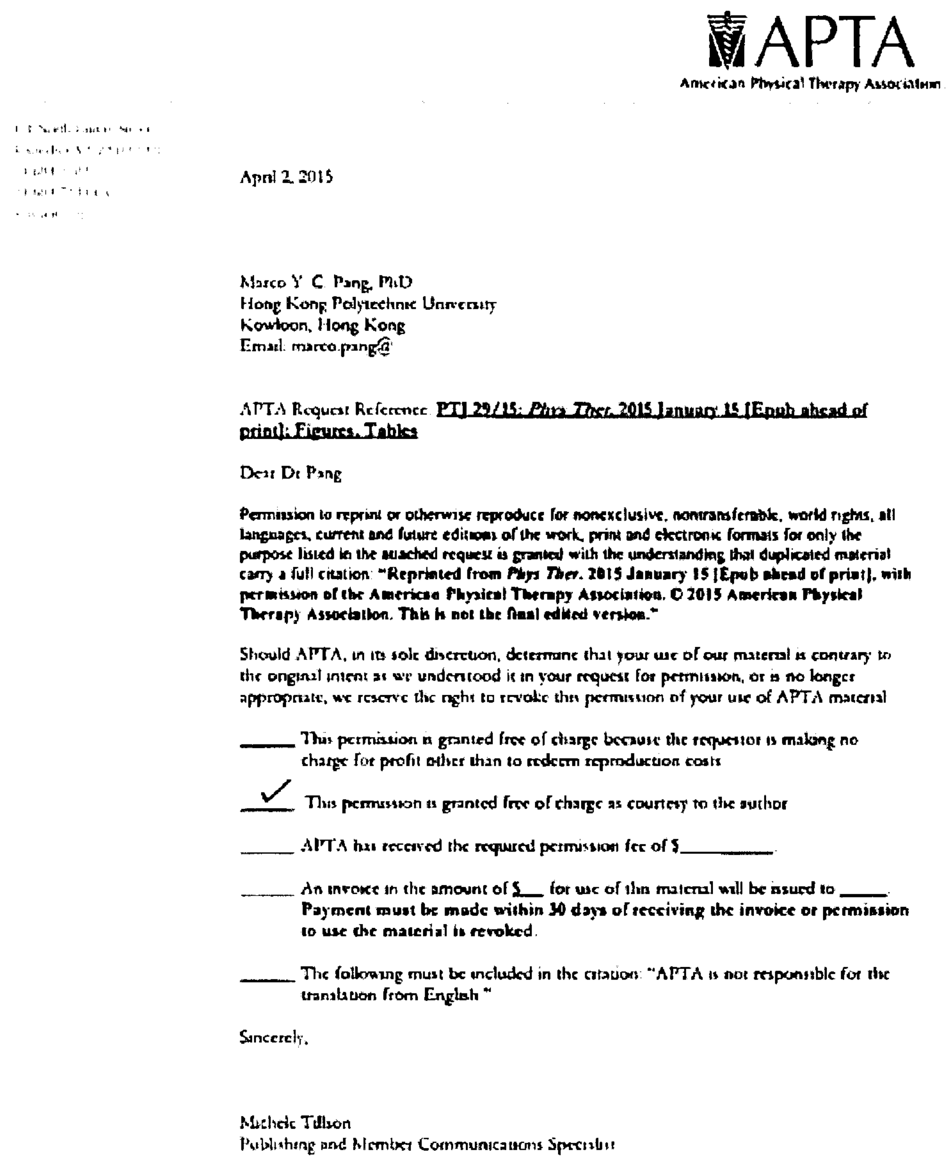

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REFERENCES

Abd-Allah F and Moustafa RR. Burden of stroke in Egypt: current status and opportunities. *Int J Stroke*. 2014;9(8):1105-8.

Abercromby AFJ, Amonette WE, Layne CS et al. Variation in neuromuscular responses during acute whole-body vibration exercise. *Med Sci Sports Exerc*. 2007;39(9):1642–50.

Ada L, Canning CG, Low SL. Stroke patients have selective muscle weakness in shortened range. *Brain*. 2003;126(Pt 3):724-31.

Adams JB, Edwards D, Serravite DH et al. Optimal frequency, displacement, duration, and recovery patterns to maximize power output following acute whole-bodyvibration. *J Strength Cond Res*. 2009;23(1):237-45.

Adsuar JC1, Del Pozo-Cruz B, Parraca JA et al. Whole body vibration improves the single-leg stance static balance in women with fibromyalgia: a randomized controlled trial. *J Sports Med Phys Fitness*. 2012;52(1):85-91.

Agabiti-Rosei E, Muiesan ML. Carotid atherosclerosis, arterial stiffness and stroke events. *Adv Cardio*. 2007;l 44:173-86.

Ahlborg L, Andersson C, Julin P. Whole-body vibration training compared with resistance training, effects on spasticity, muscle strength and motor performance in adults with cerebral palsy. *J Rehabil Med*. 2006;38(5):302-8.

Ahtsio B, Britton M, Murray V, et al. Disablement and quality of life after stroke. *Stroke*. 1984;15:886-890.

Ainsworth BE, Haskell WL,Whitt MC et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc.* 2000; 32:498–504.

Alentorn-Geli E, Moras G, Padilla J et al. Effect of acute and chronic whole-body vibration exercise on serum insulin-like growth factor-1 levels in women with fibromyalgia. *J Altern Complement Med*. 2009;15(5):573-8.

Alentorn-Geli E, Padilla J, Moras G et al. Six weeks of whole-body vibration exercise improves pain and fatigue in women with fibromyalgia. *J Altern Complement Med.* 2008;14(8):975-81.

Alguacil Diego I. M., Pedrero Hernandez C., Molina Rueda F et al. Effects of vibrotherapy on postural control. functionality and fatigue in multiple sclerosis patients. A randomised clinical trial. *Neurologia*. 2012; 27(3), 143-53.

Algurén B, Lundgren-Nilsson A, Sunnerhagen KS. Functioning of stroke survivors – A validation of the ICF core set for stroke in Sweden. *Disabil Rehabil*. 2010;32:551-9.

Andersen LL, Zeeman P, Jørgensen JR et al. Effects of intensive physical rehabilitation on neuromuscular adaptations in adults with poststroke hemiparesis. *J Strength Cond Res*. 2011;25(10):2808-17.

Andrenelli E, Ippoliti E, Coccia M, et al. Features and predictors of activity limitations and participation restriction 2 years after intensive rehabilitation following first-ever stroke. *Eur J Phys Rehabil Med*. 2015.

Andrew NE, Kilkenny M, Naylor R, et al. Understanding long-term unmet needs in Australian survivors of stroke. *Int J Stroke*. 2014; 9 Suppl A100:106-12.

Angeleri F, Angeleri VA, Foschi N, et al. The influence of depression, social activity and family stress on functional outcome after stroke. *Stroke.* 1993;24:1478-83.

Ansari NN, Naghdi S, Arab TK, Jalaie S. The interrater and intrarater reliability of the Modified Ashworth Scale in the assessment of muscle spasticity: limb and muscle group effect. *NeuroRehabilitation*. 2008;23:231-7.

Antonelli Incalzi R, Cesari M, Pedone C et al. Construct validity of the abbreviated mental test in older medical inpatients. *Dement Geriatr Cogn Disord*. 2003; 15(4):199-206.

Arias P, Chouza M, Vivas J et al. Effect of whole body vibration in Parkinson's disease: a controlled study. *Mov Disord*. 2009;24:891–8.

Armstrong RB, Phelps RO. Muscle fiber type composition of the rat hindlimb. *Am J Anat.* 1984;171:259–72

Armstrong WJ, Grinnell DC, Warren GS. The acute effect of whole-body vibration on the vertical jump height. *J Strength Cond Res*. 2010;24(10):2835-9.

Armstrong WJ, Nestle HN, Grinnell DC et al. The acute effect of whole-body vibration on the Hoffmann reflex. *J Strength Cond Res*. 2008;22: 471–6.

Asselin P, Spungen AM, Muir JW et al. Transmission of low-intensity vibration through the axial skeleton of persons with spinal cord injury as a potential intervention for preservation of bone quantity and quality. *J Spinal Cord Med*. 2011; 34(1):52–9.

Astrom M, Asplund K, Astrom T. Psychosocial function and life satisfaction after stroke. *Stroke*. 1992;23:527-31.

Au-Yeung S, Ng J, Lo S. Does balance or motor impairment discriminate the ambulatory status of stroke survivors? *AmJ Phys Med RehabiL*. 2003;82:279-83.

Avelar, Simão, Tossige-Gomes et al. Oxygen consumption and heart rate during repeated squatting exercises with or without whole-body vibration in the elderly. *J Strength Cond Res*. 2011,25(12): 3495-500.

Bai YL, Hu YS, Wu Y et al. Long-term three-stage rehabilitation intervention alleviates spasticity of the elbows, fingers, and plantar flexors and improves activities of daily living in ischemic stroke patients: a randomized, controlled trial. *Neuroreport*. 2014;25(13):998-1005.

Barry SC, Gallagher CG. Corticosteroids and skel- etal muscle function in cystic fibrosis. *J Appl Physiol*. 2003;95(4):1379-84.

Batchelor F, Hill K, Mackintosh S et al. What works in falls prevention after stroke?: a systematic review and meta-analysis. *Stroke*. 2010;41(8):1715-22.

Batchelor F, K. Hill, S. Mackintosh et al. What Works in Falls Prevention After Stroke? A Systematic Review and Meta-Analysis. *Stroke*. 2010; 41:1715-22.

Baum K, Votteler T, Schiab J. Efficiency of vibration exercise for glycemic control in type 2 diabetes patients. *Int J Med Sci*. 2007;4(3):159-63.

Bautmans I, Van Hees E, Lemper JC et al. The feasi- bility of Whole Body Vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility: a randomised controlled trial. *BMC Geriatr*. 2005;5:17.

Bazett-Jones DM, Finch HW, Dugan EL et al. Comparing the effects of various whole-body vibration accelerations on counter-movement jump performance. *J Sports Sci Med.* 2008;7(1):144-50.

Beaton DE, Bombardier C, Guillemin F et al. Guidelines for the process of cross-cultural adaptation of self-report measures. *Spine.* 2000; 25: 3186-91.

Beck BR, Norling TL. The effect of 8 mos of twice-weekly low- or higher intensity whole body vibration on risk factors for postmenopausal hip fracture. *Am J Phys Med Rehabil.* 2010;89:997-1009.

Bedient AM, Adams JB, Edwards DA et al. Displacement and frequency for maximizing power output resulting from a bout of whole-body vibration. *J Strength Cond Res*. 2009 ;23(6):1683-7.

Belavý DL, BellerG, Armbrecht G, et al. Evidence for an additional effect of whole-body vibration above resistive exercise alone in preventing bone loss during prolonged bed rest. *Osteoporos Int*. 2011;22:1581–91.

Berschin G, Sommer B, Behrens A et al. Whole Body Vibration Exercise Protocol versus a Standard Exercise Protocol after ACL Reconstruction: A Clinical Randomized Controlled Trial with Short Term Follow-Up. *J Sports Sci Med*. 2014;13(3):580-9.

Berschin G, Sommer B, Behrens A et al. Whole Body Vibration Exercise Protocol versus a Standard Exercise Protocol after ACL Reconstruction: AClinical Randomized Controlled Trial with Short Term Follow-Up. *J Sports Sci Med.* 2014;13(3):580-9.

Bhakta B.B., Cozens J.A., Chamberlain M.A., et al. Impact of botulinum toxin type A on disability and carer burden due to arm spasticity after stroke: a randomized double blind placebo controlled trial. *J Neurol Neurosurg Psychiatry*. 2000; 69: 217-21.

Bhogal SK, Teasell RW, Foley NC et al. The PEDro scale provides a more comprehensive measure of methodological quality than the Jadad scale in stroke rehabilitation literature. *J Clin Epidemiol*. 2005;58:668–73.

Bickenbach JE, Chatterji S, Badley EM et al. Models of disablement, universalism and the international classification of impairments, disabilities and handicaps. *Soc Sci Med*. 1999; 48: 1173–87.

Bogaerts A, Delecluse C, Claessens AL et al. Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men: a 1-year randomized controlled trial. *J Gerontol A Biol Sci Med Sci*. 2007a;62(6):630-5.

Bogaerts A, Verschueren S, Delecluse C et al. Effects of whole body vibration training on postural control in older individuals: a 1 year randomized controlled trial. *Gait Posture*. 2007b;26(2):309-16.

Bogaerts AC, Delecluse C, Claessens AL et al. Effects of whole body vibration training on cardiorespiratory fitness and muscle strength in older individuals (a 1-year randomised controlled trial). *Age Ageing*. 2009,38:448-54.

Bohannon BW, Smith MB. Interrater reliability of a Modified Ashworth Scale of muscle spasticity. *Phys Ther*. 1987;67(2):206-7.

Bohannon RW, Andrews AW. Correlation of knee extensormuscle torque and spasticity with gait speed in patients with stroke. *Arch Phys Med Rehabil.* 1990;71:330–3.

Bohannon RW, Walsh S. Association of paretic lower extremity muscle strength and standing balance with stair climbing ability in patients with stroke. *Journal of Stroke and Cerebrovascular Disorders*. 1991;1: 129–33.

Bohannon RW. Muscle strength and muscle training after stroke. *J Rehabil Med*. 2007;39: 14-20.

Böhm M, Cotton D, Foster L, et al. Impact of resting heart rate on mortality, disability and cognitive decline in patients after ischaemic stroke. *Eur Heart J*. 2012;33:2804-12.

Boissy P, Bourbonnais D, Carlotti MM et al. Maximal grip force in chronic stroke participants and its relationship to global upper extremity activity. *Clil Rehabil.* 1999;13: 354–62.

Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med*. 1970;2: 92–8.

Bosco C, Cardinale M, Tsarpela O. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur J Appl Physiol Occup Physiol*. 1999;79:306–11.

Bosco C, Iacovelli M, Tsarpela O et al. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol*. 2000; 81: 449–54.

Bosco, C , Cardinale, M., Tsarpela, O et al. The influence of whole body vibration on the mechanical behaviour of skeletal muscle. *Biol Sport*. 1998;15(3):157-64.

Bouffioulx E, Arnould C, Vandervelde L et al. Changes in satisfaction with activities and participitation between acute, post-acute and chronic stroke phases: a responsiveness study of the SATIS-Stroke questionnaire. *J Rehabil Med.* 2010 ;42(10):944-8.

Bramlett HM, Dietrich WD, Marcillo A, et al. Effects of low intensity vibration on bone and muscle in rats with spinal cord injury. *Osteoporos Int.* 2014;25(9):2209-19.

Braz Júnior DS, Dornelas de Andrade A, Teixeira AS et al. Whole-body vibration improves functional capacity and quality of life in patients with severe chronic obstructive pulmonary disease (COPD): a pilot study. *Int J Chron Obstruct Pulmon Dis.* 2015;10:125-32.

Broekmans T, Roelants M, Alders G et al. Exploring the effects of a 20-week whole-body vibration training programme on leg muscle performance and function in persons with multiple sclerosis. *J Rehabil Med.* 2010;42:866–72.

Broekmans T, Roelants M, Alders G et al. Exploring the effects of a 20-week whole-body vibration training programme on leg muscle performance and function in persons with multiple sclerosis. *J Rehabil Med.* 2010;42(9):866-72.

Brogardh C, Flansbjer U-B, Lexell J. No specific effect of whole-body vibration training in chronic stroke: a double-blind randomized controlled study. *Arch Phys Med Rehabil.* 2012;93(2):253-8.

Brogårdh C, Flansbjer UB, Lexell J. No specific effect of whole-body vibration training in chronic stroke: a double-blind randomized controlled study. *Arch Phys Med Rehabil.* 2012a;93:253–8.

Brogårdh C, Lexell J. Effects of cardiorespiratory fitness and muscle-resistance training after stroke. *PM R*. 2012b;4(11):901-7.

Brown WF and Snow R. Denervation in hemiplegic muscles. *Stroke*. 1990;21: 1700-4.

Bruyere O, Wuidart MA, Di Palma E, et al. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. *Arch Phys Med Rehabil*. 2005;86:303-7.

Buckinx F, Beaudart C, Maquet D et al. Evaluation of the impact of 6-month training by whole body vibration on the risk of falls among nursing home residents, observed over a 12-month period: a single blind, randomized controlled trial. *Aging Clin Exp Res*. 2014;26(4):369-76.

Bullock N, Martin DT, Ross A et al. Acute effect of whole-body vibration on sprint and jumping performance in elite skeleton athletes. *J Strength Cond Res*. 2008;22(4):1371-4.

Burke D. Spasticity as an adaptation to pyramidal tract injury. *Advances in Neurology* 1988;47: 401–18.

Campos TF, Rodrigues CA, Farias IM, et al. Comparison of instruments for sleep, cognition and function evaluation in stroke patients according to the international classification of functioning, disability and health (ICF). *Rev Bras Fisioter*. 2012;16(1):23-9.

Canning C, Ada L, Adams R, O'Dwyer NJ. Loss of strength contributes more to physical disability after stroke than loss of dexterity. *Clin Rehabil*. 2004; 18: 300–8.

Cardinale M, Leiper J, Erskine J etal. The acute effects of different whole body vibration amplitudes on the endocrine system of young healthy men: a preliminary study. *Clin Physiol Funct Imaging*. 2006;26:380–4.

Cardinale M, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res*. 2003;17:621–4.

Cardinale M, Lim J. The acute effects of two different whole body vibration frequencies on vertical jump performance. *Med Sport*. 2003;56(4):287–92.

Cardinale M, Soiza RL, Leiper JB et al. Hormonal responses to a single session of whole body vibration exercise in older individuals. *Br J Sports Med*. 2010; 44: 284–8.

CARDiNALE, M., and C. Bosco. The use of vibration as an exercise intervention. Exerc. *Sport Sci. Rev*. 2003;31:3-7.

Carod-Artal J, Egido JA, Gonzalez JL et al. Quality of life among stroke survivors evaluated 1 year after stroke: experience of a stroke unit. *Stroke.* 2000;31:2995-3000.

Carstanjen B, Balali M, Gajewski Z et al. Short-term whole body vibration exercise in adult healthy horses. *Pol J Vet Sci.* 2013;16(2):403-5.

Carvalho C, Willen C, Sunnerhagen KS. Relationship between walking function and one-legged bicycling test in subjects in the later stage post-stroke. *J Rehabil Med*. 2008;40:721-6.

Castillo AB, Alam I, Tanaka SM et al. Low-amplitude, broad-frequency vibration effects on cortical bone formation in mice. *Bone.* 2006 ;39(5):1087-96.

Centre for Evidence-Based Physiotherapy. The George Institute for Global Health. Physiotherapy Evidence Database Web site. Available at: http://www.pedro.org.au. Accessed May 7, 2013.

Cerniauskaite M, Quintas R, Koutsogeorgou E et al. Quality-of-life and disability in patients with stroke. *Am J Phys Med Rehabil*. 2012;91(13 Suppl 1):S39-47.

Chae J, Yang G, Park BK, Labatia I. Muscle weakness and cocontraction in upper limb hemiparesis: relationship to motor impairment and physical disability. *Neurorehabil Neural Repair*. 2002;16: 241–8.

Chan KS, Liu CW, Chen TW et al. Effects of a single session of whole body vibration on ankle plantarflexion spasticity and gait performance in patients with chronic stroke: a randomized controlled trial. *Clin Rehabil*. 2012;26:1087–95.

Chau JP, Thompson DR, Twinn S et al. Determinants of participation restriction among community dwelling stroke survivors: a path analysis. *BMC Neurol*. 2009;9:49.

Chau PH, Woo J, Goggins WB et al. Analysis of spatio-temporal variations in stroke incidence and case-fatality in Hong Kong. *Geospat Health*. 2011;6(1):13-20.

Cheng HY, Ju YY, Chen CL et al. Effects of whole body vibration on spasticity and lower extremity function in children with cerebral palsy. *Hum Mov Sci*. 2015;39:65-72.

Cheung WH, Mok HW, Qin L et al. High-frequency whole-body vibration improves balancing ability in elderly women. Arch Phys Med Rehabil. 2007;88(7):852-7.

Cheung WH, Sun MH, Zheng YP, et al. Stimulated angiogenesis for fracture healing augmented by low-magnitude, high-Frequency vibration in a rat model-evaluation of pulsed-wave doppler, 3-D power doppler ultrasonography and micro-Ct microangiography. *Ultrasound Med Biol*. 2012; 38:2120–9.

Chow DH, Leung KS, Qin L, et al. Low-magnitude high-frequency vibration (LMHFV) enhances bone remodeling in osteoporotic rat femoral fracture healing. *J Orthop Res.* 2011;29:746–52.

Chow JW, Stokic DS. Intersegmental coordination of gait after hemorrhagic stroke. *Exp Brain Res*. 2015;233(1):125-35.

Christiansen BA, Silva MJ. The effect of varying magnitudes of whole-body vibration on several skeletal sites in mice. *Ann Biomed Eng.* 2006;34:1149–56.

Chung PH, Lin GL, Liu C et al. The effects of tai chi chuan combined with vibration training on balance control and lower extremity musclepower. *J Sports Sci Med*. 2013;12:19-26.

Claerbout M, Gebrara B, Ilsbroukx S et al. Effects off 3 weeks' whole body vibration training on muscle strength and functional mobility in hospitalized persons with multiple sclerosis. *Mult Scler*. 2012;18:498–505.

Clarke PJ, Lawrence JM, Black SE. Changes in quality of life over the first year after stroke: findings from the Sunnybrook Stroke Study. *J Stroke Cerebrovasc Dis.* 2000;9: 121–7.

Cochrane and Stannard. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. *Br J Sports Med*. 2005; 39(11): 860–5.

Cochrane D. The sports performance application of vibration exercise for warm-up, flexibility and sprint speed. *Eur J Sport Sci*. 2013;13(3):256-71.

Cochrane DJ, Legg SJ, Hooker MJ. The short-term effect of whole-body vibration training on vertical jump, sprint, and agility performance. *J Strength Cond Res.* 2004;18(4):828-32.

Cochrane DJ, Sartor F, Winwood K et al. A comparison of the physiologic effects of acute whole-body vibration exercise in young and older people. *Arch Phys Med Rehabil.* 2008;89:815-21.

Cochrane DJ, Sartor F, Winwood K et al. A comparison of the physiologic effects of acute whole-body vibration exercise in young and older people. *Arch Phys Med Rehabil.* 2008,89:815-21.

Cochrane DJ. The potential neural mechanisms of acute indirect vibration. *J Sports Sci Med.* 2011;10:19-30.

Colebatch JG1, Gandevia SC. The distribution of muscular weakness in upper motor neuron lesions affecting the arm. *Brain*. 1989;112 (Pt 3):749-63.

Coons SJ, Rao S, Keininger DL et al. A comparative review of quality of life instruments. *Pharmacoeconomics*. 2000; 17: 13-35.

Cormie P, Deane RS, Triplett NT et al. Acute effects of whole-body vibration on muscle activity, strength, and power. *J Strength Cond Res*. 2006;20(2):257-61.

Corriveau H, Hebert R, Raiche M et al. Evaluation of postural stability in the elderly with stroke. *Arch Phys Med Rehabil.* 2004;85: 1095-101.

Cott C, Wiles R, Devitt R. Continuity, transition and participation: preparing clients for life in the community post-stroke. *Disabil Rehabil*. 2007;29:1566-75.

Courbon A, Calmels P, Roche F et al. Relationship between maximal exercise capacity and walking capacity in adult hemiplegic stroke patients. *Am J Phys Med Rehabil*. 2006;85:436-442.

Da Silva ME, Fernandez JM, Castillo E et al. Influence of vibration training on energy expenditure in active men. *J Strength Cond Res*. 2007;21(2):470-5.

Dallas G, Kirialanis P, Mellos V. The acute effect of whole body vibration training on flexibility and explosive strength of young gymnasts. *Biol Sport*. 2014a;31(3):233-7.

Dallas G, Smirniotou A, Tsiganos G, et al. Acute effect of different stretching methods on flexibility and jumping performance in competitive artistic gymnasts. *J Sports Med Phys Fitness*. 2014b;54(6):683-90.

Darlington AS, Dippel DW, Ribbers GM et al. Coping strategies as determinants of quality of life in stroke patients: a longitudinal study. *Cerebrovasc Dis*. 2007;23(5-6):401-7.

Dattola R, Girlanda P, Vita G et al. Muscle rearrangement in patients with hemiparesis after stroke: an electrophysiological and morphological study. *European neurology*. 1993;33: 109-114.

Davis R, Sanborn C, Nichols D et al. The effects of whole body vibration on bone mineral density for a person with a spinal cord injury: a case study. *Adapted Physical Activity Quarterly*. 2010; 27(1):60–72.

de Haan RJ, Limburg M, Van der Meulen JH et al. Quality of life after stroke: Impact of stroke type and lesion location. *Stroke*. 1995;26:402-8.

De Haart M, Geurts A, Huidekoper S et al. Recovery of standing balance in post-actite stroke patients: a rehabilitation cohort study. *Arch Phys Med Rehabil*. 2004;85:886-95.

de Ruiter CJ, van der Linden RM, van der Zijden MJ et al. Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. *Eur J Appl Physiol*. 2003; 88(4-5):472-5.

De Wit L, Putman K, Devos H, Brinkmann N et al. Long-term prediction of functional outcome after stroke using single items of the Barthel Index at discharge from rehabilitation centre. *Disabil Rehabil*. 2014;36(5):353-8.

del Pozo-Cruz B, Adsuar JC et al. Using whole-body vibration training in patients affected with common neurological diseases: a systematic literature review. *J Altern Complement Med*. 2012;18(1):29-41.

del Pozo-Cruz B, Hernández Mocholí MA et al. Effects of whole body vibration therapy on main outcome measures for chronic non-specific low back pain: a single-blind randomized controlled trial. *J Rehabil Med*. 2011;43(8):689-94.

Delecluse C, Roelants M, Diels R et al. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. *Int J Sports Med.* 2005;26(8):662-8.

Delecluse C, Roelants M, Verschueren S. Strength in- crease after whole-body vibration compared with resist- ance training. *Med Sci Sports Exerc*. 2003;35:1033-41.

Desalu OO, Wahab KW, Fawale B et al. A review of stroke admissions at a tertiary hospital in rural Southwestern Nigeria. *Ann Afr Med*. 2011;10(2):80-5.

Desrosiers J, Noreau L, Rochette A, et al. Predictors of long-term participation after stroke. *Disabil Rehabil*. 2006;28(4):221-30.

Di Giminiani R, Manno R, Scrimaglio R et al. Effects of individualized whole-body vibration on muscle flexibility and mechanical power. *J Sports Med Phys Fitness.* 2010;50(2):139-51.

Di Giminiani R, Masedu F, Tihanyi J et al. The interaction between body position and vibration frequency on acute response to whole body vibration. *J Electromyogr Kinesiol*. 2013;23:245-51.

Di Loreto C, Ranchelli A, Lucidi P et al. Effects of whole-body vibration exercise on the endocrine system of healthy men. *J Endocrinol Invest*. 2004; 27: 323–7.

Dickin DC, McClain MA, Hubble RP et al. Changes in postural sway frequency and complexity in altered sensory environments following whole body vibrations. *Hum Mov Sci.* 2012;31(5):1238-46.

Doan QV, Brashear A, Gillard PJ et al. Relationship between disability and health-related quality of life and caregiver burden in patients with upper limb poststroke spasticity. *PM R*. 2012;4(1):4-10.

Dolny DG, Reyes GF. Whole body vibration exercise: training and benefits. *Curr Sports Med Rep.* 2008;7(3):152-7.

Dorsch S, Ada L, Canning CG et al. The strength of the ankle dorsiflexors has a significant contribution to walking speed in people who can walk independently after stroke: an observational study. *Arch Phys Med Rehabil*. 2012;93(6):1072-6.

Dugan, S. A., & Bhat, K. P. Biomechanics and analysis of running gait. *Phys Med Rehabil Clin N Am.* 2005;16,:603–21.

Duncan P, Studenski S, Richards L, et al. Randomized clinical trial of therapeutic exercise in subacute stroke. *Stroke*. 2003;34:2173-80.

Earl JE, Schmitz RJ, Arnold BL. Activation of the VMO and VL during dynamic mini-squat exercises with and without isometric hip adduction. *J Electromyogr Kinesiol*. 2001;11(6):381-6.

Ebersbach G, Edler D, Kaufhold O et al. Whole body vibration versus conventional physiotherapy to improve balance and gait in Parkinson's disease. *Arch Phys Med Rehabil.* 2008;89:399–403.

Eckhardt H, Wollny R, Müller H et al. Enhanced myofiber recruitment during exhaustive squatting performed as whole-body vibration exercise. *J Strength Cond Res.* 2011;25:1120-5.

Edwards RG, McCutcheon EP, Knapp CF. Cardiovascular changes produced by brief whole-body vibration of animals. *J Appl Physiol.* 1972;32(3):386-90.

Eklund G, Hagbarth KE. Normal variability of tonic vibration reflexes in man. *Exp Neurol.* 1966;16:80–92.

El-Shamy SM. Effect of whole
body vibration on muscle strength and balance in diplegic cerebral palsy: a randomized controlled trial. *Am J Phys Med Rehabil.* 2014;93(2):114-21.

Eng JJ, Chu KS, Dawson AS et al. Functional walk tests in individuals with stroke. Relation to perceived exertion and myocardial exertion. *Stroke*. 2002;33:756–61.

Eng JJ, Chu KS, Dawson AS et al. Functional walk tests in individuals with stroke: relation to perceived exertion and myocardial exertion. Stroke. 2002;33:756-61.

Eng JJ, Lomaglio MJ, Macintyre DL. Muscle torque preservation and physical activity in individuals with stroke. *Med Sci Sports Exerc*. 2009;41(7):1353-60.

Eng JJ, Pang MY, Ashe MC. Balance, falls, and bone health: role of exercise in reducing fracture risk after stroke. *J Rehabil Res Dev.* 2008;45(2):297-313.

EngJ, Chu K. Reliability and comparison of weight-bearing ability during standing tasks for individuals with chronic stroke. *Arch Phys Med Rehabil*. 2002;83:l 138-44.

English C, McLennan H, Thoirs K et al. Loss of skeletal muscle mass after stroke: a systematic review. *Int J Stroke*. 2010;5(5):395-402

Ephraim PL, MacKenzie EJ, Wegener ST et al. Environmental barriers experienced by amputees: the Craig Hospital Inventory of Environmental Factors–Short Form. *Arch Phys Med Rehabil*. 2006;87:328-33.

Eriksson G1, Carolyn Baum M, Wolf TJ et al. Perceived participation after stroke: the influence of activity retention, reintegration, and perceived recovery. *Am J Occup Ther*. 2013;67(6):e131-8.

et al. Preliminary results on the mobility after whole body vibration in immobilized children and adolescents. *J Musculoskelet Neuronal Interact.* 2007;7(1):77-81.

Feigin VL, Lawes CM, Bennett DA et al. Stroke epidemiology: a review of population-based studies of incidence, prevalence, and case-fatality in the late 20th century. *Lancet Neurol*. 2003;2(1):43-53.

Feigin VL, Lawes CMM, Bennett DA et al. Worldwide stroke incidence and early case fatality reported in 56 population-based studies: a systematic review. *Lancet Neurol*. 2009;8(4):355–69.

Flansbjer U-B, Downham D, Lexell J. Knee muscle strength, gait performance, and perceived participation after stroke. *Arch Phys Med Rehabil*. 2006;87(7):974–80.

Flansbjer UB, Lexell J, Brogårdh C. Long-term benefits of progressive resistance training in chronic stroke: a 4-year follow-up. *J Rehabil Med*. 2012;44(3):218-21.

Flieger J, Karachalios T, Khaldi L et al. Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. *Calcif Tissue Int*. 1998;63:510–4.

Flieger J, Karachalios T, Khaldi L et al. Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. *Calcif Tissue Int*. 1998; 63: 510-4.

Forster A and Young J. Incidence and consequences of falls due to stroke: a systematic inquiry. *BMJ*. 1995; 311: 83-6.

Fougeyrollas P, Noreau L, St-Michel G et al. Measure of the quality of the environment, Version 20. Lac St-Charles, Québec, Canada, International Network of the Disability Creation Process; Canadian Society for the International Classification of Impairments, Disabilities and Handicaps; 1999.

Foulkes MA, Wolf PA, Price TR et al. The stroke data bank: design, methods, and baseline characteristics. *Stroke*. 1988; 19: 547–54.

Fransson EI, Nyberg ST, Heikkilä K et al. Job Strain and the Risk of Stroke: An Individual-Participant Data Meta-Analysis. *Stroke*. 2015;46(2):557-9.

Fu, C.L., Yung, S.H., Law, K.Y et al. The effect of early whole-body vibration therapy on neuromuscular control after anterior cruciate ligament reconstruction: a randomized controlled trial. *American Journal of Sports Medicine*. 2013;41, 804-14.

Fuentes B, Tejedor ED. Stroke. The worldwide burden of stroke-a blurred photograph. *Nat Rev Neurol*. 2014;10:127-8.

Fugl-Meyer AR, Jaasko L, Leyman I et al. The post-stroke hemiplegic patient. a method for evaluation of physical performance. *Scand J Rehabil Med*. 1975;7:13-31.

Furness T, Bate N, Welsh L et al. Efficacy of a whole-body vibration intervention to effect exercise tolerance and functional performance of the lower limbs of people with chronic obstructive pulmonary disease. *BMC Pulm Med*. 2012;12:71.

Furness T, Joseph C, Naughton G et al. Benefits of whole-body vibration to people with COPD: a community-based efficacy trial. *BMC Pulm Med*. 2014;14:38.

Furness TP, Maschette WE, Lorenzen C et al. Efficacy of a whole-body vibration intervention on functional performance of community-dwelling older adults. *J Altern Complement Med.* 2010;16(7):795-7.

Furness TP, Maschette WE. Influence of whole body vibration platform frequency on neuromuscular performance of community-dwelling older adults. *J Strength Cond Res*. 2009;23(5):1508-13.

Gadidi V, Katz-Leurer M, Carmeli E et al. Long-term outcome poststroke: predictors of activity limitation and participation restriction. *Arch Phys Med Rehabil*. 2011;92:1802-8.

Games KE, Sefton JM. Whole-body vibration influences lower extremity circulatory and neurological function. *Scand J Med Sci Sports*. 2013;23(4):516-23.

Garland SJ, Willems DA, Ivanova TD et al. Recovery of standing balance and functional mobility after stroke. *Arch Phys Med Rehabil*. 2003;84(12):1753-9.

Garman R, Gaudette G, Donahue LR et al. Low-level accelerations applied in the absence of weight bearing can enhance trabecular bone formation. *J Orthop Res*. 2007;25(6):732-40.

Gaßner H, Janzen A, Schwirtz A, et al.
Random Whole Body Vibration over 5 Weeks Leads to Effects Similar to Placebo:
A Controlled Study inParkinson's Disease. *Parkinsons Dis*. 2014;2014:386495.

Gemperline JJ, Allen S, Walk D et al. Characteristics of motor unit discharge in subjects with hemiparesis. *Muscle & nerve*. 1995;18:1101-14.

Gerodimos V., Zafeiridis A., Karatrantou K et al. The acute effects of different whole-body vibration amplitudes and frequencies on flexibility and vertical jumping performance. *J Sci Med Sport*. 2010;13:438-43.

Geyh S, Cieza A, Kollerits B et al. Content comparison of health-related quality of life measures used in stroke based on the international classification of functioning, disability and health (ICF): a systematic review. *Qual Life Res*. 2007;16(5):833-51.

Gialanella B, Santoro R, Ferlucci C. Predicting outcome after stroke: the role of basic activities of daily living predicting outcome after stroke. *Eur J Phys Rehabil Med*. 2013;49(5):629-37.

Gialanella B, Santoro R, Ferlucci C. Predicting outcome after stroke: the role of basis activities of daily living. *Eur J Phys Rehabil Med*. 2012;48:1–9.

Gladstone DJ, Danells CJ, Black SE. The fugl-meyer assessment of motor recovery after stroke: a critical review of its measurement properties. *Neurorehabil Neural Repair*. 2002; 16: 232-40.

Gloeckl R, Heinzelmann I, Baeuerle S et al. Effects of whole body vibration in patients with chronic obstructive pulmonary disease--a randomized controlled trial. *Respir Med*. 2012;106(1):75-83.

Gloeckl R, Heinzelmann I, Kenn K. Whole body vibration training in patients with COPD: A systematic review. *Chron Respir Dis*. 2015.

Golomb BA, Vickrey BG, Hays RD. A review of health-related quality-of-life measures in stroke. *Pharmacoeconomics*. 2001;19(2):155-85.

Goodship AE, Lawes TJ, Rubin CT. Low-magnitude high-frequency mechanical signals accelerate and augment endochondral bone repair: preliminary evidence of efficacy. *J Orthop Res*. 2009;27:922–30.

Gorza L, Gundersen K, Lo¨mo T et al. Slow-to-fast transformation of denervated soleus muscles by chronic high-frequency stimulation in the rat. *J Physiol (Lond).* 1988;398:177–89.

Gowland C, Stratford P, Ward M, et al. Measuring physical impairment and disability with the Chedoke-McMaster Stroke Assessment. *Stroke.* 1993:24:58-63.

Gracies J-M. Pathophysiology of spastic paresis. I: Paresis and soft tissue changes. *Muscle Nerve*. 2005;31(5):535–51.

Gray DB, Hollingsworth HH, Stark S et al. A subjective measure of environmental facilitators and barriers to participation for people with mobility limitations. *Disabil Rehabil.* 2008;30:434-57.

Greulich T, Nell C, Koepke J et al. Benefits of whole body vibration training in patients hospitalised for COPD exacerbations - a randomized clinical trial. *BMC Pulm Med.* 2014;14:60.

Gunaydin R, Karatepe AG, Kaya T et al. Determinants of quality of life (QoL) in elderly stroke patients: a short-term follow-up study. *Arch Gerontol Geriatr*. 2011;53(1):19-23.

Gusi N, Raimundo A, Leal A. Low-frequency vibratory exercise reduces the risk of bone fracture more than walking: a randomized controlled trial. *BMC Musculoskelet Disord*. 2006;7:92.

Guyatt G, Feeny D, Patrick D.Measuring health-related quality of life. *Ann Intern Med.* 1993; 118: 622-9.

Haas CT, Buhlmann A, Turbanski S et al. Proprioceptive and sensorimotor performance in Parkinson's disease. *Res Sports Med*. 2006;12:273–87.

Haas CT, Turbanski S, Kessler K et al. The effects of random wholebody-vibration on motor symptoms in Parkinson's disease. *NeuroRehabilitation*. 2006;21:29 –36.

Hak L, Houdijk H, van der Wurff P et al. Stepping strategies used by post-stroke individuals to maintain margins of stability during walking. *Clin Biomech (Bristol, Avon).* 2013;28(9-10):1041-8.

Hannah R, Minshull C, Folland JP. Whole-body vibration does not influence knee joint neuromuscular function or proprioception. *Scand J Med Sci Sports*. 2013;23(1):96-104.

Hannan MT, Cheng DM, Green E et al. Establishing the compliance in elderly women for use of a low level mechanical stress device in a clinical osteoporosis study. *Osteoporos Int.* 2004;15:918-26.

Hardie K, Hankey GJ, Jamrozik K et al. Ten-year risk of first recurrent stroke and disability after first-ever stroke in the Perth Community Stroke Study. *Stroke*. 2004;35:731-5.

Harris J. E., Eng J. J., Marigold D. S et al. Relationship of balance and mobility to fall incidence in people with chronic stroke. *Phys Ther*. 2005;85:150- 8.

Harris JE, Eng JJ, Marigold DS et al. Relationship of balance and mobility to fall incidence in people with chronic stroke. *Phys Ther*. 2005;85(2):150-8.

Harris JE, Eng JJ. Paretic upper-limb strength best explains arm activity in people with stroke. *Phys Ther*. 2007;87(1):88-97.

Harrison-Felix, C. The Craig Hospital Inventory of Environmental Factors. The Center for Outcome Measurement in Brain Injury. 2001;Available from: http://www.tbims.org/combi/chief.

Hazell TJ, Jakobi JM, Kenno KA. The effects of whole-body vibration on upper- and lower-body EMG during static and dynamic contractions. *Appl Physiol Nutr Metab*. 2007;32:1156-63.

Hazell TJ, Kenno KA, Jakobi JM. Evaluation of muscle activity for loaded and unloaded dynamic squats during vertical whole-body vibration. *J Strength Cond Res*. 2010;24(7):1860–5.

Hazell TJ, Lemon PW. Synchronous whole-body vibration increases VO2 during and following acute exercise. *Eur J Appl Physiol*. 2012;112:413-20.

Hazell TJ, Thomas GW, Deguire JR et al. Vertical whole-body vibration does not increase cardiovascular stress to static semi-squat exercise. *Eur J Appl Physiol*. 2008;104:903-8.

Hedges L, Olkin I. Statistical methods for meta-analysis. *Orlando: Academic Press*; 1985.

Hermens HJ, Freriks B, Disselhorst-Klug C et al. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10(5):361–74.

Herrero AJ, Menéndez H, Gil L, et al. Effects of whole-body vibration on blood flow and neuromuscular activity in spinal cord injury. *Spinal Cord*. 2011;49(4):554-9.

Hilgers C, Mündermann A, Riehle H et al. Effects of whole-body vibration training on physical function in patients with multiple sclerosis. *NeuroRehabilitation*. 2013;32(3):655-63.

Holbrook M, Skilbeck CE. An activities index for use with stroke patients. *Age Ageing*. 1983;12:166–70.

Horstman AM, Beltman MJ, Gerrits KH, et al. Intrinsic muscle strength and voluntary activation of both lower limbs and functional performance after stroke. *Clin Physiol Funct Imaging.* 2008;28:251-61.

Hospital Authority. Hospital Authority statistical report 2012-2013. *Hong kong: Hospital Authority*, 2014.

Hoy DG, Smith E, Cross M, et al. The global burden of musculoskeletal conditions for 2010: an overview of methods. *Ann Rheum Dis.* 2014; 73:982–9.

Hsieh YF, Turner CH. Effects of loading frequency on mechanically induced bone formation. *J Bone Miner Res*. 2001;16:918–24.

Hsu AL, Tang PF, Jan MH. Analysis of impairments influencing gait velocity and asymmetry of hemiplegic patients after mild to moderate stroke. *Arch Phys Med Rehabil.* 2003;84(8):1185-93.

Hsueh IP, Chen JH, Wang CH et al. Development of a computerized adaptive test for assessing activities of daily living in outpatients with stroke. *Phys Ther*. 2013;93(5):681-93.

Hsueh IP, Hsieh CL. A revalidation of the Frenchay Activities Index in stroke: a study in Taipei area. *Formos J Med*. 1997; 1:696-702.

Hsueh IP, Huang SL, Chen MH et al. Evaluation of stroke patients with the extended activities of daily living scale in Taiwan. *Disabil Rehabil*. 2000;22:495-500.

Hsueh IP, Wang WC, Sheu CF et al. Rasch analysis of combining two indices to assess comprehensive ADL function in stroke patients. *Stroke*. 2004;35(3):721-6.

Huang CC, Tseng TL, Huang WC, et al. Whole-body vibration training effect on physical performance and obesity in mice. *Int J Med Sci*. 2014;11(12):1218-27.

Hubli M, Bolliger M, Limacher E et al. Spinal neuronal dysfunction after stroke. *Exp Neurol*. 2012;234(1):153-60.

Hussey J, Gormley J, Leen G et al. Peripheral mus- cle strength in young males with cystic fibrosis. *J Cyst Fibros*. 2002;1(3):116-21.

Hutin E, Pradon D, Barbier F et al. Walking velocity and lower limb coordination in hemiparesis. *Gait Posture*. 2012;36(2):205-11.

Ikai T, Kamikubo T, Takehara I, et al. Dynamic postural control of patients with hemiparesis. *Am J Phys Med Rehabil.* 2003;82:463-9.

Iodice P, Bellomo RG, Gialluca G et al. Acute and cumulative effects of focused high-frequency vibrations on the endocrine system and muscle strength. *Eur J Appl Physiol*. 2011;111(6):897-904.

Issurin VB, Liebermann DG, Tenenbaum G. Effect of vibratory stimulation training on maximal force and flexibility. *J Sports Sci*. 1994;12:561–6.

Issurin VB, Tenenbaum G. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J Sports Sci*. 1999;17(3):177-82.

Issurin, VB. Vibrations and their applications in sport. A review. *J Sports Med Phys Fitness*. 2005;45:324–36.

Iwamoto J, Takeda T, Sato Y, Uzawa M. Effect of whole-body vibration exercise on lumbar bone mineral density, bone turnover, and chronic back pain in post-menopausal osteoporotic women treated with alendronate. *Aging Clin Exp Res*. 2005;17:157-63.

Jackson, K. J., Merriman, H. L.,Vanderburgh, P. M et al. Acute effects of whole-body vibration on lower extremity muscle performance in persons with multiple sclerosis. *J Neurol Phys Ther*. 2008;32(4):171-6.

JacobsP.L.,BurnsP. Acuteenhancement of lower-extremity dynamic strength and flexibility with whole-body vibration. *J Strength Cond Res*. 2009;2:51–7.

Jakobsen MD, Sundstrup E, Andersen CH et al. Muscle activity during knee-extension strengthening exercise performed with elastic tubing and isotonic resistance. *Int J Sports Phys Ther*. 2012;7(6):606-16.

Jette AM. Toward a common language for function, disability, and health. *Phys Ther*. 2006;86:726–34.

Johansson BB, Jadback G, Norrving B, et al. Evaluation of long-term functional status in first-ever stroke patients in a defined population. *Scand J Rehabil Med.* 1992;26:105-14 (suppl).

Jones MT. Progressive-Overload Whole-Body Vibration Training as Part of Periodized, Off-season Strength Training in Trained Women Athletes. *J Strength Cond Res*. 2014;28(9):2461-9.

Jordan MJ, Norris SR, Smith DJ et al. Vibration training: an overview of the area, training consequences, and future considerations. *J Strength Cond Res*. 2005;19(2):459–66.

Jrgensen H, Nakayama H, Raaschou H et al. Recovery of walking function in stroke patients: the Copenhagen Stroke Study. *Arch Phys Med and Rehabili*. 1995;76:27–32.

Judex S, Boyd S, Qin YX et al. Adaptations of trabecular bone to low magnitude vibrations result in more uniform stress and strain under load. *Ann Biomed Eng*. 2003;31:12–20.

Judex S, Gupta S, Rubin C. Regulation of mechanical signals in bone. *Orthod Craniofac Res*. 2009;12:94–104.

Judex S, Lei X, Han D, et al. Low-magnitude mechanical signals that stimulate bone formation in the ovariectomized rat are dependent on the applied frequency but not on the strain magnitude. *J Biomech*. 2007;40:1333–9.

Judex S, Zhong N, Squire ME et al. Mechanical modulation of molecular signals which regulate anabolic and catabolic activity in bone tissue. *J Cell Biochem*. 2005;94:982–94.

Kadi F, Karlsson C, Larsson B et al. The effects of physical activity and estrogen treatment on rat fast and slow skeletal muscles following ovariectomy. *J Muscle Res Cell Motil*. 2002;23:335–9.

Kao PC, Dingwell JB, Higginson JS, et al. Dynamic instability during post-stroke hemiparetic walking. *Gait Posture*. 2014;40(3):457-63.

Kawanabe K, Kawashima A, Sashimoto I et al. Effect of whole-body vibration exercise and muscle strengthening, balance, and walking exercises on walking ability in the elderly. *Keio J Med*. 2007;56(1):28-33.

Kelly JO, Kilbreath SL, Davis GM et al. Cardiorespiratory fitness and walking ability in subacute stroke patients. *Arch Phys Med Rehabil*. 2003;84:1780-5.

Kemertzis MA, Lythgo ND, Morgan DL, et al. Ankle flexors produce peak torque at longer muscle lengths after whole-body vibration. *Med Sci Sports Exerc*. 2008;40:1977-83.

Kerschan-Schindl K, Grampp S, Henk C et al. Whole body vibration exercise leads to alterations in muscle blood volume. *Clin Physiol.* 2001;21(3):377-82.

Kiiski J, Heinonen A, Jarvinen TL et al. Transmission of vertical whole body vibration to the human body. *J Bone Miner Res*. 2008;23:1318-25.

Kim CM, Eng JJ. Symmetry in vertical ground reaction force is accompanied by symmetry in temporal but not distance variables of gait in persons with stroke. *Gait Posture*. 2003;18:23-28.

Kim CM, Eng JJ. The relationship of lower-extremitymuscle torque to locomotor performance in people with stroke. *Phy Ther*. 2003;83: 49–57.

Kim K, Kim YM, Kim EK.Correlation between the Activities of Daily Living of Stroke Patients in a Community Setting and Their Quality of Life. *J Phys Ther Sci.* 2014;26(3):417-9.

Kim P, Warren S, Madill H, et al. Quality of life of stroke survivors. *Qual Life Res.* 1999;8:293-301.

King LK, Almeida QJ, Ahonen H. Shortterm effects of vibration therapy on motor impairments in Parkinson's disease. NeuroRehabilitation. 2009;25:297–306.

King RB. Quality of life after stroke. *Stroke*. 1996;27:1467-72.

Kinser A.M., Ramsay M.W., O' Bryant H.S et al. Vibration and stretching effects on flexibility and explosive strength in young gymnasts. *Med Sci Sports Exer*. 2008;40:133-40.

Kipp K, Johnson ST, Doeringer JR et al. Spinal reflex excitability and homosynaptic depression after a bout of whole-body vibration. *Muscle Nerve*. 2011;43:259–62.

Klefter and Feldt-Rasmussen. Is increase in bone mineral content caused by increase in skeletal muscle mass/strength in adult patients with GH-treated GH deficiency? A systematic literature analysis. *Eur J Endocrinol*. 2009;161(2):213-21.

Kluding P, Gajewski B. Lower-extremity strength differences predict activity limitations in people with chronic stroke. *Phys Ther*. 2009;89(1):73–81.

Knarr BA, Reisman DS, Binder-Macleod SA et al. Changes in predicted muscle coordination with subject-specific muscle parameters for individuals after stroke. *Stroke Res Treat*. 2014;2014:321747.

Knuttson E. and Richards C. Different types of disturbed motor control in gait of hemiparetic patients. *Brain*. 1979;102(2):405–30.

Kobori M, Yamamuro. Effects of gonadectomy and estrogen administration on rat skeletal muscle. *Clin Orthop*. 1989;243:306–11.

Komrakova M, Sehmisch S, Tezval M, et al. Identification of a vibration regime favorable for bone healing and muscle in estrogen-deficient rats. *Calcif Tissue Int*. 2013; 92:509–20.

Kong KH, Woon VC, Yang SY. Prevalence of chronic pain and its impact on health-related quality of life in stroke survivors. *Arch Phys Med Rehabil*. 2004;85(1):35-40.

Krol P, Piecha M, Slomka K et al. The effect of whole-body vibration frequency and amplitude on the myoelectric activity of vastus medialis and vastus lateralis. *J Sports Sci Med.* 2011;10:169-74.

Kuriki HU, de Azevedo FM, Takahashi LSO et al. The Relationship Between Electromyography and Muscle Force. In: Schwartz M, editor. EMG Methods for Evaluating Muscle and Nerve Function. *Manhattan: Intech*. 2012; 32-54.

Kuys S, Brauer S, Ada L. Routine physiotherapy does not induce a cardiorespiratory training effect post-stroke, regardless of walking ability. *Physiother Res Int*. 2006;11219-27.

Kvorning T, Bagger M, Caserotti P et al. Effects of vibration and resistance training on neuromuscular and hormonal measures. *Eur J Appl Physiol*. 2006;96:615-25.

Kyriakides ZS, Petinakis P, Kaklamanis L et al. Intramuscular administration of estrogen may promote angiogenesis and perfusion in a rabbit model of chronic limb ischemia. *Cardiovasc Res*. 2001;49:626–33.

Lam CL, Tse EY, Gandek B. Is the standard SF-12 health survey valid and equivalent for a Chinese population? *Qual Life Res*. 2005;14(2):539-47.

Lam FMH, Lau RWK, Chung RCK et al. The effect of whole body vibration on balance, mobility and falls in older adults: a systematic review and meta-analysis. *Maturitas*. 2012;72:206-13.

Lam SC, Wong YY, Woo J. Reliability and validity of the abbreviated mental test (Hong Kong version) in residential care homes. *J Am Geriatr Soc*. 2010;58:2255-7.

Lamb SE, Ferrucci L, Volapto S et al. Women's Health and Aging Study. Risk factors for falling in home-dwelling older women with stroke: The Women's Health and Aging Study. *Stroke.* 2003;34(2):494–501.

Lamont HS, Cramer JT, Bemben DA et al. The acute effect of whole-body low-frequency vibration on countermovement vertical jump performance in college-aged men. *J Strength Cond Res*. 2010;24(12):3433-42.

Lamontagne A, Paqtiet N, FungJ. Postural adjustments to voluntary head motions during standing are modified following stroke. *Clin Biomech*. 2003;18:832-42.

Lance JW. Symposium synopsis. In: Feldman RG, Young RR, Koella WP, editors. Spasticity: Disordered Motor Control. Miami: Year Book Medical Publishers; 1980:485–94.

Lance JW. The control of muscle tone, reflexes, and movement: Robert Wartenberg Lecture. *Neurology*. 1980;30(12):1303-13.

Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. *Lancet Neurol.* 2009;8(8):741-54.

Lau ALD, Cummins RA, McPherson W. An investigation into the cross-cultural equivalence of the Personal Wellbeing Index. *Soc Indicator Res.* 2005;72:403-30.

Lau RWK, Liao L-R, Yu F et al. The effects of whole body vibration therapy on bone mineral density and leg muscle strength in older adults: a systematic review and meta-analysis. *Clin Rehabil*. 2011;25:975-88.

Lau RWK, Yip SP, Pang MYC. Whole-body vibration has no effect on neuromotor function and falls in chronic stroke. *Med Sci Sports Exerc*. 2012;44:1409–18.

Laufer Y, Sivan D, Schwarzmann R et al. Standing balance and functional recovery of patients with right and left hemiparesis in the early stages of rehabilitation. *Neurorehabil Neural Repair*. 2003;17(4):207-13.

Lee BK, Chon SC. Effect of whole body vibration training on mobility in children with cerebral palsy: A randomized controlled experimenter-blinded study. *Clin Rehabil*. 2013; 27(7):599-607.

Lee D-K, Kim J-S, Kim T-H et al. Comparison of the electromyographic activity of the tibialis anterior and gastrocnemius in stroke patients and healthy subjects during squat exercise. *J Phys Ther Sci*. 2015;27:247-9.

Lee KJ, Jung KH, Byun JI et al. Infarct pattern and clinical outcome in acute ischemic stroke following middle cerebral artery occlusion. *Cerebrovasc Dis*. 2014;38:31-8.

Lee MJ, Kilbreath SL, Singh MF et al. Comparison of effect of aerobic cycle training and progressive resistance training on walking ability after stroke: a randomized sham exercise-controlled study. *J Am Geriatr Soc*. 2008;56:976-85.

Lee NK, Kwon JW, Son SM et al. The effects of closed and open kinetic chain exercises on lower limb muscle activity and balance in stroke survivors. *NeuroRehabilitation.* 2013;33:177-83.

Lee YC, Yu WH, Lin YF, et al. Reliability and Responsiveness of the Activities of Daily Living Computerized Adaptive Testing System in Patients With Stroke. *Arch Phys Med Rehabil.* 2014; 95(11):2055-63.

Lennon O, Carey A, Gaffney N et al. A pilot randomized controlled trial to evaluate the benefit of the cardiac rehabilitation paradigm for the non-acute ischaemic stroke population. *Clin Rehabil*. 2008;22:125-33.

Letombe A, Cornille C, Delahaye H et al. Early post-stroke physical conditioning in hemiplegic patients: A preliminary study. *Ann Phys Rehabil Med*. 2010,53:632-42.

Leung KS, Shi HF, Cheung WH, et al. Low-magnitude high-frequency vibration accelerates callus formation, mineralization, and fracture healing in rats. *J Orthop Res*. 2009;27(4):458-65.

Levendoglu F, Ugurlu H, Gurbilek M et al. Increased bone resorption in the proximal femur in patients with hemiplegia. *Am J Phys Med Rehabil*. 2004;83:835-41.

Li F, Wu Y, Li X. Test-retest reliability and inter-rater reliability of the Modified Tardieu Scale and the Modified Ashworth Scale in hemiplegic patients with stroke. *Eur J Phys Rehabil Med*. 2014;50:9-15.

Li S. W. Stroke and functional rehabilitation: the Chinese experience. *Eur Neurol*. 1998;39 (suppl l):26-30.

Liao LR, Lam FM, Pang MY et al. Leg muscle activity during whole-body vibration in individuals with chronic stroke. *Med Sci Sports Exerc*. 2014a;46:537-45.

Liao LR, Huang M, Lam FM et al. Effects of Whole-Body Vibration Therapy on Body Functions and Structures, Activity, and Participation Poststroke: A Systematic Review. *Phys Ther*. 2014b;94:1232-51.

Liao LR, Ng GY, Jones AY et al. Cardiovascular Stress Induced by Whole-Body Vibration Exercise in Individuals With Chronic Stroke. *Phys Ther*. 2015.

Liao LR, Ng GY, Jones AY, Chung RC, Pang MY. Effects of vibration intensity, exercise, and motor impairment on leg muscle activity induced by whole-body vibration in people with stroke.

Phys Ther [Internet]. 2015 [cited 2015 May 30] Available from: http://ptjournal.apta.org/content/early/recent. doi:10.2522/ptj.20140507.

Lieber RL, Fridén J. Mechanisms of muscle injury gleaned from animal models. *Am J Phys Med Rehabil*. 202;81(11):70–9.

Lienhard K, Cabasson A, Meste O et al. Determination of the optimal parameters maximizing muscle activity of the lower limbs during vertical synchronous whole-body vibration. *Eur J Appl Physiol*. 2014;114:1493-501.

Lienhard K, Vienneau J, Nigg S et al. Relationship between lower limb muscle activity and platform acceleration during whole-body vibration exercise. *J Strength Cond Res*. 2015.

Lin PY, Yang YR, Cheng SJ et al. The relation between ankle impairments and gait velocity and symmetry in people with stroke. *Arch Phys Med Rehabil*. 2006;87(4):562-8.

Lin S. Motor function and joint position sense in relation to gait performance in chronic stroke patients. *Arch Phys Med Rehabil*. 2005;86: 197–203.

Łochyński D, Bączyk M, Kaczmarek D et al. Adaptations in physiological properties of rat motor units following 5 weeks of whole-body vibration. *Appl Physiol Nutr Metab.* 2013;38(9):913-21.

Łochyński D, Kaczmarek D, Rędowicz MJ et al. Long-term effects of whole-ody vibration on motor unit contractile function and myosin heavy chaincomposition in the rat medial gastrocnemius. *J Musculoskelet Neuronal Interact.* 2013;13(4):430-41.

Lohman EB, Petrofsky JS, Maloney-Hinds C et al. The effect of whole body vibration on lower extremity skin blood flow in normal subjects. *Med Sci Monit.* 2007;13(2):CR71-6.

Lomaglio MJ, Eng JJ. Nonuniform weakness in the paretic knee and compensatory strength gains in the nonparetic knee occurs after stroke. *Cerebrovasc Dis*. 2008;26(6):584-91.

Lu W-S, Chen CC, Huang S-L et al. Smallest real difference of 2 instrumental activities of daily living measures in patients with chronic stroke. *Arch Phys Med Rehabil.* 2012;93:1097-100.

Luo J, McNamara B, Moran K. The use of vibration training to enhance muscle strength and power. *Sports Med*. 2005;35:23–41.

Lynn K, Nichole K, Harriet C et al. Returning to work after the onset of illness: experiences of right hemisphere stroke survivors. *Rehabil Couns Bull*. 2005;48:209-18.

Lythgo N, Eser P, de Groot P et al. Whole-body vibration dosage alters leg blood flow. *Clin Physiol Funct Imaging*. 2009;29:53-9.

Machado A, García-López D, González-Gallego et al. Whole-body vibration training increases muscle strength and mass in older women: a randomized-controlled trial. *Scand J Med Sci Sports*. 2010;20(2):200-7.

MacIntyre NJ, Rombough R, Brouwer B. Relationships between calf muscle density and muscle strength, mobility and bone status in the stroke survivors with subacute and chronic lower limb hemiparesis. *J Musculoskelet Neuronal Interact*. 2010;10(4):249-55.

Mackay J, Mensah G,World Health Organization (WHO). The atlas of heart disease and stroke. http://www.who.int/cardiovascular_diseases/resources/atlas/en/ (accessed 2 September 2014) 2004.

MacKay-Lyons MJ, Makrides L. Cardiovascular stress during a contemporary stroke rehabilitation program: is the intensity adequate to induce a training effect? *Arch Phys Med Rehabil.* 2002;83:1378-83.

Mackenzie AE, Chang AM. Predictors of quality of life following stroke. *Disabil Rehabil.* 2002;24:259-65.

Mackintosh SF, Goldie P, Hill K. Falls incidence and factors associated with falling in older, community-dwelling, chronic stroke survivors (> 1 year after stroke) and matched controls. *Aging Clin Exp Res*. 2005;17(2):74-81.

Mackintosh SF, Hill K, Dodd KJ, Goldie P et al. Falls and injury prevention should be part of every stroke rehabilitation plan. *Clin Rehabil*. 2005;19(4):441-51.

Macko RF, Ivey FM, Forrester LW et al. Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke: a randomized, controlled trial. *Stroke.* 2005;36:2206-11.

MacLellan MJ, Richards CL et al. Use of segmental coordination analysis of nonparetic and paretic limbs during obstacle clearance in community-dwelling persons after stroke. *PM R.* 2013;5(5):381-91.

Maddalozzo GF, Iwaniec UT, Turner RT et al. Wholebody vibration slows the acquisition of fat in mature female rats. *Int J Obes (London)*. 2008: 32:1348–54.

Madou KH, Cronin JB. The effects of whole body vibration on physical and physiological capabilities in special populations. *Hong Kong Physiother J*. 2008;26:24–38.

Madou KH. Leg muscle activity level and rate of perceived exertion with different whole-body vibration frequencies in multiple sclerosis patients: An exploratory approach. *Hong Kong Physiother J*. 2011;29(1):12-9.

Mahieu NN, Witvrouw E, Van de Voorde D et al. Improving strength and postural control in young skiers: whole-body vibration versus equivalent resistance training. *J Athl Train.* 2006; 41:286-93.

Manns PJ, Baldwin E. Ambulatory activity of stroke survivors: measurement options for dose, intensity, and variability of activity. *Stroke*. 2009;40(3):864-7.

Manthou M, Nohroudi K, Moscarino S et al. Functional recovery after experimental spinal cord compression and whole body vibration therapy requires abalanced revascularization of the injured site. *Restor Neurol Neurosci*. 2015;33(2):233-49.

Marín PJ, Bunker D, Rhea MR, Ayllón FN. Neuromuscular activity during whole-body vibration of different amplitudes and footwear conditions: implications for prescription of vibratory stimulation. *J Strength Cond Res*. 2009;23:2311-6.

Marín PJ, Ferrero CM, Menéndez H, Martín J, Herrero AJ. Effects of whole-body vibration on muscle architecture, muscle strength, and balance in stroke patients: a randomized controlled trial. *Am J Phys Med Rehabil*. 2013;92:881-8.

Marin PJ, Hazell T. Effects of whole-body vibration with an unstable surface on muscle activation. *J Musculoskelet Neuronal Interact*. 2014;14:213-9.

Marín PJ, Hazell TJ, García-Gutiérrez MT et al. Acute unilateral leg vibration exercise improves contralateral neuromuscular performance. *J Musculoskelet Neuronal Interact*. 2014;14(1):58-67.

Marín PJ, Herrero AJ, Milton JG et al. Whole-body vibration applied during upper body exercise improves performance. *J Strength Cond Res*. 2013;27(7):1807-12.

Marin PJ, Rhea MR. Effects of vibration training on muscle power: a meta-analysis. *J Strength Cond Res.* 2010; 24:871-8.

Marsden DL, Dunn A, Callister R et al. Characteristics of exercise training interventions to improve cardiorespiratory fitness after stroke: a systematic review with meta-analysis. *Neurorehabil Neural Repair*. 2013;27(9):775-88.

Martínez F, Rubio JA., Ramos DJ et al. Effects of 6-week whole body vibration training on the reflex response of the ankle muscles: a randomized controlled trial. *Int J Sports Phys Ther*. 2013;8:15–24.

Marwa M. Ibrahim, Mohamed A. Eid, Samah A. Moawd. Effect of whole-body vibration on muscle strength, spasticity, and motor performance in spastic diplegic cerebral palsy children. *The Egyptian Journal of Medical Human Genetics*. 2014:15 (2):173 -9.

Mason, R. R., Cochrane, D. J., Denny, G. J et al. Is 8 weeks of side-alternating whole-body vibration a safe and acceptable modality to improve functional performance in multiple sclerosis? *Disabil Rehabil*. 2012;34(8), 647-654.

Mauritz K. Gait training in hemiplegia. *Eur J Neurology*. 2002;9:23–9.

Mayer NH, Esquenazi A, Childers MK. Common patterns of clinical motor dysfunction. *Muscle Nerve Suppl.* 1997; 6:S21–S35.

Mayo NE, Wood-Dauphinee S, Cote R, Durcam L et al. Activity, participation and quality of life 6 months poststroke. Arch Phys Med Rehabil. 2002;83:1035 –42.

McBride JM, Nuzzo JL, Dayne AM et al. Effect of an acute bout of whole body vibration exercise on muscle force output and motor neuron excitability. *J Strength Cond Res.* 2010;24:184–9.

McCann MR, Patel P, Beaucage KL et al. Acute vibration induces transient expression of anabolic genes in the murine intervertebral disc. *Arthritis Rheum*. 2013;65(7):1853-64.

McComas AJ, Sica RE, Upton AR et al. Functional changes in motoneurones of hemiparetic patients. *J Neurol Neurosurg Psychiatry*. 1973;36: 183-93.

McCrea PH, Eng JJ, Hodgson AJ. Time and magnitude of torque generation is impaired in both arms following stroke. *Muscle Nerve*. 2003;28(1):46-53.

Mead GE, Greig CA, Cunningham I, et al. Stroke: a randomized trial of exercise or relaxation. *J Am Geriatr Soc*. 2007;5:892-9.

Mead GE, van Wijck F. Physical fitness training after stroke: time to translate research into practice. *J R Coll Physicians Edinb.* 2011; 41:98–9.

Mehta S, Pereira S, Viana R, Mays R et al. Resistance training for gait speed and total distance walked during the chronic stage of stroke: a meta-analysis. *Top Stroke Rehabil.* 2012;19(6):471-8.

Merkert J, Butz S, Nieczaj R et al. Combined whole body vibration and balance training using Vibrosphere®: improvement of trunk stability, muscle tone, and postural control in stroke patients during early geriatric rehabilitation. *Z Gerontol Geriatr.* 2011;44:256–61.

Michael K, Macko RF. Ambulatory activity intensity profiles, fitness, and fatigue in chronic stroke. *Top Stroke Rehabil*. 2007;14(2):5-12.

Michael KM, Allen JK, Macko RF. Reduced ambulatory activity after stroke: the role of balance, gait, and cardiovascular fitness. *Arch Phys Med Rehabil*. 2005;86(8):1552-6.

Michael KM, Allen JK, Macko RF. Reduced ambulatory activity after stroke: the role of balance, gait, and cardiovascular fitness. *Arch Phys Med Rehabil*. 2005,86:1552-6.

Mikhael M, Orr R, Amsen F et al. Effect of standing posture during whole body vibration training on muscle morphology and function in older adults: a randomised controlled trial. *BMC Geriatr*. 2010a;10:74.

Mikhael M, Orr R, Fiatarone Singh MA. The effect of whole body vibration exposure on muscle or bone morphology and function in older adults: a systematic review of the literature. *Maturitas*. 2010b;66(2):150-7.

Mileva KN, Bowtell JL, Kossev AR. Effects of low-frequency whole-body vibration on motor-evoked potentials in healthy men. *Exp Physiol*. 2009;94:103–16.

Moezy, A., Olyaei, G., Hadian, M et al. A comparative study of whole body vibration training and conventional training on knee proprioception and postural stability after anterior cruciate ligament reconstruction. *Br J Sports Med*. 2008;42,:373-8.

Munn, J., Sullivan, S. J., & Schneiders, A. G. Evidence of sensorimotor deficits in functional ankle instability: A systematic review with meta-analysis. *J Sci Med Sport.* 2010;13:2–12.

Murfee WL, Hammett LA, Evans C et al. High-frequency, low-magnitude vibrations suppress the number of blood vessels per muscle fiber in mouse soleus muscle. *J Appl Physiol.* 2005;98:2376-80.

Murfee WL, Hammett LA, Evans C et al. High-frequency, low-magnitude vibrations suppress the number of blood vessels per muscle fiber in mousesoleus muscle. *J Appl Physiol (1985).* 2005;98(6):2376-80.

Murphy B, Herrman H, Hawthorne G et al. Australian WHOQoL instruments: User's manual and interpretation guide. *Melbourne, Australia: Australian WHOQoL Field Study Centre*; 2000.

Nadeau S, Arsenault AB, Gravel D et al. Analysis of the clinical factors determining natural and maximal gait speeds in adults with a stroke. *Am J Phys Med Rehabil.* 1999;78:123–30.

Nadeau S, Gravel D, Arsenault AB et al. Plantarflexor weakness as a limiting factor of gait speed in stroke subjects and the compensating role of hip flexors. *Clin Biomech.* 1999;14:125–35.

Nascimento LR, Michaelsen SM, Ada L et al. Cyclical electrical stimulation increases strength and improves activity after stroke: a systematic review. *J Physiother*. 2014;60(1):22-30.

Ness LL, and Field-Fote EC. Effect of whole-body vibration on quadriceps spasticity in individuals with spastic hypertonia due to spinal cord injury. *Restor Neurol Neurosci.* 2009a;27:621–31.

Ness LL, and Field-Fote EC. Whole-body vibration improves walking function in individuals with spinal cord injury: A pilot study. *Gait Posture*. 2009b;30:436–40.

Ness LL, Field-Fote EC. Effect of whole-body vibration on quadriceps spasticity in individuals with spastic hypertonia due to spinal cord injury. *Restor Neurol Neurosci.* 2009; 27(6):621–31.

Ng SS, Hui Chan CW. The Timed Up & Go test: its reliability and association with lower-limb impairments and locomotor capacities in people with chronic stroke. *Arch Phys Med Rehabil.* 2005;86:1641–7.

Ng SS, Hui-Chan CW. Contribution of ankle dorsiflexor strength to walking endurance in people with spastic hemiplegia after stroke. *Arch Phys Med Rehabil*. 2012;93:1046-51.

Nieman DC, Austin MD, Benezra L et al. Validation of Cosmed's FitMate in measuring oxygen consumption and estimating resting metabolic rate. *Res Sports Med*. 2006;14:89-96.

Nordlund MM, Thorstensson A. Strength training effects of whole-body vibration? *Scand J Med Sci Sports*. 2007;17:12-7.

O'Halloran R, Worrall L, Hickson L. Stroke patients communicating their healthcare needs in hospital: a study within the ICFframework. *Int J Lang Commun Disord*. 2012;47(2):130-43.

O'Keefe K, Orr R, Huang P et al. The effect of whole body vibration exposure on muscle function in children with cystic fibrosis: a pilot efficacy trial. *J Clin Med Res*. 2013;5(3):205-16.

Olivares PR, Gusi N, Parraca JA et al. Tilting Whole Body Vibration improves quality of life in women with fibromyalgia: a randomized controlled trial. *J Altern Complement Med*. 2011;17(8):723-8.

Olney SJ, Richards C. Hemiparetic gait following stroke. Part I: Characteristics. *Gait Posture*. 1996;4:136-48.

Omar H, Shen G, Jones AS et al. Effect of low magnitude and high frequency mechanical stimuli on defects healing in cranial bones. *J Oral Maxillofac Surg*. 2008;66(6):1104-11.

Ones K, Yilmaz E, Cetinkaya B et al. Quality of life for patients poststroke and the factors affecting it. *J Stroke Cerebrovasc Dis*. 2005;14(6):261-6.

Orenstein DM, Hovell MF, Mulvihill M et al. Strength vs aer- obic training in children with cystic fibrosis: a random- ized controlled trial. *Chest*. 2004;126(4):1204-14.

Osawa Y, Oguma Y, Ishii N. The effects of whole-body vibration on muscle strength and power: a meta-analysis. *J Musculoskelet Neuronal Interact*. 2013a;13(3):380-90.

Osawa Y, Oguma Y, Onishi S. Effects of whole-body vi- bration training on bone-free lean body mass and muscle strength in young adults. *J Sports Sci Med.* 2011;10:97-104.

Osawa Y, Oguma Y. Effects of resistance training with whole-body vibration on muscle fitness in untrained adults. *Scand J Med Sci Sports*. 2013b;23:84-95.

Oxlund BS, Ørtoft G, Andreassena TT et al. Low-intensity, highfrequency vibration appears to prevent the decrease in strength of the femur and tibia associated with ovariectomy of adult rats. *Bone.* 2003;32:69–77.

Ozcivici E, Garman R, Judex S. High-frequency oscillatory motions enhance the simulated mechanical properties of non-weight bearing trabecular bone. *J Biomech*. 2007;40:3404–11.

Paanalahti, M., Murphy, M. A., Lundgren-Nilsson et al. Validation of the Comprehensive ICF Core Set for stroke by exploring the patient's perspective on functioning in everyday life: a qualitative study. *Int J Rehabil Res*. 2014;37(4):302-10.

Padulo J, Filingeri D, Chamari K et al. Acute effects of whole-body vibration on running gait in marathon runners. *J Sports Sci*. 2014;32(12):1120-6.

Pallant, J. SPSS survival manual. 4th ed. *New York: McGraw-Hill Education*; 2007:254.

Pang MY, Ashe MC, Eng JJ. Tibial bone geometry in chronic stroke patients: influence of sex, cardiovascular health, and muscle mass. *J Bone Miner Res*. 2008;23:1023-30.

Pang MY, Eng JJ, Dawson AS et al. A community-based fitness and mobility exercise program for older adults with chronic stroke: a randomized, controlled trial. *J Am Geriatr Soc*. 2005a;53:1667-74.

Pang MY, Eng JJ, McKay HA et al. Reduced hip bone mineral density is related to physical fitness and leg lean mass in ambulatory individuals with chronic stroke. *Osteoporos Int.* 2005c;16(12):1769-79.

Pang MY, Eng JJ, Miller WC. Determinants of satisfaction with community reintegration in older adults with chronic stroke: role of balance self-efficacy. *Phys Ther*. 2007;87(3):282-91.

Pang MY, Eng JJ. Muscle strength is a determinant of bone mineral content in the hemiparetic upper extremity: implications for stroke rehabilitation. *Bone*. 2005b;37(1):103-11.

Pang MYC, Ashe MC, Eng JJ. Compromised bone strength index in the hemiparetic distal tibia among chronic stroke patients: the role of cardiovascular function, muscle atrophy, mobility, and spasticity. *Osteoporos Int*. 2010;21:997-1007.

Pang MYC, Charlesworth SA, Lau RWK et al. Using aerobic exercise to improve health outcomes and quality of life in stroke: evidence-based exercise prescription recommendations. *Cerebrovasc Dis*. 2013a;35(1):7-22.

Pang MYC, Cheng AQ, Warburton D et al. Relative impact of neuromuscular and cardiovascular factors on bone strength index of the hemiparetic distal radius epiphysis among individuals with chronic stroke. *Osteoporos Int*. 2012;23(9):2369-79.

Pang MYC, Eng JJ, Dawson AS et al. The use of aerobic exercise training in improving aerobic capacity in individuals with stroke: a meta-analysis. *Clin Rehabil*. 2006;20:97-111.

Pang MYC, Eng JJ, Dawson AS. Relationship between ambulatory capacity and cardiorespiratory fitness in chronic stroke: influence of stroke-specific impairments. *Chest.* 2005d;127:495-501.

Pang MYC, Eng JJ. Determinants of improvement in walking capacity among individuals with chronic stroke following a multi-dimensional exercise program. *J Rehabil Med.* 2008;40:284-90.

Pang MYC, Lau RWK, Yeung PK et al. Development and validation of the Chinese version of the Reintegration to Normal Living Index for use with stroke patients. *J Rehabil Med*. 2011;43:243-50.

Pang MYC, Lau RWK, Yip SP. The effects of whole-body vibration therapy on bone turnover, muscle strength, motor function, and spasticity in chronic stroke: a randomized controlled trial. *Eur J Phys Rehabil Med*. 2013b;49:439-450.

Park J, Lee S, Hwangbo G. The effects of a bridge exercise with vibration training and an unstable base of support on lumbar stabilization. *J Phys Ther Sci*. 2015;27(1):63-5.

Park YG, Kwon BS, Park JW, et al. Therapeutic effect of whole body vibration on chronic knee osteoarthritis. *Ann Rehabil Med*. 2013;37(4):505-15.

Patten C, Lexell J, Brown HE. Weakness and strength training in persons with poststroke hemiplegia: rationale, method, and efficacy. *J Rehabil Res Dev*. 2004;41(3a):293-312.

Patterson KK, Gage WH, Brooks D et al. Changes in gait symmetry and velocity after stroke: a cross-sectional study from weeks to years after stroke. *Neurorehabil Neural Repair*.

2010;24(9):783-90.

Pawlak M, Kaczmarek D, Nowak A et al. Low-volume whole-body vibration lasting 3 or 6 months does not affect biomarkers in blood serum of rats. *Acta Physiol Hung*. 2013;100(1):48-53.

Perchthaler D, Grau S, Hein T. Evaluation of a six-week whole-body vibration intervention on neuromuscular performance in older adults. *J Strength Cond Res*. 2015;29(1):86-95.

Perenboom RJ, Chorus AM. Measuring participation according to the International Classification of Functioning, Disability and Health (ICF). *Disabil Rehabil.* 2003; 25: 577–87.

Petit PD, Pensini M, Tessaro J et al. Optimal whole-body vibration settings for muscle strength and power enhancement in human knee extensors. *J Electromyogr Kinesiol*. 2010;20:1186-95.

Piercy M, Carter J, Mant J et al. Interrater reliability of the Frenchay Activities Index in patients with stroke and their careers. *Clin Rehabil*. 2000;14:433–40.

Pinet C, Cassart M, Scillia P et al. Function and bulk of respiratory and limb muscles in patients with cystic fibrosis. *Am J Respir Crit Care Med*. 2003;168(8):989-94.

Pleguezuelos E, Pérez ME, Guirao L et al. Effects of whole body vibration training in patients with severe chronic obstructive pulmonary disease. *Respirology*. 2013;18(6):1028-34.

Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991;39(2):142-8.

Pollock ML, Gaesser GA, Butcher JD et al. American College of Sports Medicine Position Stand: the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc*. 1998;30:975–91.

Pollock RD, Provan S, Martin FC et al. The effects of whole body vibration on balance, joint position sense and cutaneous sensation. *Eur J Appl Physiol*. 2011;111(12):3069-77.

Pollock RD, Woledge RC, Mills KR, Martin FC, Newham DJ. Muscle activity and acceleration during whole body vibration: effect of frequency and amplitude. *Clin Biomech (Bristol, Avon)*. 2010;25(8):840–6.

Pompili M, Venturini P, Lamis DA et al. Suicide in stroke survivors: epidemiology and prevention. *Drugs Aging*. 2015;32(1):21-9.

Portney LG, Watkins MP. Foundations of clinical research: applications to practice. 3rd ed. Upper Saddle River, NJ: Pearson/Prentice Hall; 2009.

Potempa K, Lopez M, Braun LT, et al. Physiological outcomes of aerobic exercise training in hemiparetic stroke patients. *Stroke*. 1995;26:101-105.

Pouwels S, Lalmohamed A, Leufkens B et al. Risk of hip/femur fracture after stroke: a population-based case-control study. *Stroke*. 2009;40(10):3281-5.

Pouwels S, Lalmohamed A, Leufkens B et al. Risk of hip/femur fracture after stroke: a population-based case-control study. *Stroke*. 2009;40(10):3281-5.

Prior BM, Lloyd PG, Yang HT et al. Exerciseinduced vascular remodelling. *Exerc Sport Sci Rev*. 2003;31:26–33.

Priori A., Cogiamanian F., Mrakic-Sposta S. Pathophysiology of spasticity. *Neurol Sci.* 2006; 27: S307-S309.

Prisby RD, Lafage-Proust MH, Malaval L et al. Effects of whole body vibration on the skeleton and other organ systems in man and animalmodels: what we know and what we need to know. *Ageing Res Rev*. 2008;7(4):319-29.

Raimundo AM, Gusi N, Tomas-Carus P. Fitness efficacy of vibratory exercise compared to walking in postmenopausal women. *Eur J Appl Physiol.* 2009;106(5):741-8.

Ramsay JW, Barrance PJ, Buchanan TS et al. Paretic muscle atrophy and non-contractile tissue content in individual muscles of the post-stroke lower extremity. *J Biomech*. 2011;44(16):2741-6.

Randall JM, Matthews RT, Stiles MA. Resonant frequencies of standing humans. *Ergonomics*. 1997;40(9):879–86.

Rauch F, Sievanen H, Boonen S et al. Reporting whole-body vibration intervention studies : Recommendations of the International Society of Musculoskeletal and Neuronal Interactions. *J Musculoskelet Neuronal Interact*. 2010;10:193–8.

Rees S, Murphy A, Watsford M. Effects of vibration exercise on muscle performance and mobility in an older population. *J Aging Phys Act*. 2007 ;15(4):367-81.

Rees SS, Murphy AJ, Watsford ML. Effects of whole body vibration on postural steadiness in an older population. *J Sci Med Sport*. 2009;12:440-4.

Rehn B, Lidström J, Skoglund J et al. Effects on leg muscular performance from whole-body vibration exercise: a systematic review. *Scand J Med Sci Sports*. 2007;17:2–11.

Riberto M, Lopes KA, Chiappetta LM et al. The use of the comprehensive International Classification of Functioning, Disability and Health core set for stroke for chronic outpatients in three Brazilian rehabilitation facilities. *Disabil Rehabil.* 2013;35(5):367-74.

Rietschel E, van Koningsbruggen S, Fricke O et al. Whole body vibration: a new therapeutic approach to improve muscle function in cystic fibrosis? *Int J Rehabil Res.* 2008;31(3):253-6.

Rigau Comas D, Fort Vanmeerhaeghe A, Santoyo Medina C et al. Whole-body vibration training for patients with neurodegenerative disease. *Cochrane Database Syst Rev*. 2012;2:CD009097.

Rimmer J. Health promotion for people with disabilities: the emerging paradigm shift from disability prevention to prevention of secondary conditions. *Phys Ther*.1999;79:495-501.

Rimmer JH, Riley B, Creviston T et al. Exercise training in a predominantly African-American group of stroke survivors. *Med Sci Sports Exerc*. 2000;32:1990-6.

Rittman M, Faircloth C, Boylstein C et al. The experience of time in the transition from hospital to home following stroke. *J Rehabil Res Dev*. 2004; 41:259-68.

Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clin Physiol*. 2000,20:134-42 .

Rittweger J, Ehrig J, Just K et al. Oxygen uptake in whole-body vibration exercise: influence of vibration frequency, amplitude, and external load. *Int J Sports Med*. 2002a,23:428-432.

Rittweger J, Just K, Kautzsch K et al. Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise: a randomized controlled trial. *Spine (Phila Pa 1976).* 2002b;27(17):1829-34.

Rittweger J, Moss AD, Colier W et al. Muscle tissue oxygenation and VEGF in VO-matched vibration and squatting exercise. *Clin Physiol Funct Imaging*. 2010,30:269-78.

Rittweger J, Schiessl H, Felsenberg D. Oxygen uptake during whole-body vibration exercise: comparison with squatting as a slow voluntary movement. *Eur J Appl Physiol*. 2001; 86: 169–73.

Ritzmann R, Gollhofer A, Kramer A. The influence of vibraiton type, frequency, body position and additiona load on the neuromuscular activity during whole body vibration. *Eur J Appl Physiol*. 2013;113:1-11.

Ritzmann R, Kramer A, Gruber M et al. EMG activity during whole body vibration: motion artifacts or stretch reflexes? *Eur J Appl Physiol*. 2010; 110:143–51.

Robinson-Smith G1, Johnston MV, Allen J. Self-care self-efficacy, quality of life, and depression after stroke. *Arch Phys Med Rehabil*. 2000;81(4):460-4.

Robling AG, Duijvelaar KM, Geevers JV et al. Modulation of appositional and longitudinal bone growth in the rat ulna by applied static and dynamic force. *Bone*. 2001; 29:105–13.

Rochette A, Desrosiers J, Noreau L. Association between personal and environmental factors and the occurrence of handicap situations following a stroke. *Disabil Rehabil.* 2001;23:559-69.

Roelants M, Delecluse C, Goris M et al. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med.* 2004a;25(1):1-5.

Roelants M, Delecluse C, Verschueren SM. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. *J Am Geriatr Soc*. 2004b;52(6):901-8.

Roelants M, Verschueren SMP, Delecluse C et al. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. *J Strength Cond Res.* 2006;20(1):124–9.

Rogan S, Hilfiker R, Herren K et al. Effects of whole-body vibration on postural control in elderly: a systematic review and meta-analysis. *BMC Geriatr*. 2011;11:72.

Rønnestad, BR. Acute effects of various whole body vibration frequencies on 1RM in trained and untrained subjects. *J Strength Cond Res*. 2009b;23: 2068–79.

Rønnestad, BR. Acute effects of various whole-body vibration frequencies on lower-body power in trained and untrained subjects. *J Strength Cond Res*. 2009a;23:1309-15.

Roth J, Wust M, Rawer R et al. Whole body vibration in cystic fibrosis--a pilot study. *J Musculoskelet Neuronal Interact*. 2008;8(2):179-87.

Rubin C, Recker R, Cullen D et al. Prevention of postmenopausal bone loss by a low-magnitude, high-frequency mechanical stimuli: a clinical trial assessing compliance, efficacy, and safety. *J Bone Miner Res*. 2004;19:343-51.

Rubin C, Turner AS, Bain S et al. Anabolism. Low mechanical signals strengthen long bones. *Nature*. 2001;412:603–04.

Rubin C, Turner AS, Mallinckrodt C et al. Mechanical strain, induced noninvasively in the highfrequency domain, is anabolic to cancellous bone, but not cortical bone. *Bone*. 2002a;30:445–52.

Rubin C, Turner AS, Muller R et al. Quantity and quality of trabecular bone in the femur are enhanced by a strongly anabolic, noninvasive mechanical intervention. *J Bone Miner Res*. 2002b;17:349–357.

Rubin C, Xu G, Judex S. The anabolic activity of bone tissue, suppressed by disuse, is normalized by brief exposure to extremely low-magnitude mechanical stimuli. *FASEB J*. 2001;15:2225–9.

Rubin CT, Capilla E, Luu YK et al. Adipogenesis is inhibited by brief, daily exposure to high-frequency, extremely lowmagnitude mechanical signals. *Proc Natl Acad Sci USA.* 2007;104:17879–84.

Rubin, C., A. S. Turner, S. Bain, C et al. Anabolism. Low mechanical signals strengthen long bones. *Nature*. 2001;412:603–4.

Rubinacci A, Marenzana M, Cavani F et al. Ovariectomy sensitizes rat cortical bone to whole-body vibration. *Calcif Tissue Int.* 2008;82:316–26.

Ruck J, Chabot G, Rauch F. Vibration treatment in cerebral palsy: A randomized controlled pilot study. *J Musculoskelet Neuronal Interact*. 2010;10:77-83.

Runge M, Rehfeld G, Resnicek E. Balance training and exercise in geriatric patients. *J Musculoskelet Neuronal Interact.* 2000;1:61-5.

Russo CR, Lauretani F, Bandinelli S et al. High-frequency vibration training increases muscle power in postmeno- pausal women. *Arch Phys Med Rehabil*. 2003;84:1854-7.

Sá-Caputo DC, Costa-Cavalcanti R, Carvalho-Lima RP et al. Systematic review of whole body vibration exercises in the treatment of cerebral palsy: Brief report. *Dev Neurorehabil*. 2015:1-7.

Sadeghi M, Sawatzky B. Effects of vibration on spasticity in individuals with spinal cord injury: a scoping systematic review. *Am J Phys Med Rehabil.* 2014;93(11):995-1007.

Sage M, Middleton LE, Tang A et al. Validity of rating of perceived exertion ranges in individuals in the subacute stage of stroke recovery. *Top Stroke Rehabil*. 2013;20:519-27.

Salbach NM, Brooks D, Romano J et al. Cariorespiratory responses during Cardiorespiratory Responses During the 6-minute walk and ramp cycle ergometer tests and their relationship to physical activity in stroke. *Neurorehabil Neural Repair*. 2014;28:111-9.

Sands W.A., McNeal J.R., Stone M.H et al. Flexibility enhancement wit vibration: Acute and long–term. *Med Sci Sports Exerc*. 2006;38:720-5.

Sands W.A., McNeal J.R., Stone M.H et al. The effect of vibration on active and passive range of motion in elite female synchronized swimmers. *Eur J Sports Sci*. 2008;8:217-23.

Santos-Filho, S. D., Cameron, M. H., & Bernardo-Filho, M. Benefits of whole-body vibration with an oscillat ing platform for people with multiple sclerosis: A systematic review. *Mult Scler Int*. 2012;2012:274728.

Sañudo B, Carrasco L, de Hoyo M et al. Changes in body balance and functional performance following whole-body vibration training in patients with fibromyalgia syndrome: a randomized controlled trial. *J Rehabil Med*. 2013;45(7):678-84.

Sañudo B, de Hoyo M, Carrasco L et al. Effect of whole-body vibration exercise on balance in women with fibromyalgia syndrome: a randomized controlled trial. *J Altern Complement Med.* 2012;18(2):158-64.

Sañudo B1, de Hoyo M, Carrasco L et al. The effect of 6-week exercise programme and whole body vibration on strength and quality of life in women with fibromyalgia: a randomised study. *Clin Exp Rheumatol*. 2010;28(6 Suppl 63):S40-5.

Sarti C, Rastenyte D, Cepaitis Z et al. International trends in mortality from stroke, 1968 to 1994. *Stroke*. 2000; 31: 1588–01.

Sartorio A, Agosti F, De Col A et al. Growth hormone and lactate responses induced by maximal isometric voluntary contractions and wholebody vibrations in healthy subjects. *J Endocrinol Invest*. 2011; 34: 216–21.

Sayenko DG, Masani, K, Alizadeh-Meghrazi M et al. Acute effects of whole body vibration during passive standing on soleus H-reflex in subjects with and without spinal cord injury. *Neurosci Lett.* 2010;482:66–70.

Scheffler TL, Gerrard DE. Mechanisms controlling pork quality development: the biochemistry controlling postmortem energy metabolism. *Meat Sci.* 2007;77:7–16.

Schinwelski M, Sławek J. Prevalence of spasticity following stroke and its impact on quality of life with emphasis on disability in activities of daily living. Systematic review. *Neurol Neurochir Pol.* 2010;44(4):404-11.

Schuhfried, O., Mittermaier, C., Jovanovic, T et al. Effects of whole-body vibration in patients with multiple sclerosis: A pilot study. *Clin Rehabil.* 2005;19(8):834-42.

Schuling J, de Haan R, Limburg M et al. The Frenchay Activities Index. Assessment of functional status in stroke patients. *Stroke*. 1993;24:1173-7.

Schyns, F., Paul, L., Finlay, K et al. Vibration therapy in multiple sclerosis: A pilot study exploring its effects on tone. muscle force, sensation and functional performance. *Clin Rehabil.* 2009;23(9):771-81.

See comment in PubMed Commons belowGlobas C, Becker C, Cerny J, et al. Chronic stroke survivors benefit from high-intensity aerobic treadmill exercise: a randomized control trial. *Neurorehabil Neural Repair*. 2012;26:85-95.

Sefton, J. M., Hicks-Little, C. A., Hubbard, T. J et al. Sensorimotor function as a predictor of chronic ankle instability. *Clinical Biomechanics*. 2009;24:451–8.

Segal NA, Glass NA, Shakoor N

Segal NA, Glass NA, Shakoor N et al.
Vibration platform training in women at risk for symptomatic knee osteoarthritis. *PM R*. 2013;5(3):201-9; quiz 209.

Sehmisch S, Galal R, Kolios L et al. Effects of low-magnitude, high-frequency mechanical stimulation in the rat osteopenia model. *Osteoporos Int.* 2009;20(12):1999-2008.

Sharififar S, Coronado RA, Romero S, et al. The effects of whole body vibration on mobility and balance in Parkinson disease: a systematic review. *Iran J Med Sci.* 2014;39(4):318-26.

Shephard RJ. Maximal oxygen intake and independence in old age. *Br J Sports Med.* 2009; 43:i342–6.

Shi HF, Cheung WH, Qin L et al. Low-magnitude high-frequency vibration treatment augments fracture healing in ovariectomy-induced osteoporotic bone. *Bone.* 2010;46:1299–305.

Shield, A and Zhou, S. Assessing voluntary muscle activation with the twitch interpolation technique. *Sports Med.* 2004;34:253–367.

Simão AP, Avelar NC, Tossige-Gomes R, et al. Functional performance and inflammatory cytokines after squat exercises and whole-body vibration in elderlyindividuals with knee osteoarthritis. *Arch Phys Med Rehabil*. 2012;93(10):1692-700.

Singh P, Joshua AM, Ganeshan S et al. Intra-rater reliability of the modified Tardieu scale to quantify spasticity in elbow flexors and ankle plantar flexors in adult stroke subjects. *Ann Indian Acad Neurol*. 2011;14:23-26.

Sitjà-Rabert M, Rigau D, Fort Vanmeerghaeghe A et al. Efficacy of whole body vibration exercise in older people: a systematic review. *Disabil Rehabil*. 2012;34(11):883-93.

Slatkovska L, Alibhai SM, Beyene J et al. Effect of 12 months of whole-body vibration therapy on bone density and structure in postmenopausal women: a randomized trial. *Ann Intern Med*. 2011;155(10):668-79, W205.

Slatkovska L, Alibhai SMH, Beyene J et al. Effect of whole-body vibration on BMD: a systematic review and meta-analysis. *Osteoporosis Int*. 2010;21:1969–80.

Smith AC, Saunders DH, Mead G. Cardiorespiratory fitness after stroke: a systematic review. *Int J Stroke*. 2012;7(6):499-510.

Sommerfeld DK, Eek EU, Svensson AK et al. Spasticity after stroke: its occurrence and association with motor impairments and activity limitations. *Stroke*. 2004;35:134–9.

Sommerfeld DK, Gripenstedt U, Welmer AK. Spasticity after stroke: an overview of prevalence, test instruments, and treatments. *Am J Phys Med Rehabil*. 2012;91(9):814-20.

Spaans F, and Wilts G. Denervation due to lesions of the central nervous system. An EMG study in cases of cerebral contusion and cerebrovascular accidents. *Journal of the neurological sciences*. 1982;57: 291-305.

Stark C, Nikopoulou-Smyrni P, Stabrey A et al. Effect of a new physiotherapy concept on bone mineral density, muscle force and gross motor function in children with bilateral cerebral palsy. *J Musculoskelet Neuronal Interact*. 2010;10:151-8.

Starrost K, Geyh S, Trautwein A et al. Interrater reliability of the extended ICF core set for stroke applied by physical therapists. Phys Ther. 2008;88:841-51.

Stein RB, Chong S, Everaert DG et al. A multicenter trial of a footdrop stimulator controlled by a tilt sensor. *Neurorehabil Neural Repair*. 2006;20:371-9.

Stineman MG, Maislin G, Fiedler RC et al. A prediction model for functional recovery in stroke. *Stroke*. 1997;28:550–6.

Stuermer EK, Komrakova M, Sehmisch S et al. Whole body vibration during fracture healing intensifies the effects of estradiol and raloxifene in estrogendeficient rats. *Bone*. 2014; 64:187–94.

Stuermer EK, Komrakova M, Werner C et al. Musculoskeletal response to whole-body vibration during fracture healing in intact and ovariectomized rats. *Calcif Tissue Int.* 2010;87:168–80.

Sturm JW, Dewey HM, Donnan GA et al.: Handicap after stroke: how does it relate to disability, perception of recovery, and stroke subtype? the north North East Melbourne Stroke Incidence Study (NEMESIS). *Stroke*. 2002;33: 762–8.

Suresh AK, Hu X, Powers RK et al. Changes in motoneuron afterhyperpolarization duration in stroke survivors. *J Neurophysiol.* 2014;112(6):1447-56.

Tang A, Sibley KM, Bayley MT et al. Do functional walk tests reflect cardiorespiratory fitness in subacute stroke? *J Neuroeng Rehabil*. 2006;3:23.

Tang A, Sibley KM, Thomas SG et al. Maximal exercise test results in subacute stroke. *Arch Phys Med Rehabil*. 2006;87:1100-5.

Tankisheva E, Bogaerts A, Boonen S et al. Effects of intensive whole-body vibration training on muscle strength and balance in adults with chronic stroke: a randomized controlled pilot study. *Arch Phys Med Rehabil*. 2014 ;95(3):439-46.

Tankisheva E, Jonkers I, Boonen S et al. Transmission of whole-body vibration and its effect on muscle activation. *J Strength Cond Res*. 2013;27(9):2533-41.

Teasell R. "Holistic" care for stroke in the context of the current health care bureaucracy and economic reality. *Top Stroke Rehabil*. 2011;18:66-69.

Teixeira-Salmela LF, Neto MG, Magalhães LC et al. Content comparisons of stroke-specific quality of life based upon the international classification of functioning, disability, and health. *Qual Life Res*. 2009;18(6):765-73.

Tesch PA. Exercise performance and beta-blockade. Sports Med. 1985;2:389-412.

Tihanyi J, Di Giminiani R, Tihanyi T et al. Low resonance frequency vibration affects strength of paretic and non-paretic leg differently in patients with stroke. *Acta Physiol Hung*. 2010;97(2):172-82.

Tihanyi TK, Horváth M, Fazekas G et al. One session of whole body vibration increases voluntary muscle strength transiently in patients with stroke. *Clin Rehabil*. 2007;21:782–93.

Tomczak CR, Jelani A, Haennel RG et al. Cardiac reserve and pulmonary gas exchange kinetics in patients with stroke. *Stroke*. 2008;39:3102-6.

Tooth LR, McKenna KT, Smith M et al. Further evidence for the agreement between patients with stroke and their proxies on the Frenchay Activities Index. *Clin Rehabil.* 2003;17:656-65.

Torvinen S, Kannu P, Sievänen H et al. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin Physiol Funct Imaging*. 2002a;22(2):145–52.

Torvinen, S., Sievanen, H., Jarvinen, T.A.H., P et al. Effect of 4-min vertical whole body vibration on muscle performance and body balance: a randomized cross-over study. *Int J Sports Med*. 2002b;23, 374–9.

Toussaint DN, Roth EJ, Chen D et al. Comparison of semen quality obtained by vibratory stimulation and masturbation. *Hum Reprod.* 1993;8(7):1067-9.

Trans T, Aaboe J, Henriksen M et al. Effect of whole body vibration exercise on muscle strength and proprioception in females with knee osteoarthritis. *Knee.* 2009;16: 256-61.

Tsang CSL, Liao LR, Chung RCK et al. Psychometric properties of the mini-balance evaluation systems test (Mini-Bestest) in community-dwelling individuals with chronic stroke. *Phys Ther*. 2013;93:1102-15.

Tseng B, Kluding P. The relationship between fatigue, aerobic fitness, and motor control in people with chronic stroke: a pilot study. *J Geriatr Phys Ther*. 2009;32:97-102.

Tsuji T, Kitano N, Tsunoda K et al. Short-term effects of whole-body vibration on functional mobility and flexibility in healthy, older adults: a randomized crossover study. *J Geriatr Phys Ther*. 2014;37(2):58-64.

Turbanski S, Haas CT, Schmidtbleicher D et al. Effects of random whole-body vibration on postural control in Parkinson's disease. Res Sports Med. 2005;13:243–56.

Turner CH and Robling AG. Designing exercise regimens to increase bone strength. *Exerc Sport Sci Rev*. 2003; 31: 45–50.

Turner S, Torode M, Climstein M et al. A randomized controlled trial of whole body vibration exposure on markers of bone turnover in postmenopausal women. *J Osteoporos*. 2011; 2011:1-10.

Tutuarima JA, Van derMeulen JH, Haan RJ. Risk factors for falls of hospitalized stroke patients. *Stroke*. 1997;28:297–301.

Umemura Y, Ishiko T, Yamauchi T et al. Five jumps per day increase bone mass and breaking force in rats. *J Bone Miner Res*. 1997;12:1480–5.

Unger M, Jelsma J, Stark C. Effect of a trunk-targeted intervention using vibration on posture and gait in children with spastic type cerebral palsy: a randomized control trial. *Dev Neurorehabil*. 2013;16(2):79-88.

University of Oxford. Centre for Evidence-Based Medicine Web site. Available at: http://www.cebm.net. Accessed May 7, 2013.

Urban PP, Wolf T, UebeleM et al. Occurrence and clinical predictors of spasticity after ischemic stroke. *Stroke*. 2010; 41:2016–20.

van Duijnhoven NT, Thijssen DH, Green DJ et al. Resistive exercise versus resistive vibration exercise to counteract vascular adaptations to bed rest. *J Appl Physiol*. 2010; 108: 28–33.

van Nes IJ, Geurts AC, Hendricks HT et al. Short-term effects of whole-body vibration on postural control in unilateral chronic stroke patients: preliminary evidence. *Am J Phys Med Rehabil*. 2004;83(11):867-73.

van Nes IJ, Latour H, Schils F et al. Long-term effects of 6-week whole-body vibration on balance recovery and activities of daily living in the postacute phase of stroke. *Stroke*. 2006;37(9):2331-5.

Van Wijk I, Lindeman E, Kappelle LJ et al. Functional status and use of healthcare facilities in long-term survivors of transient ischaemic attack or minor ischaemic stroke. *J Neurol Neurosurg Psychiatry*. 2006;77:1238-43.

Vanleene M, Shefelbine SJ. Therapeutic impact of low amplitude high frequency whole body vibrations on the osteogenesis imperfecta mouse bone. *Bone*. 2013; 53:507–14.

Venna VR, McCullough LD. Role of social factors on cell death, cerebral plasticity and recovery after stroke. Metab Brain Dis. *Metab Brain Dis*. 2015;30(2):497-506.

Verschueren SM, Bogaerts A, Delecluse C et al. The effects of whole-body vibration training and vita- min D supplementation on muscle strength, muscle mass, and bone density in institutionalized elderly women: a 6-month randomized, controlled trial. *J Bone Miner Res*. 2011;26:42-9.

Verschueren SMP, Roelants M, Delecluse C et al. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res*. 2004;19:352–9.

Vissers D, Baeyens JP, Truijen S et al. The effect of whole body vibration short-term exercises on respiratory gas exchange in overweight and obese women. *Phys Sports Med*. 2009;37:88-94.

von Stengel S, Kemmler W, Engelke K et al. Effect of whole-body vibration on neuromuscular per- formance and body composition for females 65 years and older: a randomized-controlled trial. *Scand J Med Sci Sports*. 2012;22(1):119-27.

Wade D, Wood V, Heller A et al. Walking after stroke. Measurement and recovery over the first 3 months. *Scand J Rehabilitation Med*. 1987;19:25–30.

Wade D. Measurement in neurological rehabilitation. Oxford: Oxford University Press, 1992.

Wade DT, Legh-Smith J, Langton Hewer J. Social activities after stroke: measurement and natural history using Frenchay Activities Index. *Int Rehabil Med*. 1985;7:176-81.

Wakeling JM, Liphardt A-M. Task-specific recruitment of motor units for vibration damping. *J Biomech*. 2006;39:1342-6.

Wakeling JM, Nigg BM, Rozitis AI. Muscle activity damps the soft tissue resonance that occurs in responseto pulsed and continuous vibration. *J Appl Physiol*. 2002; 93:1093-103.

Walsh ME, Galvin R, Loughnane C et al. Factors associated with community reintegration in the first year after stroke: a qualitative meta-synthesis. *Disabil Rehabil*. 2014;10:1-10.

Wang HH, Chen WH, Liu C et al. Whole-body vibration combined with extra-load training for enhancing the strength and speed of track and field athletes. *J Strength Cond Res*. 2014a;28(9):2470-7.

Wang J, An Z, Li B, et al. Increasing stroke incidence and prevalence of risk factors in a low-income Chinese population. Neurology. *Neurology*. 2015;84(4):374-81.

Wang J, Ning X, Yang L et al. Sex differences in trends of incidence and mortality of first-ever stroke in rural Tianjin, China, from 1992 to 2012. *Stroke*. 2014b;45(6):1626-31.

Wang P, Yang X, Yang Y et al. Effects of whole body vibration on pain, stiffness and physical functions in patients with knee osteoarthritis: A systematic review and meta-analysis. *Clin Rehabil*. 2014c.

Warlow C, van Gijn J, Dennis M et al. Stroke: practical management, 3rd edn. Oxford: Blackwell Publishing, 2008.

Weber T, Beijer Å, Rosenberger A et al. Vascular adaptations induced by 6 weeks WBV resistance exercise training. *Clin Physiol Funct Imaging*. 2013;33(2):92-100.

Webster J, Feinglass J. Stroke patients, ‘managed care’, and distributive justice. *JAMA*. 1997; 278: 161-2.

Weerdesteyn V, de Niet M, van Duijnhoven HJ et al. Falls in individuals with stroke. *J Rehabil Res Dev*. 2008;45(8):1195-213.

Wehrle E, Wehner T, Heilmann A et al. Distinct frequency dependent effects of whole-body vibration on non-fractured bone and fracture healing in mice. *J Orthop Res*. 2014;32(8):1006-13.

Weinstein J, Pope M, Schmidt R, Seroussi R. Neuropharmacologic effects of vibration on the dorsal root ganglion. An animal model. *Spine (Phila Pa 1976)*. 1988;13(5):521-5.

Whaley MH, Brubaker PH,Otto RMet al. ACSM's Guidelines for Exercise Testing and Prescription, 7th edn. Philadelphia, PA, Lippincott Williams & Wilkins, 2006:55–92.

Whiteneck G, Dijkers MP. Difficult to measure constructs: conceptual and methodological issues concerning participation and environmental factors. *Arch Phys Med Rehabil*. 2009;90(11 Suppl.):S22-35.

Whiteneck G, Harrison-Felix C, Mellick D et al. Quantifying environmental factors: a measure of physical, attitudinal, service, productivity, and policy barriers. *Arch Phys Med Rehabil.* 2004;85:1324–35.

Whiteneck GG, Gerhart KA, Cusick CP. Identifying environmental factors that influence the outcomes of people with traumatic brain injury. *J Head Trauma Rehabil*. 2004;19:191-204.

WHO MONCA Project Principal Investigators. The World Health Organization MONICA Project: a major international collaboration. *J Clin Epidemiol.* 1988;41:105-14.

WHO. International Classification of Functioning, Disability and Health (ICF). *Geneva: World Health Organization*; 2001.

WHO. Stroke1989 Recommendation on stroke prevention, diagnosis and therapy: reports of the WHO Taskforce on stroke and other cerebrovascular disease. *Stroke.*1989;20:1407-31.

WHO. The World Health Report 2003: Shaping the Future. http://www.who.int/whr/2003/en/ (accessed 2 September 2014) October 2003.

Wilcock, IM, Whatman, C, Harris, N et al. Vibration training: Could it enhance the strength, power, or speed of athletes? *J Strength Cond Res*. 2009;23: 593–603.

Windisch A, Gundersen K, Szabolcs MJ et al. Fast to slow transformation of denervated and electrically stimulated rat muscle. *J Physiol*. 1988;510:623–32.

Wirth B, Zurfluh S, Müller R. Acute effects of whole-body vibration on trunk muscles in young healthy adults. *J Electromyogr Kinesiol*. 2011;21(3):450-7.

Wirth F, Schempf G, Stein G et al. Whole-body vibration improves functional recovery in spinal cord injured rats. *J Neurotrauma*. 2013;30(6):453-68.

Wissel J, Schelosky LD, Scott J et al. Early development of spasticity following stroke: a prospective, observational trial. *J Neurol*. 2010;257:1067–72.

Wolf S, Augat P, Eckert-Hubner K et al. Effects of high-frequency, low-magnitude mechanical stimulus on bone healing. *Clin Orthop Relat Res*. 2001;385:192–198.

Wolfsegger T, Assar H, Topakian R. 3-week whole body vibration does not improve gait function in mildly affected multiple sclerosis patients-a randomized controlled trial. *J Neurol Sci*. 2014;347(1-2):119-23.

Wright RW, Preston E, Fleming BC et al. A systematic review of anterior cruciate ligament reconstruction rehabilitation: part II: open versus closed kinetic chain exercises, neuromuscular electrical stimulation, accelerated rehabilitation, and miscellaneous topics. *J Knee Surg*. 2008;21(3):225-34.

Wunderer K, Schabrun SM, Chipchase LS. Effects of whole body vibration on strength and functional mobility in multiple sclerosis. *Physiother Theory Pract*. 2010;26(6):374-84.

Wyon M, Guinan D, Hawkey A. Whole-body vibration training increases vertical jump height in a dance popu- lation. *J Strength Cond Res.* 2010;24:866-70.

Xie L, Jacobson J, Choi ES et al. Low-level mechanical vibrations can influence bone resorption and bone formation in the growing skeleton. *Bone*. 2006;39:1059–66.

Xie L, Rubin C, Judex S. Enhancement of the adolescent murine musculoskeletal system using low-level mechanical vibrations. *J Appl Physiol*. 2008;104:1056–62.

Yamada E, Kusaka T, Miyamoto K et al. Vastus lateralis oxygenation and blood volume measured by near-infrared spectroscopy during whole body vibration. *Clin Physiol Funct Imaging*. 2005;25(4):203-8.

Yang Y-R, Wang R-Y, Lin K-H et al. Task-oriented progressive resistance strength training improves muscle strength and functional performance in individuals with stroke. *Clin Rehabil*. 2006;20(10):860-70.

Yang X, Wang P, Liu C, He C, Reinhardt JD. The effect of whole body vibration on balance, gait performance and mobility in people with stroke: a systematic review and meta-analysis. *Clin Rehabil*. 2015;29(7):627-38.

Yarar-Fisher C, Pascoe DD, Gladden LB et al. Acute physiological effects of whole body vibration (WBV) on central hemodynamics, muscle oxygenation and oxygen consumption in individuals with chronic spinal cord injury. *Disabil Rehabil*. 2014;36:136-45.

Yoo J, im K-B, Lee H-J et al. Cardiovascular response during submaximal underwater treadmill exercise in stroke patients. *Ann Rehabil Med*. 2014;38:628-36.

Zafar H, Alghadir A, Anwer S et al. Therapeutic effects of whole body vibration training in knee osteoarthritis: a systematic review and meta-analysis. *Arch Phys Med Rehabil*. 2015.

Zhao L, He LX, Huang SN et al. Protection of dopamine neurons by vibration training and up-regulation of brain-derived neurotrophic factor in a MPTP mouse model of Parkinson's disease. *Physiol Res*. 2014;63(5):649-57.

Zorowitz RD, Gillard PJ, Brainin M. Poststroke spasticity: sequelae and burden on stroke survivors and caregivers. *Neurology*. 2013;80(3 Suppl 2):S45-52.