Assessing the physiological effects of an exercise intervention in older adults: Is there a role for core-stability training?

By

Behnaz Shahtahmassebi

BSc, MSc in Physical Education and Sport Sciences

This dissertation is presented for the degree of Doctor of Philosophy of Science

School of Psychology and Exercise Science
Murdoch University

Perth, Western Australia
2016

Statement of Declaration

I declare that this dissertation is my own account of my research and contains as its main content work, which has not previously been submitted for a degree at any tertiary education institution.

To the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis. Any contribution made to the research by others, with whom I have worked at Murdoch University or elsewhere, is explicitly acknowledged in the thesis.

Behnaz Shahtahmassebi ____________________
15/8/2016

A note on formatting and style

This PhD dissertation comprises a published peer-reviewed research paper (chapter 2; *Sports Medicine, (2014), 44(10): p. 1439-58. DOI 10.1007/s40279-014-0213-7*) and two chapters (4 and 5) which have been individually formatted according to their targeted journal requirements. Therefore, there may be some minor inconsistencies in the specific formatting styles between chapters.

ABSTRACT

Preliminary evidence indicates that age-related changes in trunk muscle morphology and function are associated with decreased balance and increased falls risk. However, the associations between trunk muscle morphology, strength, and functional ability, as well as the trainability of these muscles are not well established. Therefore, the aims of this thesis were to identify the relationships between trunk muscle morphology, strength, and functional ability and to determine the effects of exercise training on these outcomes in healthy older adults.

We initially undertook a systematic review to determine the effect of exercise training on trunk muscle morphology. Our results identified motor control and machine-based exercises targeting the trunk muscles resulted in the largest change in the trunk muscle morphology.

Using a cross-sectional design, we then explored the relationships between trunk muscle morphology, strength, and functional ability in 64 older adults. Our results showed anterior and lateral abdominal and posterior trunk muscle size and strength were positively associated with functional ability.

Finally, we conducted a randomised clinical trial investigating the effectiveness of a 12-week exercise programme on trunk muscle size, strength, and functional ability. Sixty-four individuals (mean(SD) age 69.8 (7.5) years; 59.4% female) were randomised to receive a multimodal exercise program comprising walking and balance exercises with or without strength/motor control training of the trunk muscles. Participants performing the trunk strengthening exercises experienced larger increases (mean difference [95%CI]) in trunk

muscle hypertrophy (1.6 [1.0, 2.2] cm) and composite trunk strength (172.6 [100.8, 244.5] N), as well as 30-Second Chair Stand Test (5.9 [3.3, 8.4] repetitions), Sitting and Rising Test (1.2 [0.22, 2.2] points), Forward Reach Test (4.2 [1.8, 6.6] cm), Backward Reach Test (2.4 [0.22, 4.5] cm), and Timed Up and Go Test (-0.74 [-1.4, -0.03] seconds) outcomes.

These findings further our understanding regarding 1) the relationships between trunk muscle morphology, strength, and functional ability and 2) appropriate exercise prescription aimed at improving these outcomes in older individuals.

I would like to dedicate this dissertation to my dearest parents who were always by my side during this journey and supported me with their constant love, great encouragement and invaluable advice. **"*Dear Mum and Dad, Thank so much for everything.*"**

I also would like to dedicate this dissertation to my dearest brother and sister. **"*Dear Amirreza and Golnaz, you always supported me with your great love, encouragement and provided me your invaluable advice*"**

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation and thanks to my supervisors ***Dr Timothy J Fairchild, Dr Jeffery J Hebert and Dr Mark Hecimovich.*** I have learned the incredible knowledge, skills, insight guidance and experiences from you through this long and challenging journey. You have thought me the value of critical and scientific thoughts that had significant positive influences on my research and academic career.

"Dear Tim, Jeff and Mark;

I am very honored and grateful to have worked under your invaluable supervision through my PhD candidature. Thank you so much for giving me this wonderful opportunity to learn, experience and discover the scientific world."

I would also like to thank to;

- Dean of the School of Psychology and Exercise Science, ***Professor Mike Anderson*** and ***staff of the University of School of Psychology and Exercise Science***, Murdoch University

- *Murdoch University Graduate Office*

- *Murdoch University Postgraduate Association (MUPSA),* for the MUPSA Small Research Support Grant

- *Dr Helen Correia* for her assistance the recruitment and conducting the psychological assessment of our study participants

- *All my senior participants* who participated in my PhD project

- My master supervisors at Ferdowsi University of Mashhad, ***Dr Ahmad Atri*** and ***Dr Hashemi Javaheri***, without your invaluable advices encouragement and support, I won't be able to step into through my PhD journey.

- *Dr Golnaz Shatahmassei* for her incredible knowledge, experience and advice in statistical modeling

- *Dr Norman J. Stomski* for the data acquisition, critical revision and final approval of the systematic review chapter

- *Miss Min Loo*, for her precise copyediting and proofreading

- *Mr Jack Burns*, his time, patience and laboratory guidance as our Exercise Physiology laboratory technician at Murdoch University

- *Miss Raelene Walton,* Murdoch University Practicum Coordinator (Exercise Science), without her assistance and encouragement we could not accomplish our project.

- My brilliant exercise physiology practicum assistances; ***Dylan, Matt, Chad, Hannah, Shahnee, Brodie, Clare, Daniel, Elouise, Kirsten Hannah, Tayla, Shara, Chamaine, Zac, Sam and Michael.***

- All my dearest friends; ***Min, Abdulsalam, Ateef, Issa, Yunis, Gayani, Sonia, Nurul, Tayabeh, and Sam***. "***Thanks for being there for me, you are all always in my heart***."

- My fellow graduate students; ***Sarah, Jacinta, Sam***, ***Faizal, Stefano, John, Nathan, and Aaron.***

List of Publications

- *Journal Publication*

Shahtahmassebi B, Hebert JJ, Stomski N, Hecimovich M, Fairchild T. ***The effect of exercise training on lower trunk muscle morphology: a systematic review.*** *Sports Medicine. 2014 Oct;44(10):1439-58* doi: 10.1007/s40279-014-0213-7.

- *Conference Publications*

Shahtahmassebi B, Hebert JJ, Stomski N, Hecimovich M, Fairchild T. (2013). ***The effect of exercise training on lower trunk muscle morphology: a systematic review.*** Paper presented at the 4th Annual MUPSA Multidisciplinary Conference, Murdoch University, Perth, Australia

Shahtahmassebi B, Hebert JJ, Stomski N, Hecimovich M, Fairchild T. (2015). ***Falls prevention exercise programme for older adults***. Oral presentation at the Three Minute Thesis (3MT)™ competition, Murdoch University, Perth, Australia

Shahtahmassebi B, Hebert JJ, Stomski N, Hecimovich M, Fairchild T. (2015). ***Falls prevention exercise programme for older adults***. Oral presentation at the Semi Final Round of Trans-Tasman 3MT competition, The University of Queensland, Australia

Shahtahmassebi B, Fairchild T, Hebert JJ, Hecimovich M. (2016). ***Lower trunk muscle morphology predicts functional abilities in healthy older adults: a cross sectional study***. Paper accepted for Oral Presentation at the 9th International Congress on Physical Education and Sport Sciences, Sport Sciences Research Institute of Iran, Tehran, Iran.

Shahtahmassebi B, Hebert JJ, Hecimovich M, Fairchild T. (2016). ***The effect of a 12-week supervised multimodal exercise training program on lower trunk muscle morphology and functional ability in healthy older adults: A randomized controlled trial***. Paper accepted for Oral Presentation at the 9th World Congress on Active Ageing, Victoria University's Institute of Sport, Exercise and Active Living, Melbourne, Australia

Shahtahmassebi B, Hecimovich M, Hebert JJ, Fairchild T. (2016). ***The effects of a supervised multimodal exercise program on anterior and lateral abdominal muscles size and functional ability in older adults: A randomized controlled trial***. Paper accepted for Poster Presentation at the 1st National Congress on Application of Sport Sciences in Health, Shiraz University, Shiraz, Iran

Awards and Grants

- ***MUPSA conference****: selected as the best oral presenter, Murdoch University 2013*

- ***Three Minutes Thesis Competition****: Awarded as" Competition Winner" and "People Choice", Murdoch University 3 MT competition 2015*

- ***MUPSA Small Research Support Grant***

Table of Contents

List of Tables per Chapter

List of Figures per Chapter

List of Abbreviations

Abbreviation	Definition
BBS	Berg Balance Scale
BRT	Backward Reach Test
CSA	Cross-sectional area
CST	30-second Chair Stand Test
ICC	Intraclass correlation coefficient
IO	Internal oblique
EO	External oblique
FSST	Four Square Step Test
FRT	Forward Reach Test
LM	Lumbar multifidus
LRT	Left Reach Test
L4/L5	Lumbar spinal level L4/L5
L5/S1	Lumbar spinal level L5/S1
MDRT	Multi-Directional Reach Test
RA	Rectus abdominis
RRT	Right Reach Test
6MWT	Six-Minute Walk Test
SRT	Sitting and Rising Test
TLAM	Total lateral abdominal muscles
TrA	Transversus abdominis
TUG	Timed Up and Go

Chapter 1

General Introduction

Background

Perspective: Aging process and changes in physical/functional ability

The progressive loss of skeletal muscle size and function (strength) with aging is known as Sarcopenia [1-3], and is often accompanied by a decrease in functional ability in older adults [2, 4-7]. These degenerative changes are in turn associated with reduced quality of life [8] and an increased risk of falls [9]. Falls are a major health concern among older adults, in terms of amplifying risks of injury, disability, socioeconomic burden, and mortality [10]. Thus improved falls prevention strategies are an important primary healthcare target for older adults [11].

Studies investigating the associations between age-related decrements in muscle strength and functional outcomes in older adults have overwhelmingly focused on peripheral musculature, through examining handgrip and knee extensor strength [4, 12-14]. These studies have provided empirical support for the benefits of multimodal exercise programs incorporating balance and resistance-based training of the peripheral musculature in reducing both the rate and risk of falls in older adults [15, 16]. More recently, studies have focused on age-related changes in the trunk musculature [9, 17-19] due to the important role of these muscles in performing activities of daily living. These studies have identified positive relationships between the trunk musculature with balance, mobility, and falls prevention in older adults [6, 20, 21].

This chapter will firstly provide a brief overview of the previously published literature investigating the associations between trunk muscle morphology (size), strength and functional ability in older adults. This chapter will then briefly describe key studies which have investigated the effects of exercise programs targeting the trunk muscles, and whether these exercise programs resulted in improved balance and functional ability in older adults.

The association between trunk muscle morphology (size) and strength in older adults

Andersen et al [22] examined the association between trunk muscle morphology (Computed Tomography of trunk muscle cross-sectional area and attenuation) and trunk extension strength in mobility-limited community-dwelling older adults (≥65 y.o.). The authors [22] demonstrated strong associations between trunk muscle cross-sectional area and absolute strength across all studied muscles (r=0.47-0.61; anterior abdominal muscles, posterior abdominal muscles, paraspinal muscles, and combined).

The association between trunk muscle morphology (size) and functional ability in older adults

Hicks et al [6] conducted a cross-sectional study to investigate the relationship between trunk muscle morphology (lumbar paraspinal, lateral abdominal, and rectus abdominis muscles) and performance in functional tasks on the Health ABC Performance Battery. The authors [6] found that after controlling for covariates (age, sex, race, height, total body fat and thigh muscle composition), the average trunk muscle area was not significantly associated with performance in functional tasks on the Health ABC Physical Performance Battery (specifically usual and narrow walk, chair stands, and standing balance tasks) in healthy older adults (70-79 y.o.). However, the authors [6] also revealed that higher fat infiltration, measured by reduced muscle attenuation in Computed Tomography (CT) images, was significantly and negatively associated with performance in functional tasks on the Health ABC Physical Performance Battery, explaining about 13% of the variance in performance, while thigh muscle attenuation explained only 5.5% of the variance. In other words, Hicks et al [6] indicated that fat infiltration in trunk muscles (a measure of muscle quality) was predictive of functional performance in older adults, while trunk muscle morphology explained little of the observed variance in performance of these functional tasks in this cross-sectional study.

The association between trunk muscle strength and functional ability in older adults

Several cross-sectional studies [17-20] examined the association between trunk muscle strength and functional ability (balance and mobility) in older adults, and these studies [17-20] generally demonstrate small to moderate significant associations (r=0.21-0.43) between trunk muscle strength and balance or functional performance in older adults. However the associations between measures of trunk muscle strength and functional ability in older adults require further investigation due to high levels of heterogeneity [21] in the study cohorts (e.g. clinical, healthy) and the adopted testing methodology between these cross-sectional studies [17-20]. For these reasons, a recent systematic review suggested the need for additional well-designed cross sectional studies to investigate the associations between measures of trunk muscle strength and functional ability in older adults [21].

The effects of exercise program (s) on trunk muscle morphology (size) in older adults

Kliziene et al examined [23] changes in the cross-sectional area of the lumbar multifidus muscle in healthy older women following a 32-week trunk strengthening exercise program comprising motor control exercises. The authors [23] indicated that there was significant hypertrophy in the cross-sectional area of the lumbar multifidus muscle (25.8% and 68.4% by week 16 and 32, respectively) in older women. On the other hand, Ryan et al. [24] compared the effects of a 24-week aerobic exercise program (treadmills and elliptical trainers) with diet-induced weight loss against diet-induced weight loss without exercise on trunk muscle composition (cross-sectional area of the erector spinae, psoas, rectus abdominis and lateral abdominal muscles) in overweight and obese older women. The authors [24] found no between group differences in trunk muscle area after 24 weeks, with both groups demonstrating reduced cross-sectional area in most muscles studied. Together these studies imply that motor control exercises can lead to trunk muscle hypertrophy (specifically lumbar multifidus), but aerobic exercise programs focusing on walking-based exercises will not increase trunk muscle morphology.

The effects of exercise program(s) on trunk muscle strength and functional ability in older adults

A recent systematic review conducted by Granacher et al [21] examined the effects of trunk strengthening exercise programs on trunk muscle strength and functional ability (balance and mobility) in older adults. Based on the findings of the review [21], trunk strengthening exercises have demonstrated significant improvements in trunk muscle strength, and these improvements translated to improved functional ability in older adults. It was noted however, that the benefits of trunk strengthening exercises on function and balance in older adults required further investigation, since studies included within the systematic review were generally low quality.

Aims and hypotheses of this dissertation

The extant literature suggests small to moderate significant associations between trunk muscle strength and functional ability in older adults, while the relationship between trunk muscle morphology and functional ability appears less clear. Additionally, trunk muscle morphology and strength appear to respond positively to targeted exercise programs incorporating motor control exercises in older adults, and increases in trunk muscle strength are associated with improvements in functional ability. There are however, limited studies which have examined these relationships and changes in trunk muscle morphology, strength and functional ability in response to a multimodal exercise program within a randomised controlled trial. The aims of this dissertation therefore, were to determine the relationships between trunk muscle morphology (size), strength, and functional ability; and to empirically examine the effects of an exercise program on these outcomes in healthy older adults, through three main studies. Specifically, we sought to i) systematically review extant literature (Chapter 2) investigating the effectiveness of different exercise programs on trunk muscle morphology; ii) explore the associations between trunk muscle morphology, strength, and functional ability in healthy older adults using a cross-sectional study design (Chapter 4); and iii) determine the effectiveness of a 12-week supervised multimodal exercise program comprising of walking and balance exercises, with or without trunk strengthening/motor control exercises on trunk muscles morphology, strength, and functional ability in healthy older adults through a single-blinded parallel group randomized controlled trial (Chapter 5).

The hypotheses of this dissertation correspond to each of the studies listed above, and are as follows:

i. Systematic review (Chapter 2): Targeted exercise program (s) recruiting the trunk musculature will alter trunk muscle morphology. Secondly, more intense forms of exercise such as machine-based resistance training, will demonstrate the largest effects on trunk muscle morphology.
ii. Cross-sectional study (Chapter 4): There will be positive relationships between
    a) trunk muscle morphology and functional ability,
    b) trunk muscle strength and functional ability, and

c) trunk muscle morphology and strength in healthy older adults.

iii. Randomized controlled trial (Chapter 5): Compared to a time-matched supervised walking and balance exercise program alone, the addition of trunk strengthening/motor control exercises will lead to:

a) greater increases in trunk muscles morphology (size),

b) greater increases in trunk muscles strength, and

c) greater improvements in functional ability in healthy older adults.

Overview of this dissertation

This dissertation consists of six chapters. Chapter 1 (this chapter) provides an introduction to the dissertation, and is followed by Chapter 2 (the systematic review). Chapter 3 (general methods) provides an overview of the general procedures used in the cross-sectional study (Chapter 4), and randomized controlled trial (Chapter 5). Finally, Chapter 6 (general discussion) provides an overview and summary of the findings of this dissertation, the implications of these findings, and recommendations for future research.

References

1. Cruz-Jentoft, A.J., et al., *Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People.* *Age Ageing*, 2010. **39**(4): p. 412-23.
2. Metter, E.J., et al., *Age-associated loss of power and strength in the upper extremities in women and men.* J Gerontol A Biol Sci Med Sci, 1997. **52**(5): p. B267-76.
3. Fielding, R.A., et al., *Sarcopenia: an undiagnosed condition in older adults. Current consensus definition: prevalence, etiology, and consequences. International working group on sarcopenia.* J Am Med Dir Assoc, 2011. **12**(4): p. 249-56.
4. Goodpaster, B.H., et al., *The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study.* J Gerontol A Biol Sci Med Sci, 2006. **61**(10): p. 1059-64.
5. Metter, E.J., et al., *Muscle quality and age: cross-sectional and longitudinal comparisons.* J Gerontol A Biol Sci Med Sci, 1999. **54**(5): p. B207-18.
6. Hicks, G.E., et al., *Cross-sectional associations between trunk muscle composition, back pain, and physical function in the health, aging and body composition study.* J Gerontol A Biol Sci Med Sci, 2005. **60**(7): p. 882-7.
7. Janssen, I., S.B. Heymsfield, and R. Ross, *Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability.* J Am Geriatr Soc, 2002. **50**(5): p. 889-96.
8. Heathcote, G., *Autonomy, health and ageing: transnational perspectives.* Health Educ Res, 2000. **15**(1): p. 13-24.
9. Kasukawa, Y., et al., *Relationships between falls, spinal curvature, spinal mobility and back extensor strength in elderly people.* J Bone Miner Metab, 2010. **28**(1): p. 82-7.
10. Sartini, M., et al., *The epidemiology of domestic injurious falls in a community dwelling elderly population: an outgrowing economic burden.* Eur J Public Health, 2010. **20**(5): p. 604-6.
11. Rubenstein, L.Z. and K.R. Josephson, *Falls and their prevention in elderly people: what does the evidence show?* Med Clin North Am, 2006. **90**(5): p. 807-24.

12. Martien, S., et al., *Is knee extension strength a better predictor of functional performance than handgrip strength among older adults in three different settings?* Arch Gerontol Geriatr, 2015. **60**(2): p. 252-8.
13. Clark, B.C. and T.M. Manini, *What is dynapenia?* Nutrition, 2012. **28**(5): p. 495-503.
14. Bohannon, R.W., *Hand-grip dynamometry predicts future outcomes in aging adults.* J Geriatr Phys Ther, 2008. **31**(1): p. 3-10.
15. Tofthagen, C., C. Visovsky, and D.L. Berry, *Strength and balance training for adults with peripheral neuropathy and high risk of fall: current evidence and implications for future research.* Oncol Nurs Forum, 2012. **39**(5): p. E416-24.
16. Granacher, U., L. Zahner, and A. Gollhofer, *Strength, power, and postural control in seniors: Considerations for functional adaptations and for fall prevention.* Eur J Sport Sci, 2008. **8**(6): p. 325-340.
17. Granacher, U., et al., *Relationships between trunk muscle strength, spinal mobility, and balance performance in older adults.* J Aging Phys Act, 2014. **22**(4): p. 490-8.
18. Pfeifer, M., et al., *Vitamin D status, trunk muscle strength, body sway, falls, and fractures among 237 postmenopausal women with osteoporosis.* Exp Clin Endocrinol Diabetes, 2001. **109**(2): p. 87-92.
19. Sakari-Rantala, R., et al., *Associations of sensory-motor functions with poor mobility in 75- and 80-year-old people.* Scand J Rehabil Med, 1998. **30**(2): p. 121-7.
20. Suri, P., et al., *Trunk muscle attributes are associated with balance and mobility in older adults: a pilot study.* PM R, 2009. **1**(10): p. 916-24.
21. Granacher, U., et al., *The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: a systematic review.* Sports Med, 2013. **43**(7): p. 627-41.
22. Anderson, D.E., et al., *Computed tomography-based muscle attenuation and electrical impedance myography as indicators of trunk muscle strength independent of muscle size in older adults.* Am J Phys Med Rehabil, 2014. **93**(7): p. 553-61.
23. Klizienė, I., et al., *Effect of core stability exercise on cross sectional area of lumbar multifidus muscle and physical capacity.* Educ Phys Train Sport, 2011. **83**: p. 9-15.

24. Ryan, A.S. and A.S. Harduarsingh-Permaul, *Effects of weight loss and exercise on trunk muscle composition in older women.* Clin Interv Aging, 2014. **9**: p. 395-402.

Chapter 2

The Effect of Exercise Training on Lower Trunk Muscle Morphology

Reprinted from

Behnaz Shahtahmassebi, Jeffrey J. Hebert, Norman J. Stomski, Mark Hecimovich, Timothy J. Fairchild

Sports Medicine, (2014), 44(10): p. 1439-58. DOI 10.1007/s40279-014-0213-7

Abstract

Background Skeletal muscle plays an important role in maintaining the stability of the lumbar region. However, there is conflicting evidence regarding the effects of exercise on trunk muscle morphology.

Objective To systematically review the literature on the effects of exercise training on lower trunk muscle morphology to determine the comparative effectiveness of different exercise interventions.

Data Source and Study Selection A systematic search strategy was conducted in the following databases: Pub-Med, SportDiscus, CINAHL, the Cochrane Library and PEDro. We included full, peer-reviewed, prospective longitudinal studies, including randomized controlled trials and single-group designs, such as pre- to post-intervention and crossover studies, reporting on the effect of exercise training on trunk muscle morphology.

Study Appraisal and Synthesis Study quality was assessed with the Cochrane risk-of-bias tool. We classified each exercise intervention into four categories, based on the primary exercise approach: motor control, machine-based resistance, non-machine-based resistance or cardiovascular. Treatment effects were estimated using within-group standardized mean differences (SMDs).

Results The systematic search identified 1,911 studies; of which 29 met our selection criteria: motor control (*n* = 12), machine-based resistance (*n* = 10), non- machine-based resistance (*n* = 5) and cardiovascular (*n* = 2). Fourteen studies (48 %) reported an increase in trunk muscle size following exercise training. Among positive trials, the largest effects were reported by studies testing combined motor control and non-machine-based resistance exercise (SMD [95 % CI] = 0.66 [0.06 to

1.27] to 3.39 [2.80 to 3.98]) and machine-based resistance exercise programmes (SMD [95 % CI] = 0.52 [0.01 to 1.03] to 1.79 [0.87 to 2.72]). Most studies investigating the effects of non-machine-based resistance exercise reported no change in trunk muscle morphology, with one study reporting a medium effect on trunk muscle size (SMD [95 % CI] = 0.60 [0.03 to 1.16]). Cardiovascular exercise interventions demonstrated no effect on trunk muscle morphology (SMD [95 % CI] = -0.16 [-1.14 to 0.81] to 0.09 [-0.83 to 1.01]).

Limitations We excluded studies published in languages other than English, and therefore it is possible that the results of relevant studies are not represented in this review. There was large clinical heterogeneity between the included studies, which prevented data synthesis. Among the studies included in this review, common sources of potential bias were random sequence generation, allocation concealment and blinding. Finally, the details of the exercise parameters were poorly reported in most studies.

Conclusion Approximately half of the included studies reported an increase in lower trunk muscle size following participation in an exercise programme. Among positive trials, studies involving motor control exercises combined with non-machine-based resistance exercise, as well as machine-based resistance exercises, demonstrated medium to large effects on trunk muscle size. Most studies examining the effect of non-machine-based resistance exercise and all studies investigating cardiovascular exercise reported no effect on trunk muscle morphology. However, these results should be interpreted with caution because of the substantial risk of bias and suboptimal reporting of exercise details in the included studies. Additional research, using methods ensuring a low risk of bias, are required to further elucidate the effects of exercise on trunk muscle morphology.

1 Introduction

The lumbar spine is subjected to a variety of complex forces during daily tasks [1] and when engaging in physical activity [2–4]. Stability of the lumbar spine plays an important role in reducing the risk of injury [5, 6]. Lumbar spine stability is dependent on three interrelated components: the passive osteoligamentous structures; the skeletal musculature; and the motor control system, which coordinates the complex muscle activity required to mitigate expected and unexpected perturbations [5]. With respect to the lower trunk musculature (i.e. the abdominal muscles and those attaching to the lumbar spine), both global and local muscles are involved in the stabilization of the lumbar spine [7–9]. The coordination of muscle recruitment is critical to this stabilization and prevention of lumbar spine buckling [10, 11], suggesting a significant role for the motor control system [5, 12].

There is a positive relationship between the size and function (e.g. muscular strength, endurance and power) of skeletal muscle [13–17]. Similarly, reductions in trunk muscle mass are associated with low back pain [18–20] and decreased functional capacity [21–23], while exercise- related increases in skeletal muscle mass are associated with better clinical outcome in patients with lumbar spine disorders [14, 18, 24, 25].

A number of studies adopting exercise-based interventions have previously demonstrated increases in trunk muscle size [14, 16, 26], while others have reported no changes [27–29]. Moreover, there is sparse information comparing the effects of different exercise interventions on trunk muscle morphology. Therefore, the aim of this study was to systematically review the literature on the effects of exercise training on lower trunk muscle morphology, in order to determine the comparative effectiveness of different exercise strategies. We hypothesized that (1) exercise training would alter trunk muscle morphology; and (2) more intense forms of exercise, such as machine-based resistance training, would demonstrate the largest effect on trunk muscle morphology.

2 Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [30].

2.1 Criteria for Considering Studies for this Review

2.1.1 Types of Studies and Participants

We included full, peer-reviewed, prospective longitudinal studies, including randomized controlled trials (RCTs) and single-group designs, such as pre- to post-intervention and crossover studies. We excluded animal studies, editorials, letters, case reports, conference proceedings and studies published in languages other than English. Because of detraining effects, we also excluded studies that measured changes in trunk muscle morphology more than 1 week after exercise cessation. Our review protocol placed no restrictions on study participants, including age, sex, clinical status and level of physical fitness.

2.1.2 Types of Interventions

The intervention of interest was participation in an exercise programme. The exercise interventions consisted of any mode of exercise directed by a healthcare provider or exercise professional. We excluded studies reporting the effects of participation in sporting or general physical activities.

2.1.3 Types of Outcome Measures

The outcome of interest was change in lower trunk muscle morphology following an exercise intervention. Specifically, we included studies reporting changes in the size (e.g. cross-sectional area, thickness or volume) or structure (e.g. fatty degeneration, density or fibre type) of individual muscles or changes in body composition related to muscle (e.g. regional or whole-body muscle mass) following an exercise intervention. We considered the lower trunk muscles to include the abdominal musculature, as well as muscles attaching to the lumbar spine. Search terms were used to define appropriate bodily regions (lumbosacral, trunk, spine, lumbar, low back, abdominal and core) and muscles (transversus abdominis, external oblique, internal oblique, rectus abdominis, iliopsoas, multifidus, erector spinae and quadratus lumborum) of interest. There were no restrictions on the type of muscle morphology measure.

2.2 Search Methods Used for Identification of Studies

2.2.1 Electronic Searches

A search strategy was developed in consultation with a reference librarian and conducted in the following databases from inception to 30 April 2012: PubMed, SportDiscus, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Cochrane Central Register of Controlled Trials (CENTRAL) and Physiotherapy Evidence Database (PEDro). We developed the search syntax for PubMed using Medical Subject Headings and free text terms (see Appendix S1 in the Electronic Supplementary Material). This syntax was then adapted as required for use in the remaining databases. Additionally, we screened the reference lists of included studies.

2.3 Data Collection and Analysis

2.3.1 Selection of Studies

Two review authors (B.S. and A.S.) independently screened the titles and abstracts of studies to identify potentially relevant studies. Next, the full texts of potentially relevant articles were retrieved and assessed for inclusion. Disagreements between review authors were resolved by third-party adjudication (by J.J.H.). The review authors were not blinded to study authors, institutions or journals.

2.3.2 Data Extraction and Management

Data were extracted by one review author (B.S.) using a customised form. The extracted information included details of the study design, participants (number of participants, age, sex, clinical status and training level), exercise intervention (exercise protocol, protocol time and frequency), control or comparator condition (protocol, time and frequency) and outcome measures (details of morphology assessment, measurement techniques and device). Any unclear information was resolved through discussion with a second review author (J.J.H.). In addition, we contacted several study authors to seek clarification and obtain additional information. There is no standard or widely adopted classification of trunk muscle exercises. Previously reported classifications [31, 32] did not adequately describe the types of exercises reported by the studies included in this review. Consequently, we classified each study into four categories based on the type of exercise that was implemented. When more than one type of exercise was included in the exercise programme, we classified the study according to the primary exercise intervention. Exercise categories were defined as:

- Motor control exercise: exercise described as ‘motor control’, ‘specific stabilization’ or ‘core stability’ exercise, using interventions targeting specific trunk muscles with a goal of improving control and coordination of the spine and pelvis [33].
- Machine-based resistance exercise: exercise aiming to improve muscular strength and/or endurance by use of machines, such as the MedX lumbar extension [14], David back [34] and Nautilus [35, 36] devices.
- Non-machine-based resistance exercise: exercise aiming to improve muscular strength and/or endurance with static or dynamic body weight resistance, and including the use of simple equipment such as dumb- bells, resistance bands and Swiss balls [37].
- Cardiovascular exercise: aerobic exercise (e.g. walking, jogging or cycling) aiming to increase the heart rate and respiration and to improve cardiovascular fitness by involving large muscle groups [38].

2.3.3 Assessment of Risks of Bias in the Included Studies

The risks of bias in all included studies were independently assessed by two reviewer authors (B.S. and N.S.), using the Cochrane risk-of-bias tool [39]. Seven domains were assessed, including sequence generation, allocation concealment, blinding (participants/personnel), blinding (out- come assessor), incomplete outcome data, selective reporting and other sources of bias. Each domain was assigned a score of '+' if the criteria for a low risk of bias were met, '-' if the criteria for a high risk of bias were met and '?' if the data were insufficient to permit judgment. Disagreements between reviewers were discussed and resolved with a third review author (J.J.H.).

2.3.4 Measures of Treatment Effects and Data Analysis

The data were analysed in Review Manager v5.1 soft- ware. The effects of exercise on trunk muscle morphology were estimated using standardized mean differences (SMDs) calculated from Hedges' *g* statistics and 95 % confidence intervals (CIs). An SMD score of 0.20 represents a small effect, 0.50 indicates a medium effect and 0.80 indicates large effect [40]. Since muscle morphology is unlikely to be influenced by nonspecific treatment effects, our estimates of treatment effect represent the within-group change in muscle morphology following exercise participation. When possible, we calculated separate treatment effect estimates for each muscle and condition separately.

3 Results

3.1 Results of the Search

The search outcome and study selection process are displayed in Fig. 1. The systematic search identified 1,910 citations: 597 from SportDiscus, 595 from PubMed, 495 from CINAHL, 143 from CENTRAL and 80 from PEDro. Of these citations, 382 were duplicates, thus yielding 1,529 unique studies. One additional study was identified during the peer review of this manuscript (*n* = 1). The manual search of references lists did not identify any additional studies.

The title and abstract screen identified 122 potentially relevant studies, which were retained for full-text review. Ultimately, 29 studies met our selection criteria and were included for analysis [14, 16, 18, 24–29, 35, 41–58]. Of the 93 studies excluded after the full-text screen, the reasons for exclusion were (a) outcome measures other than muscle morphology (*n* = 44); (b) no exercise training intervention (*n* = 35); (c) study was an abstract or review paper (*n* = 10); (d) greater than 1-week duration between exercise cessation and follow-up assessment (*n* = 3); and (e) language other than English (*n* = 1). A list of excluded articles is available from the corresponding author.

3.2 Description of the Included Studies

Twenty-nine studies, comprising 1,244 participants, were classified into motor control (12 studies, *n* = 733), machine-based resistance exercise (10 studies, *n* = 280), non-machine-based resistance exercise (5 studies, *n* = 128) and cardiovascular exercise (2 studies, n = 103) conditions. The study characteristics and outcomes are presented in Tables 1 and 2. Large clinical heterogeneity was observed among the included studies. Major sources of heterogeneity were (1) sample populations (age, sex and health status); (2) exercise mode (motor control, machine-based resistance, non-machine-based resistance or cardiovascular); (3) exercise prescription (frequency, intensity and duration); (4) outcome muscle; (5) type of muscle morphology assessment (e.g. thickness, density or cross-sectional area [CSA]); and (6) method used for muscle measurement (e.g. ultrasound, magnetic resonance imaging [MRI] or computed tomography [CT]). As a result, the planned analyses of statistical heterogeneity and random-effects meta-analysis were not conducted.

3.3 Risks of Bias in the Included Studies

The results of the risk-of-bias assessments for each study are presented in Fig. 2 and are summarized as percentages across all studies in Fig. 3. The most common sources of bias involved random sequence generation, allocation concealment and blinding of study participants. While no studies reported the blinding of participants or personnel, the nature of exercise interventions typically precludes this. The blinding of outcome assessors was reported in 15 trials (52 %) [18, 24, 26–29, 41–47, 49, 52]. Thirteen studies (44 %) [14, 24, 27–29, 41, 43–47, 51, 58] randomly assigned participants to intervention groups; however only six trials (20 %) [27–29, 43, 45, 47] sufficiently detailed the method used to generate the sequence of random numbers. Five studies (17 %) [18, 28, 29, 41, 45] adequately reported the method used to conceal group allocation. Eleven studies (37 %) [13, 18, 28, 35, 45, 47, 50, 54, 55, 57, 58] stated that they used methods to address incomplete outcome data, such as using intention-to-treat analysis. Only one study (3 %) [45] referred to a published study protocol that clearly defined the primary and secondary study outcomes.

3.4 Effects of Interventions

We were able to calculate standardized within-group treatment effects from data reported in 23 of the 29 studies [13, 14, 18, 24, 25, 27–29, 35, 41–49, 51, 54, 56–58]. Forest plots summarizing the within-group treatment effects from baseline to the final follow-up point of each study are presented in Figs. 4, 5, 6 and 7. In addition, we computed standardized within-group treatment effects at all time points, including comparator group outcomes (Table 1).

Of the 22 included studies, 10 (45 %) [14, 16, 24, 35, 47–51, 56] reported positive changes in trunk muscle morphology following participation in an exercise training programme. Among trials demonstrating significant treatment effects on trunk muscle morphology, the largest effects were reported by studies [16, 24, 47, 49, 50] that used combined motor control and non-machine-based resistance exercise programmes (SMD [95 % CI] = 0.66 [0.06 to 1.27] to 3.39 [2.80 to 3.98]) and studies [14, 35, 48, 51, 56] that investigated machine-based resistance exercise protocols (SMD [95 % CI] = 0.52 [0.01 to 1.03] to 1.79 [0.87 to 2.72]). Most studies investigating the effects of non-machine-based resistance exercise interventions reported no change in trunk muscle size morphology, while one study [24] reported a significant increase in trunk muscle size (SMD [95 % CI] = 0.60 [0.03 to 1.16]). Cardiovascular exercise interventions [29, 43] demonstrated no effect (SMD [95 % CI] = -0.16 [-1.14 to 0.81] to 0.09[-0.83 to 1.01]). Because of data limitations, we were unable to calculate SMD statistics for six studies (21 %) [18, 26, 44, 52, 53, 55], and those study outcomes are presented in Table 2.

4 Discussion

4.1 Summary of the Main Results

This was the first systematic review to examine the effect of exercise training on trunk muscle morphology. Of the 29 included studies, 14 (48 %) [14, 16, 18, 24, 26, 35, 44, 46– 51, 56] reported positive changes in trunk muscle morphology following participation in an exercise training programme. Among positive trials for which we were able to estimate treatment effects, programmes including motor control exercises combined with non-machine-based resistance exercises [16, 24, 47, 49, 50] and programmes including machine-based exercise interventions [14, 35, 48, 51, 56] reported medium to large effects on trunk muscle size.

Most studies investigating the effects of non-machine- based resistance exercise interventions [13, 28, 41, 45] reported no change in trunk muscle morphology, while three studies reported significant increases in trunk muscle size [24–26]. Cardiovascular exercise interventions [29, 43] had no effect on trunk muscle morphology. These results should be interpreted cautiously because of limitations in the included studies, such as investigation of small samples, suboptimal reporting of exercise details and substantial risks of bias.

4.1.1 Effect of Motor Control Exercise on Trunk Muscle Morphology

Six studies [16, 24, 46, 47, 49, 50] reported positive changes in trunk muscle size following participation in a combined motor control and non-machine-based resistance exercise programme. Kliziene et al. [16] examined changes in lumbar multifidus CSA among 22 elderly women participating in a 32-week motor control and resistance exercise programme. While the authors reported large increases in lumbar multifidus CSA, this study demonstrated several potential sources of methodological bias, including selection, performance and detection bias. Additionally, there was a lack of detailed reporting of the exercise parameters, making it difficult to identify several aspects of the exercise intervention. The large treatment effects may have resulted from the longer duration of training (32 weeks); this is particularly evident when considering the effect sizes at 16 weeks, which were comparable to those in other studies of similar exercise duration.

An RCT with a low risk of bias [47] investigated the effects of three multimodal training programmes (which included motor control exercises) on lumbar multifidus, quadratus lumborum and psoas muscle CSA. The study participants comprised 46 elite male Australian Football League athletes. Each of the three training programmes was defined by the duration and sequencing of two exercise periods implemented during the 22-week playing season: motor control exercises plus routine team training (the motor control period) or Pilates exercises plus routine team training (the Pilates period). Group 1 (prolonged motor control training) completed a 15-week motor control exercise period, followed by a 7-week Pilates period. Group 2 (short-term motor control training) completed a 7-week Pilates period, followed by an 8-week motor control period and then another 7-week Pilates period. Group 3 (control) participants completed a 15-week Pilates period and then a 7-week motor control period. Muscle CSA was assessed by MRI at baseline, week 15 and week 22. Participants in group 1 (prolonged training) demonstrated no change in lumbar multifidus CSA by week 15 but moderate to large increases in lumbar multifidus CSA at the L2 to L4 lumbar spinal levels by week 22. Participants in group 2 (short-term training) demonstrated large increases in lumbar multifidus CSA at the L2 to L3 lumbar spinal levels by week 15 and at L2 to L4 by week 22. Finally, group 3 (control) participants experienced no change in lumbar multifidus CSA by week 15 but large increases in lumbar multifidus CSA at L2 to L3 by week 22 (following the 7-week motor control intervention). There were no changes in lumbar multifidus CSA at the remaining spinal levels, nor were there differences in muscle size among the other muscles that were measured (the quadratus lumborum and psoas major). It is noteworthy that as professional athletes, the study participants maintained an intensive exercise training schedule prior to and throughout the duration of the study. Therefore, these study results may not generalize beyond similar athletic populations.

Two studies with high risks of bias [24, 46] reported that lumbar multifidus thickness and CSA increased in patients with low back pain following participation in a combined motor control and non-machine-based resistance exercise programme. However, our treatment effect estimates demonstrated no significant changes in lumbar multifidus thickness or CSA. Akbari et al. [24] investigated the effect of an 8-week motor control and resistance exercise programme on transversus abdominis and lumbar multifidus muscle thickness among 25 patients with chronic low back pain. They reported increases in transversus abdominis and lumbar multifidus muscle thickness. Another study [46] examined the impact of a 10-week motor control exercise programme on lumbar multifidus CSA in 59 patients with chronic low back pain. Participants were randomly assigned to receive motor control exercises, motor control and dynamic resistance exercises, or motor control and dynamic–static resistance exercises. Lumbar multifidus CSA was measured at the upper end-plate of L3, lower end-plate of L4 and upper end-plate of L4. The authors reported increases in lumbar multifidus muscle CSA at the upper end-plate of L3, upper end-plate of L4 and lower end-plate of L4 among participants performing the motor control and dynamic–static resistance exercises, with no change in muscle morphology occurring in the other groups.

One study with a high risk of bias [49] examined changes in lumbar multifidus CSA at the L2 to L5 lumbar spinal levels in 21 young elite cricketers with and without low back pain. Participants with low back pain performed 8 weeks of motor control and non-machine-based resistance exercises, followed by 4 weeks of cricket matches (on 4 days per week). Participants without low back pain completed 8 weeks of non-machine-based resistance exercises and 4 weeks of cricket matches (on 4 days per week). The athletes in both groups demonstrated no change in lumbar multifidus CSA at the L2 to L4 lumbar spinal levels. However, for athletes with low back pain, there were large increases in lumbar multifidus CSA at L5 on the asymptomatic and symptomatic sides. Similarly, Jansen et al. [50] reported the effect of exercises targeting the lateral abdominal muscles among 21 young football players with chronic groin pain. There were moderate increases in transversus abdominis thickness and no change in internal or external oblique muscle thickness following 14 weeks of motor control and resistance exercises. However, the results of this study must be interpreted cautiously because of the high risk of bias and small sample size.

Two studies with high risks of bias [27, 42] reported no differences in abdominal and lumbar multifidus muscle size following motor control and non-machine-based resistance exercise training. Finally, one higher-quality study [45] and one lower-quality study [54] evaluating the effects of short-term motor control exercise programmes reported no changes in lumbar and abdominal muscle CSA.

4.1.2 Effect of Machine-Based Resistance Exercise on Trunk Muscle Morphology

Two studies with high risks of bias [14, 48] demonstrated significant increases in lumbar multifidus and lateral abdominal muscle size following participation in a machine-based resistance exercise. Dorado et al. [48] examined changes in rectus abdominis and lateral abdominal muscle volume in nine sedentary female participants participating in a 36-week Pilates exercise programme using the 'balance body reformer' device. There were large increases in rectus abdominis volume on the dominant and nondominant sides, while lateral abdominal muscle volume remained unchanged. Participants (*n* = 35) in another study [14] completed 12 weeks of training on a MedX lumbar extension machine, 6 weeks after lumbar disc surgery. Following the 12-week exercise intervention, there was a large increase in paraspinal muscle CSA.

One study with a high risk of bias [51] examined the impact of an 8-week exercise intervention using a MedX lumbar extension machine, with or without motor control exercises, on paraspinal and lumbar multifidus muscle CSA, among 14 young male adults. Participants performing the machine-based resistance and motor control exercises demonstrated increases in paraspinal and lumbar multifidus muscle CSA.

One study with a high risk of bias, reported by Parkkola et al. [35], examined changes in psoas major and paraspinal muscle CSA following an 18-week machine-based resistance exercise programme using a Nautilus multi-station device. Among the 12 sedentary participants, there were large increases in psoas muscle CSA but no changes in paraspinal muscle CSA. Another study with a high risk of bias [56] investigated the effect of a 12-week machine-based and non-machine-based resistance exercise training programme on lumbar multifidus type I and II muscle fibre size. Lumbar multifidus muscle biopsies were obtained from 30 patients with chronic low back pain before and after a 12-week exercise programme. There were moderate increases in type II muscle fibre size and no changes in the size of type I muscle fibres. Finally, one higher-quality study [28] and one lower-quality study [57] reported no effects on lateral abdominal and lumbar muscle size following 12 weeks of machine-based resistance exercise training interventions.

4.1.3 Effect of Non-machine-Based Resistance Exercise on Trunk Muscle Morphology

One study with a high risk of bias [24] examined changes in transversus abdominis and lumbar multifidus muscle thickness among 25 patients with chronic low back pain participating in an 8-week progressive non-machine-based resistance exercise intervention. The authors reported increases in transversus abdominis and lumbar multifidus muscle thickness. However, the findings on lumbar multifidus thickness must be interpreted cautiously because our treatment effect estimates demonstrated no significant changes in lumbar multifidus thickness.

Another study with a high risk of bias [25] investigated the effect of a 12-week Swiss ball exercise programme on psoas major, quadratus lumborum, erector spinae and lumbar multifidus muscle CSA among 17 patients with chronic low back pain. The authors reported increases in psoas major, quadratus lumborum, erector spinae and lumbar multifidus muscle CSA. However, the results from this study must be interpreted cautiously because our treatment effect estimates demonstrated no significant changes in psoas major, quadratus lumborum, erector spinae and lumbar multifidus muscle CSA.

The remaining five studies investigating the effect of non-machine-based resistance exercise [13, 28, 41, 45, 58] demonstrated no significant changes in trunk muscle morphology. The methodological quality of these studies varied from high to low.

4.1.4 Effect of Cardiovascular Exercise on Trunk Muscle Morphology

One higher-quality study [29] and one lower-quality study [43] examined the effects of cardiovascular exercise training interventions on trunk muscle morphology. Neither exercise programme resulted in morphological changes in the iliopsoas, abdominal and lumbar paraspinal muscles. Kuk et al. [29] investigated the effect of 24 weeks of cardiovascular exercise on abdominal muscle mass among 86 overweight or obese postmenopausal women. Participants exercised three to four times per week on a cycle ergometer or a treadmill at 50% of maximal oxygen consumption (VO_2max), expending 4, 8 or 12 kcal/ kg per week. In the second study, Sakamaki et al. [43] examined changes in iliopsoas volume and lumbar paraspinal muscle volume in 17 young males following a 3-week treadmill walking programme.

4.1.5 Descriptive Interpretation of the Results of Six Studies

We were unable to estimate treatment effects from the data reported in six studies [18, 26, 44, 52, 53, 55]. One higher- quality study by Hides et al. [18] investigated the effect of medical treatment, with and without motor control exercises, on lumbar multifidus

CSA among 41 patients with acute, unilateral low back pain. At baseline, the patients exhibited asymmetry in lumbar multifidus CSA, purportedly resulting from unilateral atrophy (mean asymmetry = 24 %). Following 4 weeks of treatment, there was a significant difference between the groups in mean asymmetry, favouring the exercise group (motor control exercise and medical treatment = 0.7 %, medical treatment only = 17 %).

Three studies with high risks of bias [26, 44, 53] reported positive changes in trunk muscle morphology following participation in different types of exercise training interventions. Lescher et al. [26] reported that an intensive period of non-machine-based resistance exercise participation (daily for 12 weeks) increased paraspinal muscle CSA among 14 sedentary, middle-aged patients with low back pain. Ten weeks of motor control exercises combined with non-machine-based resistance exercises were shown to increase lumbar paraspinal muscle CSA among patients with chronic back pain and back muscle atrophy [44]. In this study, 59 participants were randomized to receive motor control exercises, motor control and dynamic resistance exercises, or motor control and dynamic–static resistance exercises. Lumbar paraspinal muscle CSA was measured at the upper end-plate of L3 and at the upper and lower end-plates of L4. The authors reported increases in paraspinal muscle CSA at the upper end-plate of L4 among participants in the motor control and dynamic resistance exercise group. Additionally, there were increases in paraspinal muscle CSA at the upper end- plate of L3 and at the lower end-plate of L4 among participants completing the motor control and dynamic–static resistance exercise programme, but no differences in the motor control exercise group. Participants in another study [53] completed 12 weeks of training on ‘David back exercise devices’ 24 weeks after lumbar spine spinal surgery. The authors reported only descriptive statistics demonstrating an increase in paraspinal muscle CSA and no change in lumbar multifidus CSA.

Finally, two studies with high risks of bias [52, 55] examined the effects of machine-based resistance exercise training on trunk muscle morphology. Neither exercise programme resulted in morphological changes in the lumbar paraspinal muscle. Kaser et al. [52] investigated the effect of 12 weeks of machine-based resistance exercises, non-machine-based resistance exercises and aerobic exercises on lumbar paraspinal muscle CSA and erector spinae muscle fibre size (types I, IIA, IIX and IIC) among 34 patients with chronic low back pain. In the second study [55], 16 participants with and without low back pain completed an 8-week machine-based resistance exercise programme using a MedX lumbar extension machine.

4.2 Quality of the Evidence

As evidenced by the lack of precision in the calculated treatment effects, many studies were likely underpowered and therefore prone to type II error. Most studies demonstrated a range of methodological limitations, such as (1) inadequate reporting of randomization sequence generation; (2) concealment of treatment allocation; and (3) incomplete reporting of outcome data. Other methodological weaknesses included a lack of blinding of participants or personnel measuring treatment outcomes, and issues of selective reporting. Given the nature of exercise interventions, it is usually not possible to blind participants and clinicians to an individual's treatment group allocation. However, the blinding of research personnel responsible for the measurement of treatment outcomes is a potentially important method of reducing bias. Indeed, a recent systematic review investigating the clinical importance of paraspinal muscle morphology reported a trend toward larger effect sizes when outcome assessors were not blinded [59].

4.3 Study Limitations and Potential Biases in the Review Process

A potentially important measurement issue among some of the included studies involves the quantification of muscle changes derived from suboptimal imaging techniques. Many studies appeared to have reported changes in muscle size from partial muscle measures (e.g. CSA or thickness) as opposed to comprehensive measures of muscle volume. Moreover, many of these studies appeared to generalize changes observed in part of the muscle to the muscle in its entirety. Such generalization requires the assumption that exercise-induced change in skeletal muscle size is a homogenous process that occurs equally throughout the muscle. However, evidence from peripheral skeletal muscle suggests that hypertrophy is a heterogeneous process, with some parts of a muscle experiencing greater hypertrophy than other parts [60]. While this phenomenon has not been investigated in the lower trunk musculature, negative changes in muscle size (i.e. atrophy) appear to occur asymmetrically within paraspinal muscles [61], suggesting that this concern is equally valid in that region. Therefore, the use of incomplete measures of muscle size represented another potential source of bias among many of the studies in this review.

The primary strengths of this review were our search strategy, which implemented a comprehensive examination of five relevant databases, and a study selection process undertaken by two independent reviewers using predefined criteria. However, we excluded studies published in languages other than English, and therefore it is possible that the results of relevant studies are not represented in this review. The quality of many of the included studies was suboptimal because of the risks of selection, performance, detection and attrition biases. We were unable to combine study results for meta-analyses, because of clinical heterogeneity related to differences in the sample populations, exercise modes, exercise prescriptions, outcome muscles and methods of muscle measurement. Finally, it was difficult to classify many exercise programmes, because of poor or incomplete reporting. Specifically, the exercise protocols often lacked details related to exercise prescription, setting, type of equipment used, a system to monitor adverse events and reasons for withdrawal, and measures of motivation, adherence and compliance.

4.4 Implications for Practice

Exercise-induced hypertrophy of skeletal muscle is a complex biological response. Several conceptual models have been developed to explain the cellular, biomechanical and molecular mechanisms involved in skeletal muscle remodeling arising from muscle loading [62]. Consequently, recommendations for exercise parameters ideally suited to inducing skeletal muscle hypertrophy have been developed. These recommendations include factors such as exercise duration of at least 6 to 8 weeks [63], high intensity of mechanical loading (i.e. 80 to 95 % of repetition maximum) [64] and high-load/low-repetition training [65]. In addition, it is assumed that training history is an important determinant of exercise-induced hypertrophy, with untrained individuals experiencing greater change [66]. However, the muscles of the lower trunk are likely to require special consideration, as high-intensity exercises may be unsafe because of low back injury [67].

Our systematic review identified that the largest effects of exercise on trunk muscle morphology have been reported by studies implementing training programmes consisting of (1) motor control exercises combined with non-machine-based resistance exercises; or (2) machine- based resistance exercises. However, the exercise prescription details were often poorly reported, and the studies were prone to several types of methodological bias. The identification of optimal exercise approaches aimed at enhancing trunk muscle morphology requires evidence from additional high-quality randomized trials.

4.5 Implications for Research

Most studies investigating the effects of exercise on trunk muscle morphology have suffered from methodological limitations. Future research should adhere to recommended methodological and reporting standards related to randomization; treatment allocation concealment; blinding of outcome assessors, participants and research personnel (if applicable; history and reasons for drop-outs; and performance of an intention-to-treat analysis. In addition, future studies should be sufficiently powered to identify effects sizes of interest.

A critical element of understanding, appraising and replicating studies investigating the effect of exercise interventions is comprehensive and detailed reporting of the exercise prescription. Traditionally, the reporting of exercise details has been suboptimal [68], and the studies included in this review are no exception. Slade and Keating [68] have developed reporting standards for trials involving exercise interventions, and adherence to these recommendations will improve the quality of future exercise trials.

5 Conclusion

This is the first systematic review to examine the effect of exercise training on lower trunk muscle morphology. Our search strategy identified 29 relevant studies. Approximately half of the included studies (n = 14, 50 %) reported an improvement in trunk muscle morphology following participation in an exercise training programme. Exercise training programmes comprising motor control exercises combined with non-machine-based resistance exercises, as well as machine-based resistance exercise programmes, demonstrated the largest treatment effects. Cardiovascular exercise programmes had no effect on trunk muscle morphology. However, these results should be interpreted with caution because of the potential for methodological bias and suboptimal reporting of exercise details among the included studies. Further, additional high-quality research is needed to identify the optimal exercise interventions to improve lower trunk muscle morphology.

Acknowledgments

The authors would like to thank Ms Margaret Solosy for assistance with developing the search strategy, Dr Golnaz Shahtahmassebi for statistical advice and Mr Andrew

Schechter (A.S.) for assisting with study selection. The contributions of the authors are as follows: B.S.—study conception and design, data acquisition, analysis and interpretation, drafting and final approval of the manuscript; J.J.H.—study conception and design, data interpretation, critical revision and approval of the final manuscript; N.J.S.— data acquisition, critical revision and final approval of the manuscript; M.H.—study conception, critical revision and final approval of the manuscript; T.J.F.—study conception and design, data interpretation, critical revision and final approval of the manuscript.

Conflicts of interest

The authors have no conflicts of interest that are directly relevant to the content of this review. No sources of funding were used in the preparation of this review.

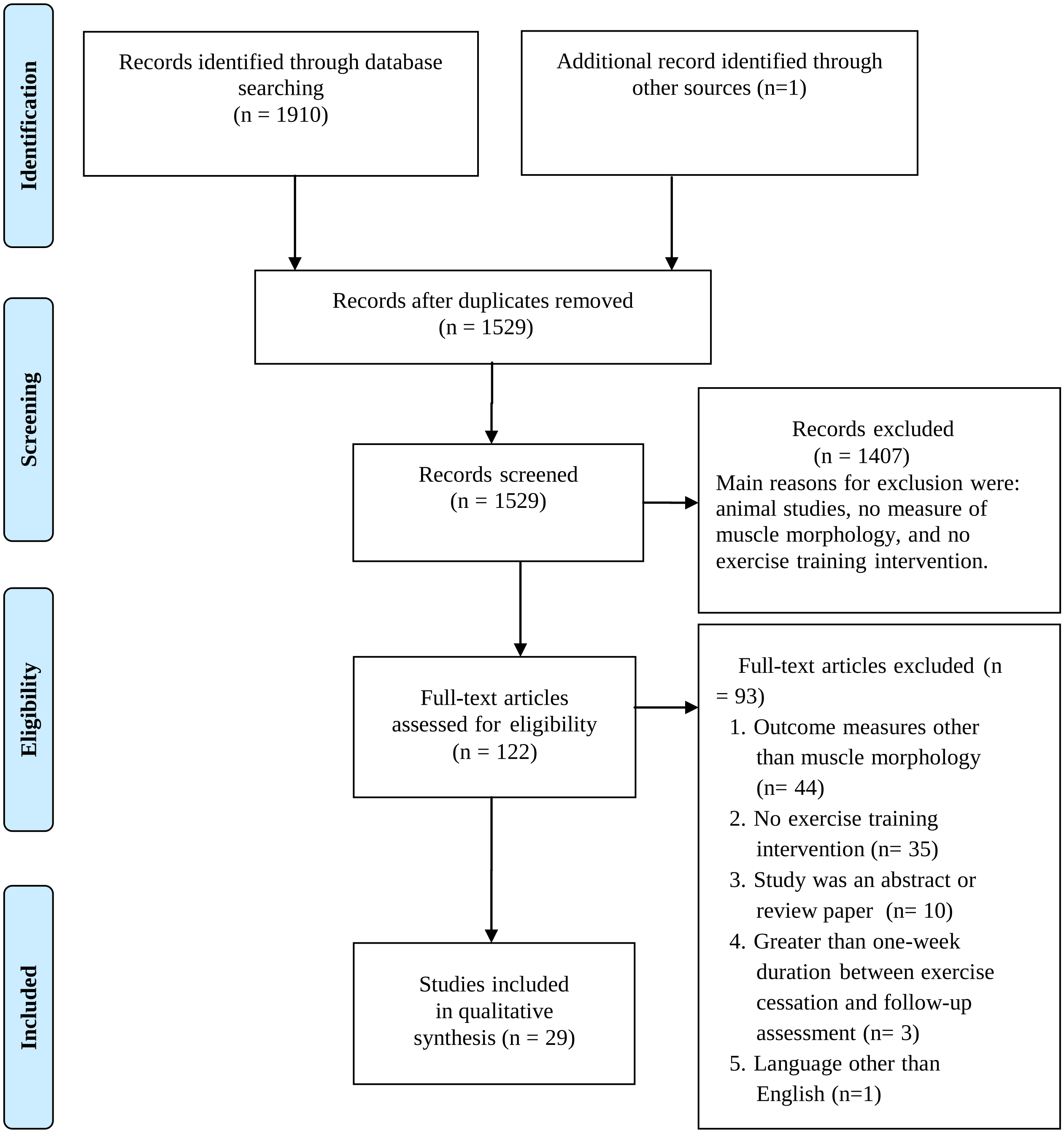


Fig. 1 Study flow diagram

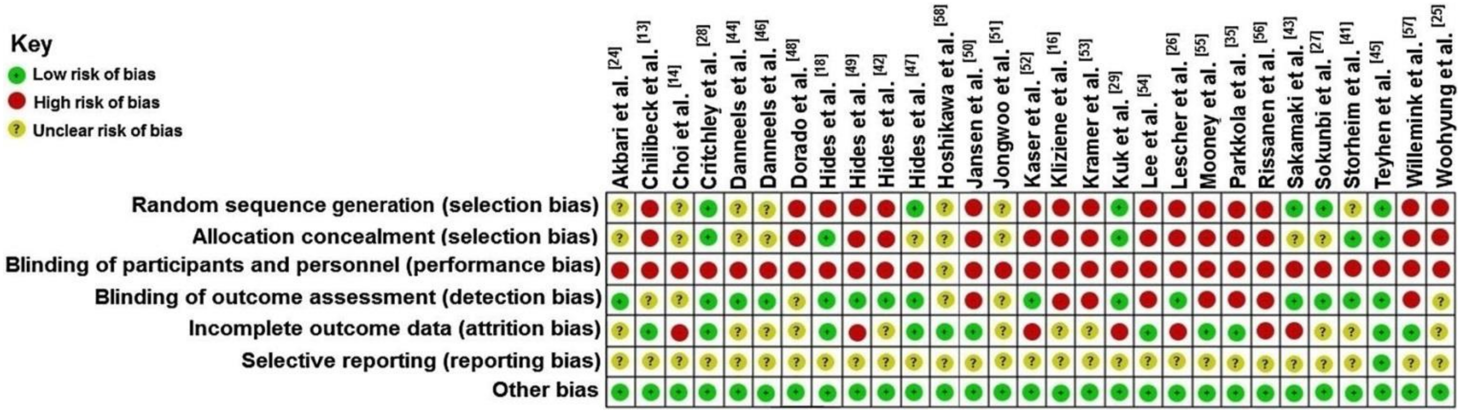


Fig. 2 Risk-of-bias summary: review authors' judgments for each risk-of-bias item from each included study

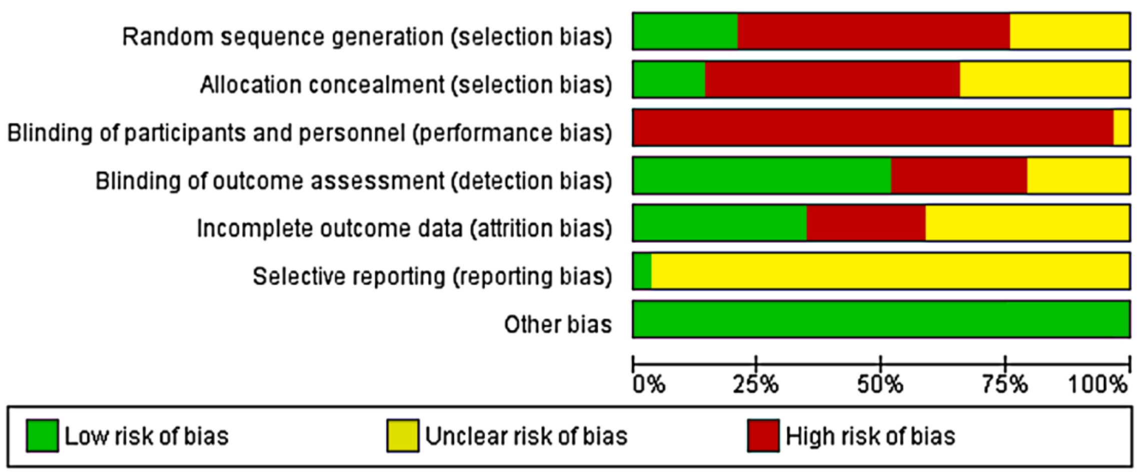


Fig. **3** Plot of the distribution of the review authors' judgments across studies for each risk-of-bias item

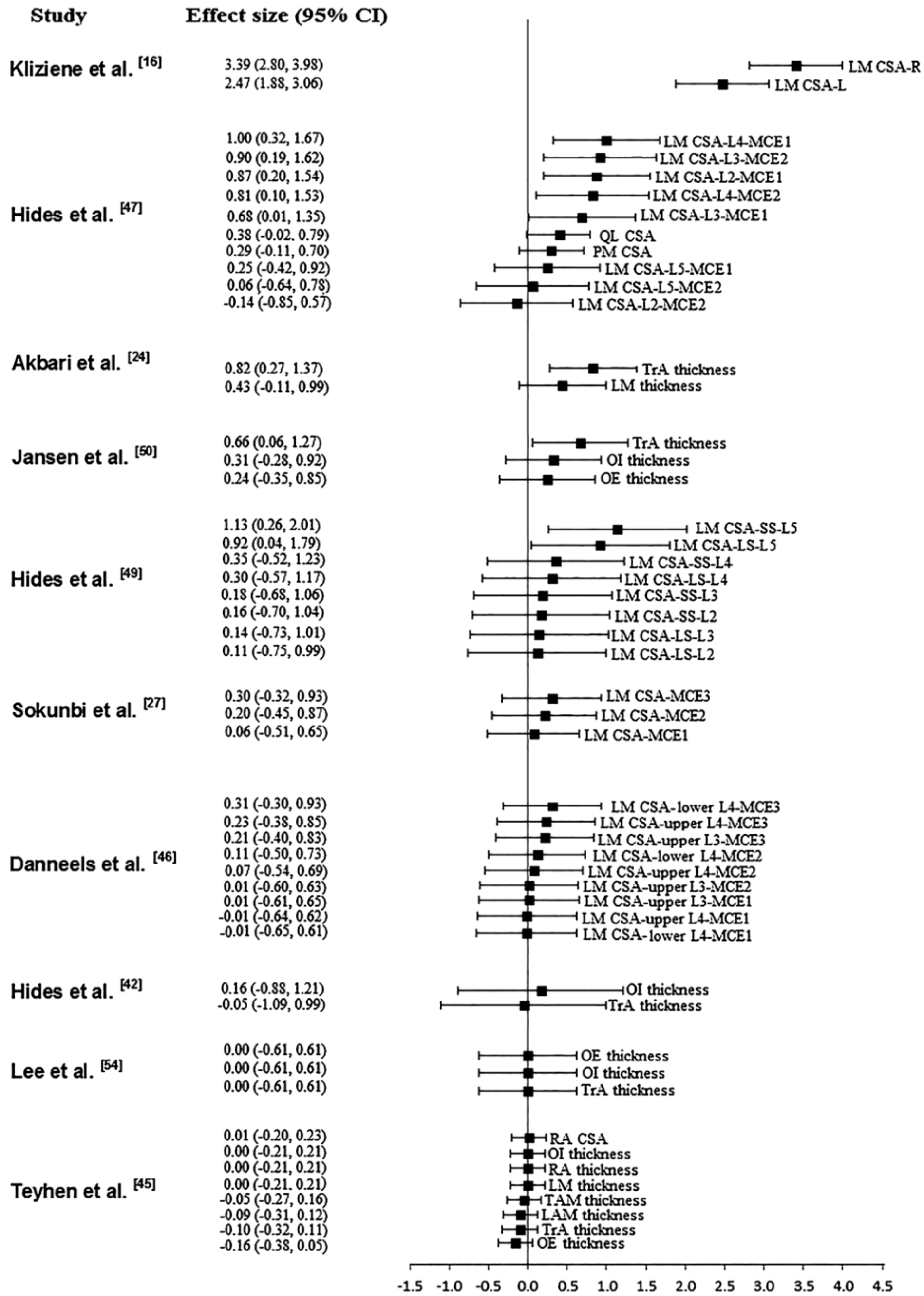


Fig. 4 Forest plot summarizing the effect [effect size, standardized mean difference and 95 % confidence interval (CI)] of motor control exercise training interventions on trunk muscle morphology (baseline versus post-training).

CSA cross-sectional area, *L* left side, *L2* lumbar spinal level 2, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *LAM* lateral abdominal muscles, *LM* lumbar multifidus, *LS* large side, *MCE1* motor control exercise group 1, *MCE2* motor control exercise group 2, *MCE3* motor control exercise group 3, *OE* external oblique, *OI* internal oblique, *PM* psoas major, *QL* quadratus lumborum, *R* right, *RA* rectus abdominis, *SS* small side, *TAM* total abdominal muscles, *TrA* transversus abdominis

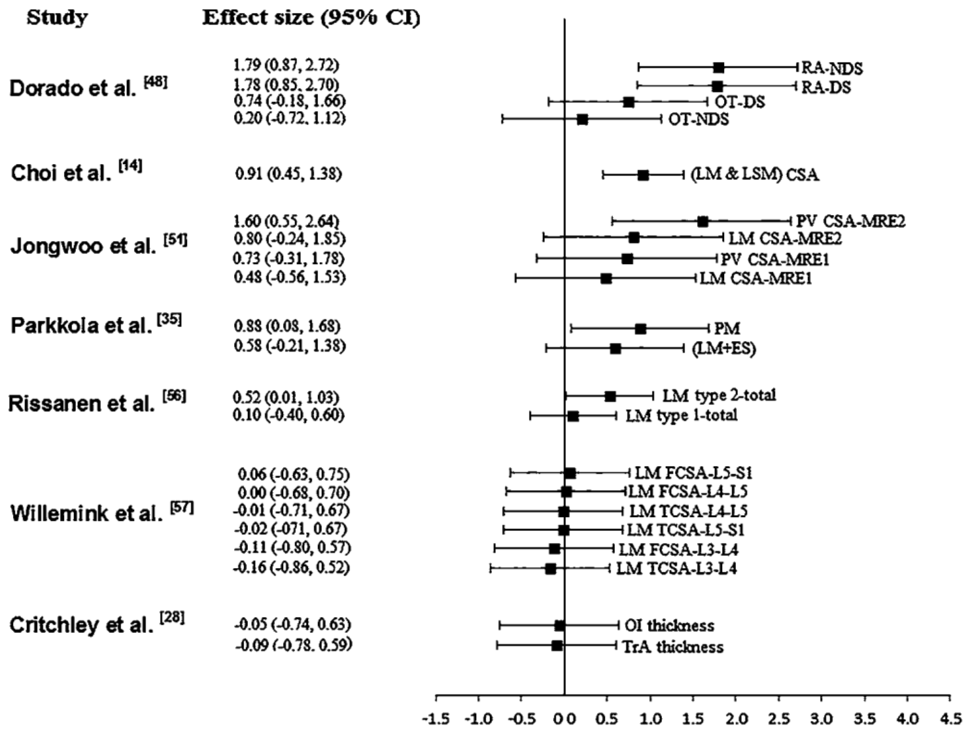


Fig. 5 Forest plot summarizing the effect [effect size, standardized mean difference and 95 % confidence interval (CI)] of machine-based resistance exercise training interventions on trunk muscle morphology (baseline versus post-training).

CSA cross-sectional area, *DS* domi- nant side, *ES* erector spinae, *FCSA* functional cross-sectional area, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *LM* lumbar multifidus, *LSM* longissimus, *MRE1* machine- based resistance exercise group 1, *MRE2* machine-based resistance exercise group 2, *NDS* nondominant side, *OI* internal oblique, *OT* obliques and transversus abdominis, *PM* psoas major, *PV* para- vertebral muscles, *RA* rectus abdominis, *S1* sacral spinal level 1, *TCSA* total cross-sectional area, *TrA* transversus abdominis

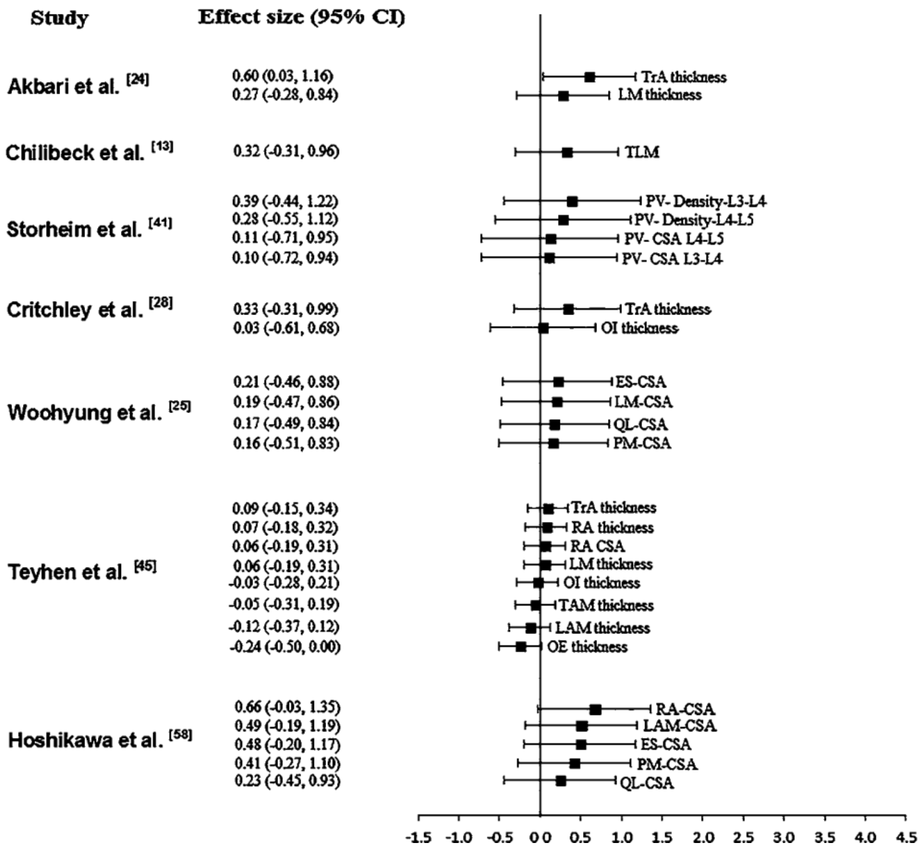


Fig. 6 Forest plot summarizing the effect [effect size, standardized mean difference and 95 % confidence interval (CI)] of non-machine-based resistance exercise training interventions on trunk muscle morphology (baseline versus post-training).
CSA cross- sectional area, *ES* erector spinae, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *LAM* lateral abdominal muscles, *LM* lumbar multifidus, *OE* external oblique,*OI* internal oblique, *PM* psoas major, *PV* paravertebral muscles, *QL* quadratus lumborum, *RA* rectus abdominis, *TAM* total abdominal muscles, *TLM* trunk lean mass, *TrA* transversus abdominis

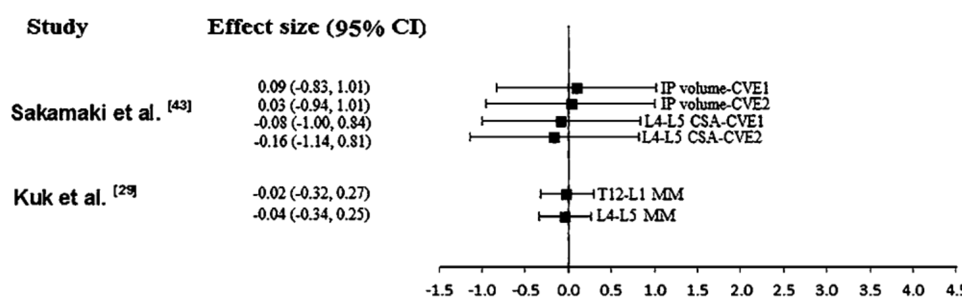


Fig. 7 Forest plot summarizing the effect [effect size, standardized mean difference and 95 % confidence interval (CI)] of cardiovascular exercise training interventions on trunk muscle morphology (baseline versus post-training).
CSA cross-sectional area, *CVE1* cardiovascular exercise group 1, *CVE2* cardiovascular exercise group 2, *IP* iliopsoas, *L1* lumbar spinal level 1, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *MM* muscle mass, *T12* thoracic spinal level 12

Table 1 Characteristics and outcomes of included studies based on exercise training categories

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Motor control exercise							
Danneels et al. [46]	MCE1: 19; 43 (13); NR	LBP; NR	MCE1: BSE	10 wk, 3 d/wk	LM; CSA: wk 0, 10; CT	LM CSA-upper L3-MCE1	0.01 (-0.61 to 0.65)
						LM CSA-upper L3-MCE2	0.01 (-0.60 to 0.63)
						LM CSA-upper L3-MCE3	0.21 (-0.40 to 0.83)
	MCE2: 20; 44 (12); NR		MCE2: MCE1+ IDLSE			LM CSA-upper L4-MCE1	-0.01 (-0.64 to 0.62)
						LM CSA-upper L4-MCE2	0.07 (-0.54 to 0.69)
						LM CSA-upper L4-MCE3	0.23 (-0.38 to 0.85)
	MCE3: 20; 43 (12); NR		MCE3: MCE1+ IDSLSE			LM CSA-lower L4-MCE1	-0.01 (-0.65 to 0.61)
						LM CSA-lower L4-MCE2	0.11 (-0.50 to 0.73)
						LM CSA-lower L4-MCE3	0.31 (-0.30 to 0.93)
Akbari et al. [24]	MCE: 25; 39.6 (3.5); NR	LBP; NR	MCE: LLMA + DRE	8 wk, 2 d/wk, 30 min	TrA, LM; thickness: wk 0, 8; US	TrA thickness-MCE	0.82 (0.27 to 1.37)
						TrA thickness-NMRE	0.60 (0.03 to 1.16)
	NMRE: 24; 40 (3.6); NR		NMRE: RE			LM thickness-MCE	0.43 (-0.11 to 0.99)
						LM thickness-NMRE	0.27 (-0.28 to 0.84)
Hides et al. [49]	MCE: 7; 21.9 (2.5); M	LBP; EA	MCE: MAE+WT+ CTM	13 wk , 18.5 h/wk	LM; CSA: wk 0, 13; US	LM CSA-LS-L2-MCE	0.11 (-0.75 to 0.99)
						LM CSA-LS-L2-C	0.11 (-0.58 to 0.80)
						LM CSA-LS-L3-MCE	0.14 (-0.73 to 1.01)
						LM CSA-LS-L3-C	0.16 (-0.52 to 0.86)
						LM CSA-LS-L4-MCE	0.30 (-0.57 to 1.17)
						LM CSA-LS-L4-C	0.15 (-0.53 to 0.84)
						LM CSA-LS-L5-MCE	0.92 (0.04 to 1.79)
						LM CSA-LS-L5-C	0.22 (-0.46 to 0.92)
	C: 14; 21.4 (2); M	Healthy; EA	C: WT+ CTM			LM CSA-SS-L2-MCE	0.16 (-0.70 to 1.04)
						LM CSA-SS-L2-C	0.24 (-0.44 to 0.93)
						LM CSA-SS-L3-MCE	0.18 (-0.68 to 1.06)
						LM CSA-SS-L3-C	0.17 (-0.51 to 0.86)
						LM CSA-SS-L4-MCE	0.35 (-0.52 to 1.23)
						LM CSA-SS-L4-C	0.17 (-0.52 to 0.86)
						LM CSA-SS-L5-MCE	1.13 (0.26 to 2.01)
						LM CSA-SS-L5-C	0.23 (-0.45 to 0.92)
Sokunbi et al. [27]	MCE1: 23; 39.6 (8.5); F: 10, M: 13	LBP; NR	MCE1: ×1 wkly MAE + NMRE	6 wk, 45 min	LM; CSA: wk 0, 6; US	LM CSA-MCE1	0.06 (-0.51 to 0.65)
	MCE2: 19; 38.1 (8.06); F: 15, M: 4		MCE2: ×2 wkly MAE + NMRE			LM CSA-MCE2	0.20 (-0.45 to 0.87)
	MCE 3: 20; 43.25 (9.5); F: 11, M: 9		MCE: ×3 wkly MAE + NMRE			LM CSA-MCE3	0.30 (-0.32 to0.93)
	C: 22; 43.25 (9.5); F: 14, M: 8		NT			LM CSA-C	0.19 (-0.45 to 0.85)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Jansen et al. [50]	21; 24.8 (7.4); F: 1, M: 20	CGP; EA	ADIM+NMRE	10 wk, 2 d/wk	TrA, OI, OE; CSA: wk 0, 10; US	TrA thickness	0.66 (0.06 to 1.27)
						OI thickness	0.31 (-0.28 to 0.92)
						OE thickness	0.24 (-0.35 to 0.85)
Hides et al. [42]	MCE: 7; 21.2 (2); M	LBP; EA	MCE: MAE+WT+ CTM	13 wk , 18.5 h/wk	TrA, OI; thickness: wk 0, 13; US	TrA thickness-MCE	-0.05 (-1.09 to 0.99)
						TrA thickness-C	-0.07 (-0.76 to 0.62)
	C: 14; 21.2 (2); M	Healthy; EA	C: WT+ CTM			OI thickness/MCE	0.16 (-0.88 to 1.21)
						OI thickness-C	0.03 (-0.65 to 0.73)
Kliziene et al. [16]	MCE: 22; 64.8 (5.4); F	NR; MOD/SED	MCE: MAE+NMRE	32 wk, 2 d/wk, 45 min	LM; CSA: wk 0, 16, 32; US	LM CSA-L-wk 0 to 16	0.44 (-0.14 to 1.03)
						LM CSA-R-wk 0 to 16	1.53 (0.93 to 2.12)
						LM CSA-L-wk 0 to 32	2.47 (1.88 to 3.06)
						LM CSA-R-wk 0 to 32	3.39 (2.80 to 3.98)
Lee et al. [54]	20; 24.4 (2.9); F: 4, M: 16	CIS; NR	ADIM with BFPU	2 wk, 7 d/wk, 20 min	TrA, OI, OE; thickness: wk 0, 2; US	TrA thickness	0.00 (-0.61 to 0.61)
						OI thickness	0.00 (-0.61 to 0.61)
						OE thickness	0.00 (-0.61 to 0.61)
Teyhen et al. [45]	MCE: 160; 21.9 (4.2); NR	Healthy; Military	MCE: MAE+ ASER	12 wk, 4 d/wk, 60 min	OE, IO, TrA, RA, LM, LAM, TAM; thickness + (RA, CSA): wk 0, 12; US	TrA thickness-MCE	-0.10 (-0.32 to 0.11)
						TrA thickness-NMRE	0.09 (-0.15 to 0.34)
						OI thickness-MCE	0.00 (-0.21 to 0.21)
						OI thickness-NMRE	-0.03 (-0.28 to 0.21)
						OE thickness-MCE	-0.16 (-0.38 to 0.05)
						OE thickness-NMRE	-0.24 (-0.50 to 0.00)
						RA thickness-MCE	0.00 (-0.21 to 0.21)
						RA thickness-NMRE	0.07 (-0.18 to 0.32)
	NMRE: 120; 21.9 (4.2); NR		NMRE: ST			RA CSA-MCE	0.01 (-0.20 to 0.23)
						RA CSA-NMRE	0.06 (-0.19 to 0.31)
						LM thickness-MCE	0.00 (-0.21 to 0.21)
						LM thickness-NMRE	0.06 (-0.19 to 0.31)
						TAM thickness-MCE	-0.05 (-0.27 to 0.16)
						TAM thickness-NMRE	-0.05 (-0.31 to 0.19)
						LAM thickness-MCE	-0.09 (-0.31 to 0.12)
						LAM thickness-NMRE	-0.12 (-0.37 to 0.12)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Hides et al. [47]	MCE1: 17; 22.8 (3.5); M	LBP + Healthy; EA	MCE1: 15 wk MAE + 7 wk PIL	22 wk, 2 d/wk, 30 min	LM, QL, PM; CSA: wk 7, 15, 22; MRI	LM CSA-L2-wk 0 to 15-MCE1	0.50 (-0.17 to 1.17)
						LM CSA-L2-wk 0 to 15-MCE2	1.00 (0.28 to 1.71)
						LM CSA-L2-wk 0 to 15-C	-0.14 (-0.88 to 0.59)
						LM CSA-L2-wk 0 to 22-MCE1	0.87 (0.20 to 1.54)
						LM CSA-L2-wk 0 to 22-MCE2	-0.14 (-0.85 to 0.57)
						LM CSA-L2-w 0 to w22-C	1.28 (0.54 to 2.02)
						LM CSA-L3-w 0 to w15-MCE1	0.39 (-0.28 to 1.06)
						LM CSA-L3-w 0 to w15-MCE2	0.90 (0.19 to 1.62)
						LM CSA-L3-w 0 to w15-C	-0.07 (-0.82 to 0.66)
						LM CSA-L3-w 0 to w22-MCE1	0.68 (0.01 to 1.35)
						LM CSA-L3-w 0 to w22-MCE2	0.90 (0.19 to 1.62)
	MCE2: 15; 22.8 (3.5); M		MCE2: 8 wk MAE + 14 wk PIL			LM CSA-L3-w 0 to w22-C	0.87 (0.13 to 1.61)
						LM CSA-L4-w 0 to w15-MCE1	0.50 (-0.17 to1.17)
	C: 14; 22.8 (3.5); M		C: 15 wk PIL + 7 wk MAE			LM CSA-L4-w 0 to w15-MCE2	0.68 (-0.03 to 1.39)
						LM CSA-L4-w 0 to w15-C	-0.71 (-1.45 to 0.02)
						LM CSA-L4-w 0 to w22-MCE1	1.00 (0.32 to 1.67)
						LM CSA-L4-w 0 to w22-MCE2	0.81 (0.10 to 1.53)
						LM CSA-L4-w 0 to w22-C	0.63 (-0.10 to 1.37)
						LM CSA-L5-w 0 to w15-MCE1	0.58 (-0.08 to 1.26)
						LM CSA-L5-w 0 to w15-MCE2	0.53 (-0.18 to 1.24)
						LM CSA-L5-w 0 to w15-C	-0.62 (-1.36 to 0.12)
						LM CSA-L5-w 0 to w22-MCE1	0.25 (-0.42 to 0.92)
						LM CSA-L5-w 0 to w22-MCE2	0.06 (-0.64 to 0.78)
						LM CSA-L5-w 0 to w22-C	-0.28 (-1.02 to 0.45)
						OL CSA[d]	0.38 (-0.02 to 0.79)
						PM CSA[d]	0.29 (-0.11 to 0.70)
Machine-based resistance exercise							
Parkkola et al. [35]	12; 23 (2); F: 11, M: 1	NR; SED	NMSM	18 wk, 2 to 3 d/wk, 45 min	(LM & ES), PM; CSA: wk 0, 11,18; MRI	(LM+ES) CSA-w0 to w11	0.53 (-0.26 to 1.33)
						(LM+ES) CSA-w0 to w18	0.58 (-0.21 to 1.38)
						PM-w0 to w11	0.88 (0.08 to 1.68)
						PM-w0 to w18	0.88 (0.08 to 1.68)
Rissanen et al. [56]	30; 39.9 (4); F: 16, M: 14	LBP; NR	HRM+ NMRE	9wk (home), 3 d/wk, 60 min; 3 wk (hospital), 5 d/wk, 120 min	LM; MFS (Type I, II): wk 0, 12; MB	LM Type I	0.100 (-0.40 to 0.60)
						LM Type II-Total	0.52 (0.01 to 1.03)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Choi et al. [14]	MRE: 35; 51.05 (9.58); F: 15, M: 20	LD; NR	MRE: MedX	12 wk, 2d/wk	(LM & LSM); CSA: wk 0, 12; CT	(LM and LSM) CSA-MRE	0.91 (0.45 to 1.38)
	C: 40; 42.02 (17.06); F: 22, M: 18		C: HLE			(LM and LSM) CSA-C	0.33 (-0.10 to 0.76)
Critchley et al. [28]	MRE: 16; 30 (8); F: 12, M: 4	Healthy; NR	MRE: Gym-M + FW	8 wk, 2 d/wk, 45 min	OI, TrA; thickness: wk 0, 8; US	TrA thickness-MRE	-0.09 (-0.78 to 0.59)
						TrA thickness-NMRE	0.33 (-0.31 to 0.99)
	NMRE: 18; 31 (5); F: 14, M: 4		NMRE: PIL			OI thickness-MRE	-0.05 (-0.74 to 0.63)
						OI thickness-NMRE	0.03 (-0.61 to 0.68)
Jongwoo et al.[51]	MRE1: 7; 26.57 (1.81); M	NR; NR	MRE1: MedX	8 wk, 3 d/wk, 50 min	LM, PV; CSA: wk 0, 8; CT	LM CSA-MRE1	0.48 (-0.56 to 1.53)
						LM CSA-MRE2	0.80 (-0.24 to 1.85)
	MRE2: 7; 26.40 (1.13); M		MRE2: MedX + MCE			PV CSA-MRE1	0.73 (-0.31 to 1.78)
						PV CSA-MRE2	1.60 (0.55 to2.64)
Dorado et al. [48]	9; 35.7 (5.4); F	Healthy; SED	PIL using BBRD	36 wk, 2 d/wk, 55 min	OT (OE & OI & TrA) + RA/ Volume: wk 0, 36/ MRI	OT CSA-DS	0.74 (-0.18 to 1.66)
						OT CSA-NDS	0.20 (-0.72 to 1.12)
						RA CSA- DS	1.78 (0.85 to 2.70)
						RA CSA-NDS	1.79 (0.87 to 2.72)
Willemink et al.[57]	16; 46.2 (9.7); M	LBP; NR	LBRD	12 wk, 1 wk/day, 30 min + 12 wk[e]	LM; TCSA, FCSA, AF: wk 0, 12, 24; MRI	LM TCSA-L3 to L4-w0 to w12	0.05 (-0.64 to 0.74)
						LM TCSA-L3 to L4-w0 to w24	-0.16 (-0.86 to 0.52)
						LM FCSA-L3 to L4-w0 to w12	0.09 (-0.59 to 0.78)
						LM FCSA-L3 to L4-w0 to w24	-0.11 (-0.80 to 0.57)
						LM AFI-L3 to L4-w0 to w12	-0.11 (-0.80 to 0.58)
						LM AFI-L3 to L4-w0 to w24	-0.12 (-0.81 to 0.57)
						LM TCSA-L4 to L5-w0 to w12	0.07 (-0.62 to 0.76)
						LM TCSA-L4 to L5-w0 to w24	-0.01 (-0.71 to 0.67)
						LM FCSA-L4 to L5-w0 to w12	0.10 (-0.58 to 0.79)
						LM FCSA-L4 to L5-w0 to w24	0.00 (-0.68 to 0.70)
						LM AFI-L4 to L5-w0 to w12	-0.01 (-0.70 to 0.68)
						LM AFI-L4 to L5-w0 to w24	-0.04 (-0.73 to 0.64)
						LM TCSA-L5 to S1-w0 to w12	0.03 (-0.65 to 0.73)
						LM TCSA-L5 to S1-w0 to w24	-0.02 (-0.71 to 0.67)
						LM FCSA-L5 toS1-w0 to w12	0.13 (-0.55 to 0.82)
						LM FCSA-L5 toS1-w0 to w24	0.06 (-0.63 to 0.75)
						LM AFI-L5 to S1-w0 to w12	-0.13 (-0.82 to 0.56)
						LM AFI-L5 to S1-w0 to w24	-0.10 (-0.79 to 0.59)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Non-machine resistance exercise							
Chilibeck et al. [13]	NMRE: 19; 20.2 (0.8); F	Healthy; NR	NMRE: RE (BP, LP)	20 wk, 2 d/wk	TLM; MM: wk 0, 10, 20; DEXA	TLM-w0 to w10-NMRE	0.04 (-0.59 to 0.67)
						TLM-w0 to w20-NMRE	0.32 (-0.31 to 0.96)
	C: 10; 20.2 (0.4); F		C: NR	NR	TM; MM: wk 0, 20; DEXA	NR	NR
Storheim et al. [41]	NMRE: 11; 44.9 (10.3); F: 5, M: 6	LBP; NR	NMRE: NSFT	15 wk, 3 d/w, 60 min	PV; CSA+Density: wk 0, 15; CT	PV CSA L3 to L4-NMRE	0.10 (-0.72 to 0.94)
						PV CSA L3 to L4-C	-0.03 (-0.80 to 0.73)
						PV CSA L4 to L5-NMRE	0.11 (-0.71 to 0.95)
						PV CSA L4 to L5-C	-0.17 (-0.94 to 0.59)
						PV Density-L3 to L4-NMRE	0.39 (-0.44 to 1.22)
	C: 13; 40.9 (11.8); F: 7, M: 6		C: UC by GP	15 wk		PV Density-L3 to L4-C	-0.10 (-0.87 to 0.66)
						PV Density-L4 to L5-NMRE	0.28 (-0.55 to 1.12)
						PV Density-L4 to L5-C	-0.10 (-0.87 to 0.66)
Woohyung et al. [25]	NMRE: 17; 32.7 (5.9); NR	LBP; NR	NMRE: BET	12 wk, 3 d/wk, 45 min	PM, QL, ES, LM; CSA: wk 0, 12; CT	PM CSA-NMRE	0.16 (-0.51 to 0.83)
						PM CSA-C	0.01(-0.67 to 0.71
						QL CSA-NMRE	0.17 (-0.49 to 0.84)
						QL CSA-C	0.03 (-0.65 to 0.73)
	C 16; 33.1 (5.7); NR		C: MHT, UST, TENS			ES CSA-NMRE	0.21 (-0.46 to 0.88)
						ES CSA-C	0.00 (-0.68 to 0.69)
						LM CSA-NMRE	0.19 (-0.47 to 0.86)
						LM CSA-C	0.02 (-0.66 to 0.71)
Hoshikawa et al. [58]	NMRE: 16; 12 to 13[f]; M	Healthy; EA	NMRE: ST+ STP	24 wk, 4d/wk + STP as per C	RA, LAM, PM, QL, ES; CSA: wk 0, 24; MRI	RA CSA-NMRE	0.66 (-0.03 to 1.35)
						RA CSA-C	0.81 (0.01 to 1.61)
						LAM-CSA-NMRE	0.49 (-0.19 to 1.19)
						LAM CSA-C	0.54 (-0.25 to 1.34)
	C: 12; 12 to 13[f]; M		C: STP	24 wk, 6 d/wk		PM CSA-NMRE	0.41 (-0.27 to 1.10)
						PM CSA-C	0.74 (-0.05 to 1.54)
						QL CSA-NMRE	0.23 (-0.45 to 0.93)
						QL CSA-NMRE	0.44 (-0.35 to 1.24)
						ES CSA-NMRE	0.48 (-0.20 to 1.17)
						ES CSA-C	0.47 (-0.32 to1.27)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Cardiovascular exercise							
Kuk et al. [29]	86, 57.8 (6.4), F	O/OP; NR	CVE: CE or TRD (50% of VO2max)	24 wk, 3 to 4 d/wk	ABM; MM + lipid: wk 0, 24; CT	L4 to L5-lipid T12 to L1-lipid L4 to L5-MM T12 to L1-MM	0.03 (-0.26 to 0.33) -0.06 (-0.36 to 0.23) -0.04 (-0.34 to 0.25) -0.02 (-0.32 to 0.27)
Sakamaki et al. [43]	CVE1: 9, 21.4 (2.1), M CVE2: 8, 21.1 (1.9), M	Healthy; NR	CVE1: BFR walk CVE2: WBFR walk	3 wk, 6 d/wk, 30 min	(PV, CSA) + (IP, volume): wk 0, 3; MRI	IP volume-CVE1 IP volume-CVE2 CSA-L4 to L5-CVE1 CSA-L4 to L5-CVE2	0.09 (-0.83 to 1.01) 0.03 (-0.94 to 1.01) -0.08 (-1.00 to 0.84) -0.16 (-1.14 to 0.81)

×*1 wkly* once weekly, 9*2 wkly* twice weekly, 9*3 wkly* three times weekly, *ABM* abdominal muscles, *ADIM* abdominal draw-in manoeuvre, *AFI* area of fatty infiltration, *ASER* army standard exercise regimen, *BBRD* balanced body reformer device, *BET* ball exercise therapy, *BFPU* biofeedback pressure unit, *BFR* blood flow restriction, *BP* bench press, *BSE* back stabilization exercise, *C* comparator or control group, *CE* cycle ergometer, *CGP* patient(s) with chronic groin pain,*CI* confidence interval, *CIS* individual(s) with core instability, *CSA* cross-sectional area, *CT* computed tomography, *CTM* cricket training and matches, *CVE* cardiovascular exercise, *d* day(s), *DEXA* dual-energy x-ray absorptiometry, *DS* dominant side, *DRE* dynamic resistance exercise, *EA* elite athlete(s), *ES* erector spinae, *F* female, *FCSA* functional cross-sectional area, *FW* free weights, *GP* general practitioner(s), *GYM* gym machines, *h* hour(s), *HLE* home-based lumbar exercise, *HRM* hydraulic resistance machine, *IDLSE* intensive dynamic lumbar-strengthening exercise, *IDSLSE* intensive dynamic–static lumbar-strengthening exercise, *IP* iliopsoas, *L* left side, *L1* lumbar spinal level 1, *L2* lumbar spinal level 2, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *LAM* lateral abdominal muscles, *LBP* patient(s) with low back pain, *LBRD* Lower Back Revival device, *LD* patient(s) post-lumbar discectomy, *LLMA* low load muscle activation, *LM* lumbar multifidus, *LP* leg press, *LS* large side, *LSM* longissimus, *M* male, *MAE* muscle activation exercise, *MB* muscle biopsy, *MCE* motor control exercise, *MCE1* MCE subject group 1, *MCE2* MCE subject group 2, *MCE3* MCE subject group 3, *MedX* MedX lumbar extension machine, *MFS* muscle fibre size, *MHT* moist heat therapy, *min* minute(s), *MM* muscle mass, *MOD* moderately active, *MRE* machine-based resistance exercise, *MRI* magnetic resonance imaging, *NDS* nondominant side, *NMRE* non-machine-based resistance exercise, *NMSM* Nautilus multi-station machine, *NR* not reported, *NSFT* Norwegian strength and fitness training, *NT* no treatment, *OE* external oblique, *OI* internal oblique, *O/OP* overweight/obese postmenopausal, *OT* obliques and transversus abdominis, *PIL* Pilates, *PM* psoas major, *PV* paravertebral muscles, *QL* quadratus lumborum, *R* right side, *RA* rectus abdominis, *RE* resistance exercise, *S1* sacral spinal level 1, *SED* sedentary, *SMD* standardized mean difference, *SS* small side, *ST* strength training, *STP* soccer training programme, *T12* thoracic spinal level 12, *TAM* total abdominal muscles, *TCSA* total cross-sectional area, *TENS* transcutaneous electrical nerve stimulation, *TLM* trunk lean mass, *TrA* transversus abdominis, *TRD* treadmill, *UC* usual care, *US* ultrasound, *UST* ultrasound therapy, *VO2max* maximal oxygen consumption, *WBFR* without blood flow restriction, *wk* week(s), *wk 0* baseline, *WT* weight training, *y* year(s)

[a] Exercise groups are stated where applicable

[b] All data are presented as mean (standard deviation), unless otherwise indicated

[c] Current physical fitness training level, based on the study authors' description of the general physical activity level

[d] Combined data from MCE1, MCE2 and C

[e] Training was continued at a frequency that was tailored to the patients' convenience

[f] Age range

Table 2 Descriptive interpretation of the outcomes of six studies for which standardized mean difference statistics could not be calculated

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes
Motor control exercise						
Hides et al. [18]	MCE: 21; 30.9 (6.5); F: 13, M: 8 C: 20; 31 (7.9); F: 10, M: 10	LBP; NR	MCE + MT MT	4 wk, NR	LM; CSA: wk 0, 1-4; US	Resolution of LM atrophy and muscle recovery was more rapid and complete in patients who received MCE ($P < 0.001$).
Danneels et al. [44]	MCE1: 19; 46 (37 to 57)[d]; F: 9, M: 10 MCE2: 20; 47 (35 to 52)[d]; F: 11, M: 9 MCE3: 20; 40 (37 to 49)[d]; F: 12, M: 8	LBP; NR	MCE1: BSE MCE2: MCE1+ IDSE MCE3: MCE1+ IDSLSE	10 wk, 3 d/wk	PV; CSA: wk 0, 10; CT	PV muscle CSA increased in the MCE2 (L4: $p < 0.02$) and MCE3 groups (L3: $p < 0.003$); L4: $p < 0.01$). There was no difference in PV CSA in the MCE group. More intense resistance exercise may be necessary to restore the size of the PV in LBP patients with atrophied back muscles.
Machine-based resistance exercise						
Mooney et al. [55]	MRE: 8; 45 to 64[e]; F: 4, M: 4 C: 8; 45 to 64[e]; F: 4, M: 4	LBP; NR Healthy; NR	MRE: MedX	8 wk, 2 d/wk	PV; MM: wk 0, 8; MRI	Four patients with severe fatty infiltration in the lumbar extensor muscles had a decrease in the degree of infiltration but no change in lean muscle mass. There were no changes in fat infiltration or muscle mass among the other patients.
Kaser et al. [52]	MRE: 25; 43.5 (10.5); F: 13, M: 12 NMRE: 16; 45.2 (11.2); F: 10, M: 6 CVE: 18; 43.4 (11.7); F: 7, M: 11	LBP; NR	MRE: DBD NMRE: ST + Physio CVE: LIA	12 wk, 2d/wk, 30 to 60 min	(PV, CSA) + (ES, MFS): wk 0, 12	There were no significant changes in PV CSA in any of the three groups. Pathologic changes in fibres type I, type II, IIX, IIC pre- to post-therapy, were not significantly different in the three groups (MRE, NMRE, CVE).
Kramer et al. [53]	15; 18 to 57[e]; F: 6, M: 9	DO for TVF; NR	DBD	12 wk, 2d/wk	(IC and LSM), LM; CSA: wk 0, 12; MRI	For the LSM and IC muscles, the median change in CSA was 1.39 cm^2 (8.3%; range, 0.22 cm^2 [0.9 %] to 5.22 cm^2 [30.5 %]); and for the LM muscle, the median change in CSA was -0.27 cm^2 (-17.5 %; range, -0.03cm^2 [-1.5 %] to -0.84 cm^2 [-45.4%]).

Table 2 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk),frequency	Muscle(s); measurement; device	Outcomes
Non-machine-based resistance exercise						
Lescher et al. [26]	14; 45 to 56[e]; M	LBP; SED	RE	12 wk,7 d/wk, 10 min	(ES and QL); CSA: wk 0, 12; MRI	There was a significant change in ES and QL CSA following 3 mo NMRE ($p < 0.01$).

BSE back stabilization exercise, *C* comparator or control group, *CSA* cross-sectional area, CT computed tomography, *CVE* cardiovascular exercise, *d* day(s), *DBD* David back device, *DO* patients post-dorsal osteosynthesis, *ES* erector spinae, *F female*, IC iliocostalis, *IDLSE* intensive dynamic lumbar-strengthening exercise, *IDSLSE* intensive dynamic–static lumbar- strengthening exercise, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *LBP* patient(s) with low back pain, *LIA* low-impact aerobics, *LM* lumbar multifidus, *LSM* longissimus, *M* male, *MCE* motor control exercise, *MCE1* MCE subject group 1, *MCE2* MCE subject group 2, *MCE3* MCE subject group 3, *MedX* MedX lumbar extension machine, *MFS* muscle fibre size, min minute(s), *MM* muscle mass, mo month(s), *MRE* machine-based resistance exercise, *MRI* magnetic resonance imaging, *MT* medical treatment, *NMRE* non-machine-based resistance exercise, *NR* not reported, *OE* external oblique, *OI* internal oblique, *physio* physiotherapy, *PIL* Pilates, *PV* paravertebral muscles, *QL* quadratus lumborum, *RE* resistance exercise, *SED* sedentary, *ST* strength training, *TVF* thoracolumbar vertebral fracture, *US* ultrasound, *wk* week(s), *wk 0* baseline, *y* year(s)

[a] Exercise groups are stated where applicable
[b] All data are presented as mean (standard deviation), unless otherwise indicated
[c] Current physical fitness training level, based on the study authors' description of the general physical activity level
[d] Median (interquartile range)
[e] Range

References

1. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. Clin Biomech. 1996;11(1):1-15.

2. d'Hemecourt PA, Luke A. Sport-specific biomechanics of spinal injuries in aesthetic athletes (dancers, gymnasts, and figure skaters). Clin Sports Med. 2012;31(3):397-408. doi:10.1016/j.csm.2012.03.010.

3. Donatelli R, Dimond D, Holland M. Sport-specific biomechanics of spinal injuries in the athlete (throwing athletes, rotational sports, and contact-collision sports). Clin Sports Med. 2012;31(3):381-96. doi:10.1016/j.csm.2012.03.003.

4. Alexander MJ. Biomechanical aspects of lumbar spine injuries in athletes: a review. Can J Appl Sport Sci. 1985;10(1):1-20.

5. Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. J Spinal Disord. 1992;5(4):383-9 (discussion 397).

6. Panjabi MM. Clinical spinal instability and low back pain. J Electromyogr Kinesiol. 2003;13(4):371-9.

7. Cholewicki J, Panjabi MM, Khachatryan A. Stabilizing function of trunk flexor-extensor muscles around a neutral spine posture. Spine (Phila Pa 1976). 1997;22(19):2207-12.

8. Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. Acta Orthop Suppl. 1989;230:1-54.

9. Stevens VK, Vleeming A, Bouche KG et al. Electromyographic activity of trunk and hip muscles during stabilization exercises in four-point kneeling in healthy volunteers. Eur Spine J. 2007;16(5):711-8. doi:10.1007/s00586-006-0181-1.

10. McGill SM. Low back stability: from formal description to issues for performance and rehabilitation. Exercise and sport sciences reviews. 2001;29(1):26-31.

11. Crisco JJ III, Panjabi MM. Euler stability of the human ligamentous lumbar spine. Part I: Theory. Clin Biomech .1992;7(1):19-26.

12. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine (Phila Pa 1976). 1996;21(22):2640-50.

13. Chilibeck PD, Calder AW, Sale DG et al. A comparison of strength and muscle mass increases during resistance training in young women. Eur J Appl Physiol Occup Physiol. 1998;77(1-2):170-5.

14. Choi G, Raiturker PP, Kim MJ et al. The effect of early isolated lumbar extension exercise program for patients with herniated disc undergoing lumbar discectomy. Neurosurgery. 2005;57(4):764-72.

15. Evans WJ. Reversing sarcopenia: how weight training can build strength and vitality. Geriatrics. 1996;51(5):46-7, 51-3; quiz 4.

16. Klizienė I, Sipavičienė S, Imbrasienė D et al. Effect of core stability exercise on cross sectional area of lumbar multifidus muscle and physical capacity. Educ Phys Train Sport. 2011;(83):9-15.

17. Singh DK, Bailey M, Lee RY. Ageing modifies the fibre angle and biomechanical function of the lumbar extensor muscles. Clin Biomech. 2011;26(6):543-7. doi:10.1016/j.clinbiomech.2011.02.002.

18. Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. Spine (Phila Pa 1976). 1996;21(23):2763-9.

19. Parkkola R, Rytokoski U, Kormano M. Magnetic resonance imaging of the discs and trunk muscles in patients with chronic low back pain and healthy control subjects. Spine (Phila Pa 1976). 1993;18(7):830-6.

20. Beneck GJ, Kulig K. Multifidus atrophy is localized and bilateral in active persons with chronic unilateral low back pain. Arch Phys Med Rehabil. 2012;93(2):300-6.

21. Hicks GE, Simonsick EM, Harris TB et al. Trunk muscle composition as a predictor of reduced functional capacity in the health, aging and body composition study: the moderating role of back pain. Gerontol A Biol Sci Med Sci. 2005;60(11):1420-4.

22. Hicks GE, Simonsick EM, Harris TB et al. Cross-sectional associations between trunk muscle composition, back pain, and physical function in the health, aging and body composition study. Gerontol A Biol Sci Med Sci. 2005;60(7):882-7.

23. Sihvonen T, Herno A, Paljarvi L et al. Local denervation atrophy of paraspinal muscles in postoperative failed back syndrome. Spine (Phila Pa 1976). 1993;18(5):575-81.

24. Akbari A, Khorashadizadeh S, Abdi G. The effect of motor control exercise versus general exercise on lumbar local stabilizing muscles thickness: Randomized controlled trial of patients with chronic low back pain. J Back Musculoskelet Rehabil. 2008;21(2):105-12.

25. Woohyung L, Yoonmi L, Wontae G. The effect of lumbar strengthening exercise on pain and the cross-sectional area change of lumbar muscles. J Phys Ther Sci. 2011;23(2):209-12.

26. Lescher S, Bender B, Eifler R et al. Isometric non-machine-based prevention training program: effects on the cross-sectional area of the paravertebral muscles on magnetic resonance imaging. Clin Neuroradiol. 2011;21(4):217-22. doi: 10.1007/s00062-011-0104-3.

27. Sokunbi O, Watt P, Moore A. A randomised controlled trial (RCT) on the effects of frequency of application of spinal stabilisation exercises on multifidus cross sectional area (MFCSA) in participants with chronic low back pain. Physiother Singap 2008;11(2):9-16.

28. Critchley DJ, Pierson Z, Battersby G. Effect of pilates mat exercises and conventional exercise programmes on transversus abdominis and obliquus internus abdominis activity: pilot randomised trial. Man Ther. 2011;16(2):183-9. doi: 10.1016/j.math.2010.10.007.

29. Kuk JL, Church TS, Blair SN et al. Associations between changes in abdominal and thigh muscle quantity and quality. Med Sci Sports Exerc. 2008;40(7):1277-81.

30. Liberati A, Altman DG, Tetzlaff J et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions:

explanation and elaboration. J Clin Epidemiol. 2009;62(10):e1-34. doi:10.1016/j.jclinepi.2009.06.006.

31. Mayer J, Mooney V, Dagenais S. Evidence-informed management of chronic low back pain with lumbar extensor strengthening exercises. Spine J. 2008;8(1):96-113. doi:10.1016/j.spinee.2007.09.008.

32. Martuscello JM, Nuzzo JL, Ashley CD et al. Systematic review of core muscle activity during physical fitness exercises. J Strength Cond Res. 2013;27(6):1684-98. doi:10.1519/JSC.0b013e318291b8da.

33. Macedo LG, Maher CG, Latimer J et al. Motor control exercise for persistent, nonspecific low back pain: a systematic review. Phys Ther. 2009;89(1):9-25. doi:10.2522/ptj.20080103.

34. Kankaanpaa M, Taimela S, Airaksinen O et al. The efficacy of active rehabilitation in chronic low back pain. Effect on pain intensity, self-experienced disability, and lumbar fatigability. Spine (Phila Pa 1976). 1999;24(10):1034-42.

35. Parkkola R, Kujala U, Rytokoski U. Response of the trunk muscles to training assessed by magnetic resonance imaging and muscle strength. Eur J Appl Physiol Occup Physiol. 1992;65(5):383-7.

36. Darden E. The Nautilus book. Chicago: Contemporary books; 1990.

37. Thompson WR, Gordon NF, Pescatello LS et al. ACSM's guidelines for exercise testing and prescription. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2010.

38. Agarwal SK. Cardiovascular benefits of exercise. Int J Gen Med. 2012;5:541-5. doi:10.2147/IJGM.S30113.

39. Higgins JP, Altman DG, Gotzsche PC et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ. 2011;343:d5928. doi:10.1136/bmj.d5928.

40. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, N.J.: L. Erlbaum Associates; 1988.

41. Storheim K, Holm I, Gunderson R et al. The effect of comprehensive group training on cross-sectional area, density, and strength of paraspinal muscles in patients sick-listed for subacute low back pain. J Spinal Disord Tech. 2003;16(3):271-9.

42. Hides JA, Stanton WR, Wilson SJ et al. Retraining motor control of abdominal muscles among elite cricketers with low back pain Scand J Med Sci Sports. 2010;20(6):834-42.

43. Sakamaki M, Bemben MG, Abe T. Legs and trunk muscle hypertrophy following walk training with restricted leg muscle blood flow. J Sports Sci Med. 2011;10(2):338-40.

44. Danneels LA, Cools AM, Vanderstraeten GG et al. The effects of three different training modalities on the cross-sectional area of the paravertebral muscles. Scand J Med Sci Sports. 2001;11(6):335-41.

45. Teyhen DS, Childs JD, Dugan JL et al. Effect of two different exercise regimens on trunk muscle morphometry and endurance in soldiers in training. Phys Ther. 2013;93(9):1211–24.

46. Danneels L, Vanderstraeten G, Cambier D et al. Effects of three different training modalities on the cross sectional area of the lumbar multifidus muscle in patients with chronic low back pain. Br J Sports Med. 2001;35(3):186-91. doi:10.1136/bjsm.35.3.186.

47. Hides JA, Stanton WR, Mendis MD et al. Effect of motor control training on muscle size and football games missed from injury. Med Sci Sports Exerc. 2012;44(6):1141-9. doi:Doi 10.1249/Mss.0b013e318244a321.

48. Dorado C, Calbet JA, Lopez-Gordillo A et al. Marked effects of pilates on the abdominal muscles: a longitudinal magnetic resonance imaging study. Med Sci Sports Exerc. 2012;44(8):1589-94. doi:10.1249/MSS.0b013e31824fb6ae.

49. Hides J, Stanton W, McMahon S et al. Effects of stabilization training on multifidus muscle cross-sectional area among young elite cricketers with low back pain. J Orthop Sports Phys Ther. 2008;38(3):101-8.

50. Jansen JA, Mens JM, Backx FJ et al. Changes in abdominal muscle thickness measured by ultrasound are not associated with recovery in athletes with longstanding groin pain associated with resisted hip adduction. J Orthop Sports Phys Ther. 2009;39(10):724-32. doi: 10.2519/jospt.2009.3068 2354 [pii].

51. Jongwoo KIM, Wontae G, Byeongjun H. The effects of resistivity and stability-combined exercise for lumbar muscles on strength, cross-sectional area and balance ability: exercises for prevention of lower back pain. J Phys Ther Sci. 2011;23(2):247-50.

52. Kaser L, Mannion AF, Rhyner A et al. Active therapy for chronic low back pain: part 2. Effects on paraspinal muscle cross-sectional area, fiber type size, and distribution. Spine (Phila Pa 1976). 2001;26(8):909-19.

53. Kramer M, Dehner C, Katzmaier P et al. Device-assisted muscle strengthening in the rehabilitation of patients after surgically stabilized vertebral fractures. Arch Phys Med Rehabil. 2005;86(3):558-64. doi: 10.1016/j.apmr.2004.09.008.

54. Lee N-G, Jung J-H, You JH et al. Novel augmented ADIM training using ultrasound imaging and electromyography in adults with core instability. J Back Musculoskelet Rehabil. 2011;24(4):233-40.

55. Mooney V, Gulick J, Perlman M et al. Relationships between myoelectric activity, strength, and MRI of lumbar extensor muscles in back pain patients and normal subjects. J Spinal Disord. 1997;10(4):348-56.

56. Rissanen A, Kalimo H, Alaranta H. Effect of intensive training on the isokinetic strength and structure of lumbar muscles in patients with chronic low back pain. Spine (Phila Pa 1976). 1995;20(3):333-40.

57. Willemink MJ, van Es HW, Helmhout PH et al. The effects of dynamic isolated lumbar extensor training on lumbar multifidus functional cross-sectional area and functional status of patients with chronic non-specific low back pain. Spine (Phila Pa 1976). 2012;37(26):E1651–8.

58. Hoshikawa Y, Iida T, Muramatsu M et al. Effects of stabilization training on trunk muscularity and physical performances in youth soccer players. J Strength Cond Res. 2013;27(11):3142-9. doi:10.1519/JSC.0b013e31828bed36.

59. Fortin M, Macedo LG. Multifidus and paraspinal muscle group cross-sectional areas of patients with low back pain and control patients: a systematic review with a focus on blinding. Phys Ther. 2013;. doi:10.2522/ptj.20120457.

60. Narici MV, Hoppeler H, Kayser B et al. Human quadriceps cross-sectional area, torque and neural activation during 6 months strength training. Acta Physiol Scand. 1996;157(2):175-86. doi:10.1046/j.1365-201X.1996.483230000.x.

61. Hebert JJ, Kjaer P, Fritz JM et al. The relationship of lumbar multifidus muscle morphology to previous, current, and future low back pain: A nine-year population-based prospective cohort study. Spine (Phila Pa 1976). 2014. doi:10.1097/BRS. 0000000000000424.

62. Timson BF. Evaluation of animal models for the study of exercise-induced muscle enlargement. J Appl Physiol. 1990;69(6):1935-45.

63. Staron RS, Karapondo DL, Kraemer WJ et al. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. J Appl Physiol. 1994;76(3):1247-55.

64. Fry AC. The role of resistance exercise intensity on muscle fibre adaptations. Sports Med. 2004;34(10):663-79.

65. Campos GE, Luecke TJ, Wendeln HK et al. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. Eur J Appl Physiol. 2002;88(1-2):50-60. doi:10.1007/s00421-002-0681-6.

66. Cardinale M, Newton R, Nosaka K. Strength and conditioning biological principles and practical applications. Chichester, West Sussex, UK ; Hoboken, NJ: John Wiley & Sons,; 2011.

67. McGill SM. Low back exercises: evidence for improving exercise regimens. Phys Ther. 1998;78(7):754-65.

68. Slade SC, Keating JL. Exercise prescription: a case for standardised reporting. Br J Sports Med. 2012;46(16):1110-3. doi:10.1136/bjsports-2011-090290.

Chapter 3

General Methods

The purpose of this chapter is to provide a detailed explanation of all procedures and measures adopted within the cross-sectional study (Chapter 4) and randomized controlled trial (Chapter 5). This chapter has been included due to space limitations associated with the targeted journal formatting requirements of each experimental chapter.

Measurement procedures

Functional ability

Functional mobility was assessed using the Six Minute Walk Test (6MWT) [1], the 30-second Chair Stand Test (CST) [2], and the Sitting and Rising Test (SRT) [3].

The Six Minute Walk Test (6MWT)

The Six Minute Walk Test (6MWT) [1] is one of the most widely-used cardiopulmonary functional tests. The 6MWT assesses distance walked over 6 minutes, as a submaximal test of aerobic capacity (endurance). Walking is an indicator of overall physical wellbeing, due to its strong influences on independent living, which in turn contributes to accomplishment in many activities of daily living [4]. A lower score (reflecting less distance covered in 6 minutes) indicates worse functioning (poorer aerobic capacity). The six minute walk distance in healthy older adults with good aerobic capacities has been reported to range from 400m to 700m [5]. The 6MWT was performed indoors, along an enclosed, flat, straight, hard-surfaced 25-metre corridor. The walking track was marked with two cones at turn-around points (start, turn around-go back). The 6MWT was administered for each participant individually. Before starting the 6MWT, each participant rested for at least 15 minutes, and his/her resting heart and blood pressure was monitored using an automatic blood pressure monitor (Omron HEM7322, Kyoto, Japan). Safety considerations including a resting heart rate of more than 120, a systolic blood pressure of more than 180 mmHg, and a diastolic blood pressure of more than 100 mmHg were considered prior to the 6MWT [6]. A pedometer (Omron HJ-320 Walking Style Pedometer, Kyoto, Japan) was rested and attached to the participant's waist belt or clothing at waist level, and the Borg Rating of Perceived Exertion (RPE) Scale [7] was explained to the participant prior to the test. When the participant stood up behind the starting point (start-cone), he/she was asked to walk the 25-metre distance back and forth, as far as, and as quick as possible, for six minutes around the track (or up and down the corridor), and was advised to slow down if necessary. Each participant's 6MWT was timed using a stopwatch. The maximum heart rate, blood pressure (using the same automatic blood pressure monitor (Omron HEM7322, Kyoto, Japan) from the pre-test described above), and the level of walk intensity experienced (RPE) [7] were recorded immediately following the 6MWT. In addition, number of steps (using the same pedometer (Omron HJ-320 Walking Style Pedometer, Kyoto, Japan) from the pre-test described above), number of laps, and exceed distance were recorded after finishing the 6MWT. Finally, post heart rate and post blood pressure were recorded using the same automatic blood pressure monitor (Omron HEM7322, Kyoto, Japan) from the pre-test described above, approximately 5 minutes after finishing the 6MWT.

The 30-Second Chair Stand Test (CST)

The 30-Second Chair Stand Test (CST) [2] is an important functional test because it measures lower body strength. Age-related decline in lower body strength is associated with balance problems and risk of falls in older adults [2]. Performance in the CST also decreases with aging and low levels of activity [2]. Older individuals who completed the CST scores (mean (SD) repetitions) are classified into two categories. The first category involves age, and is divided into three subcategories: 60-69 y.o. (14.0 (2.4) repetitions), 70-79 y.o. (12.9 (3.0) repetitions), and 80-89 y.o. (11.9 (3.6) repetitions).

The second category is based on physical activity levels, and is divided into two subcategories: high active older individuals (13.3 (2.8) repetitions) and low active older individuals (10.8 (3.6) repetitions) [2]. The CST required participants to stand fully upright (with arms crossed over the chest) from a chair without arms, with a seat height of 43.2 cm, and then return to the seated position as many times as possible, within 30 seconds. Prior to testing, a practice trial of one or two slow paced repetitions was recommended, to ensure that the participant understood the test and the techniques required. The test commenced when the examiner said "3-2-1-start" while simultaneously starting the stopwatch, and the participant was then stopped after 30 sec. Only full standing positions were counted in this test.

The Sitting and Rising Test (SRT)

The ability to sit and rise from the floor unassisted (represented in the Sitting and Rising Test; SRT) has been identified as being predictive of all-cause mortality and is an important functional measure in older adults [3]. The SRT measures the individual's ability to sit and rise unassisted from the floor. Partial scores are assigned for each of the two required actions of sitting (5 points) and rising (5 points) from the floor (sit to rise). The final composite SRT point/s, varying from 0 to 10, is obtained by adding sitting and rising points (see Appendix B for more details). Each point increase in the SRT is associated with a 21% reduction in all-cause mortality [3]. The SRT was administered on a non-slippery flat surface, in a minimal space of 2×2 m, with the participant standing barefoot and wearing comfortable clothing that did not restrict movement. A mat was placed behind the participant to create a safe testing area. The examiner positioned himself/herself in front or at the side of the participant, to get a clear vision of the test and to optimize accuracy of test scoring. Prior to the SRT, the participant was given the following instructions: "without worrying about the speed of movement, try to sit and then to rise from the floor, using the minimum support that you believe is needed”. The participant was allowed to cross his/her legs either during the sitting or rising test; however, the sides of feet could not be used for support.

Balance

Balance was assessed using the Berg Balance Scale (BBS) [8], the Multi-Directional Reach Test (MDRT) [9], the Timed Up and Go Test (TUG) [10], and the Four Square Step Test (FSST) [11]. The results from the Multi-Directional Reach Test are presented as Forward Reach Test (FRT); Backward Reach Test (BRT); Right Reach Test (RRT); and Left Reach Test (LRT).

The Berg Balance Scale (BBS)

The Berg Balance Scale (BBS) [8] is a widely used clinical test of static and dynamic balance abilities, both of which are good predictors of risk of falls in older adults. The BBS comprises 14 items of static and dynamic balance tasks of varying difficulties. The 14 items of BBS are as follows; 1. Sitting to standing, 2. Standing unsupported, 3. Sitting unsupported, 4. Standing to sitting, 5. Transfers, 6. Standing with eyes closed, 7. Standing with feet together, 8. Reaching forward with outstretched arm, 9. Turning to look behind, 10. Turning 360 degrees, 11. Turning 360 degrees, 12. Placing alternate foot on stool, 13. Standing with one foot in front, 14. Standing on one foot. All items were based on a 5 -point ordinal scale (ranging from 0-4). “0” indicates the lowest level of function and “4” the highest level of function. The maximum score on the BBS is 56 (see Appendix B for more details). A cut-off score of 45 is an established criterion to identify older adults with high risk of falls [8]. A change of 4 points is needed, to be 95% confident that “genuine” change has occurred if a patient scores within 45-56 initially [12]. Each participant went through all 14 items of the BBS. The BBS assessed each participant’s ability to carry out postural changes without assistive devices from standing to sitting and vice versa, perform transfers, and to change standing positions [8].

The Multi-Directional Reach Test (MDRT)

The Multi-Directional Reach Test (MDRT) [9, 13] was used to measure the limits of postural stability in four directions: forward, backward, leftward and rightward. Performance on the MDRT can be predictive of recurrent falls (individuals at high risk of falls with two or more eligible falls in the past 6-months) [14]. Newton [9] reported that the mean distances on the MDRT achieved by healthy older adults with good (normal) postural stability (FRT = 22.58 (8.63) cm, BRT = 11.78 (7.79) cm, RRT = 15.62 (7.59) cm, and LRT = 16.78 (7.31) cm) can be applied as norms for clinical populations with limited postural stability. The MDRT required participants to voluntarily reach and shift their centre of gravity to the limits of the base of support with the feet stationary [13]. To administer the MDRT, a yardstick was first affixed to the wall at the level of the patient's acromion process [13]. Prior to the reach, the yardstick was leveled so that it was horizontal to the floor. The participant lifted an outstretched arm to shoulder height, maintained his/her arm outstretched for an initial reading, then reached as far forward as possible. For the forward direction, instructions were given to the participant were: “without moving your feet or taking a step, reach as far (direction given) as you can, and try to keep your hand along the yardstick, try to keep your knees straight, feet flat on the floor, but do not rotate your upper body”. For the backward direction, the participant was instructed to “lean as far back as you can.” Participants could use their preferred arm for forward and backward reach tests. However, for the right and left reaches, only the respective arms were used. The start and end positions of the index finger of the outstretched hand were recorded, and the difference represented the total reach for that direction. Participants were required to keep their feet flat on the floor and if they moved their feet, the trial was discarded. Each participant performed two trials for each direction (forward, backward, right, and left), and the average of two trials was recorded as the final score of the MDRT for each direction.

The Timed Up and Go Test (TUG)

The Timed Up and Go Test (TUG) [10] is highly correlated with functional mobility, gait speed, and risk of falls in older adults. Longer TUG times are associated with decreased mobility and may accurately predict risk of falls [10]. Older individuals who completed the TUG in < 10 seconds are regarded as independent with good physical mobility; older individuals who completed TUG in < 20 seconds are described as having good mobility and can walk and go out alone without a gait aid. However, older individuals who completed the TUG in ≥30 seconds are described as being unable to go outside alone, may require a gait aid and have high risk of falls [10]. For the TUG, participants were instructed by the examiner to stand from a standard armchair (approximately seat height 46 cm) without using the arms or any physical assistance, walk at a comfortable and safe pace to a line on the floor 3 metres away, turn, return to the chair, and sit down on the chair. Each participant did the test once without being timed (practice trial), to ensure familiarity with the test. After the practice trial, the participant was then timed while he/she completed the two recorded trials and an average of the two recorded trials was used in data analysis.

The Four Step Square Test (FSST)

The Four Step Square Test (FSST) [11] is a reliable, easy to score, and quick to administer clinical test, to predict risk of falls in older adults [11]. The FSST is a timed agility test used to measure dynamic standing balance, quick stepping, and coordination in four different directions [11]. A cut-off score of 15 serves as the criterion to predict risk of falls in older adults. Participants with scores >15 seconds are considered as multiple fallers with greater risk of falls, and those with scores ≤ 15 seconds regarded as non-multiple fallers with less risk of falls [11]. For the FSST, four canes (height 2.5 cm and length 90 cm) were placed flat on the floor in a cross formation to mark four squares (1,2,3,4). Participants were instructed to step forward sideways and backwards over the four canes. Participants were then asked to stand and touch the floor with both feet in square 1, and then step as fast as possible from one square to another in the order; 2-3-4-1-4-3-2 and 1. Timing commenced when the first foot contacted the floor in square 2 and was stopped when the last foot came back to touch the floor in square 1. The following instructions were given to the participants: "Try to complete the sequences as quick as possible without touching the sticks. Both feet must touch the floor in each square. If possible, face forward during the entire sequence." The sequence was demonstrated to the participants, and participants were allowed to practice one trial, prior to the actual tests, to ensure that they understood the sequence. Two trials were then performed, and the best (shortest) time was considered as the final score of the FSST (no more than four attempts were allowed). A trial was repeated if the participant failed to complete the sequence successfully, lost balance, or made contact with the canes during the sequence.

Trunk muscle morphology

A SonoSite M-Turbo (SonoSite™, Bothell, WA, USA) ultrasound unit with a 60 mm broadband curved array (5-2 MHz) was used to measure the size of the rectus abdominis (RA), internal oblique (IO), external oblique (EO), transversus abdominis (TrA) and lumbar multifidus (LM) muscles. Previous studies using ultrasound imaging to measure trunk muscle size in older adults have demonstrated high inter-rater and intra-rater reliability (ICC ≥0.86) [15, 16].

Images of the lumbar multifidus (LM) were obtained at the L4-5 level (L4/L5) with the participant in the prone position using methods described in previous studies [17].

The transducer was positioned lateral to the L4 and L5 spinous process and angled slightly medial until the L4-5 facet joint could be identified. Lumbar multifidus thickness measurements were made between the posterior most portion of the L4-5 facet joint and the plane between the superficial muscle and subcutaneous tissue.

Rectus abdominis (RA) thickness and cross-sectional area (CSA), as well as transversus abdominis (TrA), internal oblique (IO) and external oblique (EO) thickness was measured with participants in the supine, hook-lying position. For acquisition of the TrA, IO and EO muscles, the transducer was positioned transversely over the anterolateral aspect of the abdominal wall, superior to the iliac crest and perpendicular to the mid-axillary line. The images were captured with the middle of the muscle belly centered in the field of view and at the end of a normal exhalation to control for the influence of respiration [17]. For acquisition of the RA, the inferior border of the transducer was placed immediately above the umbilicus and moved laterally from the midline until the muscle cross-section was centered in the image [18]. A single assessor performed image acquisition three times bilaterally and exported the images for offline analysis using Image J (National Institutes of Health, version 1.41). The same assessor averaged all measures across the three repetitions to reduce measurement error [17].

We created a composite trunk muscle size variable by summing the thickness of TrA, IO, and EO (total lateral abdominal muscles; TLAM), as well as other trunk muscles (rectus abdominis and lumbar multifidus muscles sizes). Composite trunk muscle size comprised the thickness of bilateral lateral abdominal muscles, rectus abdominis, lumbar multifidus at lumbar spinal level L4/L5 (L4/L5) (the average of right and left) and lumbar multifidus at lumbar spinal level L5/S1 (L5/S1) (the average of right and left). The formula of composite trunk muscle size is as follows; [Composite trunk muscle size = TLAM + RA + LM (L4/L5) + LM (L5/S1)].

Trunk muscle strength

We measured maximal isometric strength in trunk flexion, extension, and lateral flexion using the Humac NORM Isokinetic dynamometer (Humac NORM, Computer Sports Medicine, Stoughton, MA, USA) with the trunk extension–flexion (TEF) modular component Isokinetic dynamometry, which has been reported to be a reliable and valid method for measuring trunk muscle strength [19, 20]. The footplate height was adjusted to align the participant's vertical anatomical axis (L5/S1 level) with the machine axis. Horizontal alignment was approximately 3.5 cm below the top of iliac crest at L5/S1 and vertical alignment was at the approximate intersection of the mid-axillary line and L5/S1 [21]. The lumbar pad was positioned to obtain a slightly flexed knee position (15º) and all other pads and belts secured in accordance with manufacturer instructions. The strength testing was performed in the same order each time: trunk flexion, extension and then lateral flexion (right, left).

Prior to testing, participants performed a standardised warm-up consisting of one set (10 repetitions) of range of motion exercises and up to five practice trials. For maximal efforts, contractions were held for 3 seconds and the peak torque from two attempts recorded. A familiarisation trial preceded each measure and the participant rested for 45 seconds between each repetition [22]. Verbal encouragement was provided during each effort. Maximum isometric trunk torque (Nm) data was normalised by adjusting for trunk height (cm) and converting the peak torque to maximum force (N) [Maximum force= Peak torque/ Moment arm (trunk height)]. Therefore, all data on trunk muscle strength are presented as maximum force. Similar to the muscle size measures, we calculated a composite trunk strength score by summing the maximum force outcomes from flexion, extension, lateral flexion right and lateral flexion left. The formula of composite trunk strength is as follows; [Composite trunk strength = Maximum force flexion+ Maximum force extension+ Maximum force lateral flexion].

Exercise programs

All exercise training sessions were conducted and supervised at Murdoch University. Each training session lasted approximately 60 minutes, and there were three training sessions per week, with exercises being gradually progressed over 12 weeks (total of 36 sessions) (see details of the protocols below). Participants were considered compliant if they attended at least 80% of the exercise sessions over the 12-week training period.

Trunk strengthening exercise program (see Appendix C for more details): this study made use of a multimodal exercise program comprising of 30 minutes of trunk strengthening/motor control exercises [23] (e.g., abdominal bracing, front bridge pose), 15 minutes of Otago balance exercises [24] (e.g., toe raises, figure 8 walking), and 15 minutes of continuous walking at approximately 60% of maximum heart rate using the age-based prediction formula (220-age). Resting, maximum, and post heart rates of each individual were checked before, halfway through, and at the end of the walking session, respectively. The participant-to-instructor ratio was kept small [25] (1 main instructor (B.S) with 2 additional assistants for 8 participants) throughout the program. All trunk strengthening/motor control exercises were conducted on gym mats using unstable training equipment (e.g., Airex mats, Bosu ball), but without the use of resistance machines. Throughout the trunk strengthening/motor control exercises, participants were always in supine, prone, quadruped and side-lying positions on the gym mats to avoid continuous position changes (from standing to lying/sitting and vice versa), which are often uncomfortable for older adults [25]. Training intensity was progressively and individually increased over the 12-week exercise program by changing the lever lengths, range of motion, movement velocity (isometric, dynamic) and the level of stability/instability.

Walking-balance exercise program (see Appendix C for more details): participants in this group performed the same Otago balance exercises [24] for 15 minutes as above and 45 minutes of continuous walking at approximately 60% of their maximum heart rate using the age-based prediction formula (220-age). Resting, maximum, and post heart rates of each individual were checked before, halfway through, and at the end of the walking session, respectively.

References

1. Lipkin, D.P., et al., *Six minute walking test for assessing exercise capacity in chronic heart failure.* Br Med J (Clin Res Ed), 1986. **292**(6521): p. 653-5.

2. Jones, C.J., R.E. Rikli, and W.C. Beam, *A 30-s chair-stand test as a measure of lower body strength in community-residing older adults.* Res Q Exerc Sport, 1999. **70**(2): p. 113-9.

3. Brito, L.B.B.d., et al., *Ability to sit and rise from the floor as a predictor of all-cause mortality.* Eur J Prev Cardiol, 2014. **21**(7): p. 892-8.

4. Makizako, H., et al., *Cognitive functioning and walking speed in older adults as predictors of limitations in self-reported instrumental activity of daily living: prospective findings from the Obu Study of Health Promotion for the Elderly.* Int J Env Res Pub He, 2015. **12**(3): p. 3002-3013.

5. Enright, P.L., et al., *The 6-min walk test: a quick measure of functional status in elderly adults.* Chest, 2003. **123**(2): p. 387-98.

6. *ATS statement: guidelines for the six-minute walk test.* Am J Respir Crit Care Med, 2002. **166**(1): p. 111-7.

7. Utter, A.C., et al., *Ratings of perceived exertion during intermittent and continuous exercise.* Percept Mot Skills, 2007. **104**(3 Pt 2): p. 1079-87.

8. Berg, K.O., et al., *Measuring balance in the elderly: validation of an instrument.* Can J Public Health, 1992. **83 Suppl 2**: p. S7-11.

9. Newton, R.A., *Validity of the multi-directional reach test: a practical measure for limits of stability in older adults.* J Gerontol A Biol Sci Med Sci, 2001. **56**(4): p. M248-52.

10. Podsiadlo, D. and S. Richardson, *The timed "Up & Go": a test of basic functional mobility for frail elderly persons.* J Am Geriatr Soc, 1991. **39**(2): p. 142-8.

11. Dite, W. and V.A. Temple, *A clinical test of stepping and change of direction to identify multiple falling older adults.* Arch Phys Med Rehabil, 2002. **83**(11): p. 1566-71.

12. Donoghue, D. and E.K. Stokes, *How much change is true change? The minimum detectable change of the Berg Balance Scale in elderly people.* J Rehabil Med, 2009. **41**(5): p. 343-6.

13. Newton, R.A., *Balance screening of an inner city older adult population.* Arch Phys Med Rehabil, 1997. **78**(6): p. 587-91.

14. Duncan, P.W., et al., *Functional reach: predictive validity in a sample of elderly male veterans.* J Gerontol, 1992. **47**(3): p. M93-8.

15. Sions, J.M., et al., *Ultrasound imaging: intraexaminer and interexaminer reliability for multifidus muscle thickness assessment in adults aged 60 to 85 years versus younger adults.* J Orthop Sports Phys Ther, 2014. **44**(6): p. 425-34.

16. Stetts, D.M., et al., *A rehabilitative ultrasound imaging investigation of lateral abdominal muscle thickness in healthy aging adults.* J Geriatr Phys Ther, 2009. **32**(2): p. 60-6.

17. Koppenhaver, S.L., et al., *Reliability of rehabilitative ultrasound imaging of the transversus abdominis and lumbar multifidus muscles.* Arch Phys Med Rehabil, 2009. **90**(1): p. 87-94.

18. Teyhen, D.S., et al., *Rehabilitative ultrasound imaging of the abdominal muscles.* J Orthop Sports Phys Ther, 2007. **37**(8): p. 450-66.

19. Kienbacher, T., et al., *Reliability of isometric trunk moment measurements in healthy persons over 50 years of age.* J Rehabil Med, 2014. **46**(3): p. 241-9.

20. Guilhem, G., et al., *Validity of trunk extensor and flexor torque measurements using isokinetic dynamometry.* J Electromyogr Kinesiol, 2014. **24**(6): p. 986-93.

21. Karatas, G.K., F. Gogus, and J. Meray, *Reliability of isokinetic trunk muscle strength measurement.* Am J Phys Med Rehabil, 2002. **81**(2): p. 79-85.

22. Van Damme, B.B.L., et al., *Velocity of isokinetic trunk exercises influences back muscle recruitment patterns in healthy subjects.* J Electromyogr Kinesiol, 2013. **23**(2): p. 378-86.

23. McGill, S.M. and A. Karpowicz, *Exercises for spine stabilization: motion/motor patterns, stability progressions, and clinical technique.* Arch Phys Med Rehabil, 2009. **90**(1): p. 118-126.

24. Gardner, M.M., et al., *Practical implementation of an exercise-based falls prevention programme.* Age Ageing, 2001. **30**(1): p. 77-83.

25. Granacher, U., et al., *Effects of core instability strength training on trunk muscle strength, spinal mobility, dynamic balance and functional mobility in older adults.* Gerontology, 2013. **59**(2): p. 105-113.

Chapter 4

Association between trunk muscle morphology, strength, and functional ability in healthy older adults

Submission planned for

Gerontology

Association between trunk muscle morphology, strength, and functional ability in healthy older adults

Running Title: Association between Trunk Muscle Morphology, Strength and Functional Ability

Authors: Behnaz Shahtahmassebi[1], Jeffrey J. Hebert[1], Mark Hecimovich[1,2], Timothy J. Fairchild[1]

Affiliations:

1. School of Psychology and Exercise Science, Murdoch University, Perth, WA, Australia

2. School of Health, Physical Education and Leisure Services University of Northern Iowa, Iowa, United States

Correspondence:

Timothy Fairchild

School of Psychology and Exercise Science, Murdoch University

Room 2.042, Social Sciences Building, 90 South Street

Murdoch WA 6150

Email: T.Fairchild@murdoch.edu.au

Tel +61 8 9360 2959

Key words: Aging, Ageing, Falls, Falling, Exercise, Walking, Balance, Core, Training

List of Abbreviations

Abbreviation	Definition
BBS	Berg Balance Scale
BRT	Backward Reach Test
CSA	Cross-sectional area
CST	30-second Chair Stand Test
ICC	Intraclass correlation coefficient
IO	Internal oblique
EO	External oblique
FSST	Four Square Step Test
FRT	Forward Reach Test
LM	Lumbar multifidus
LRT	Left Reach Test
L4/L5	Lumbar spinal level L4/L5
L5/S1	Lumbar spinal level L5/S1
MDRT	Multi-Directional Reach Test
RA	Rectus abdominis
RRT	Right Reach Test
6MWT	Six-Minute Walk Test
SRT	Sitting and Rising Test
TLAM	Total lateral abdominal muscles
TrA	Transversus abdominis
TUG	Timed Up and Go

Abstract

Background: Preliminary evidence demonstrates that age-related changes in trunk muscle morphology and function may be associated with decreased balance, and increased falls risk.

Objectives: To examine the associations between trunk muscle morphology, strength, and functional ability in healthy older adults.

Methods: We recruited healthy adults, 60 years or older, with no history of lumbar surgery or medical conditions precluding safe participation in an exercise program. Trunk muscle morphology and strength (flexion, extension, and lateral flexion) were assessed using ultrasound imaging and isokinetic dynamometry, respectively. Functional and balance outcomes were assessed using the Six-Minute Walk Test (6MWT), 30-second Chair Stand Test (CST), Sitting and Rising Test (SRT), Berg Balance Scale (BBS), Forward, Backward, Right and Left Reach Test (FRT,BRT,RRT,LRT), Timed Up and Go (TUG) and Four Square Step Test (FSST). Univariate and multivariate analyses were performed with correlation and linear regression and reported with correlation coefficients (*r*) and standardized beta coefficients (*β*) respectively. Age, sex, and BMI were evaluated as potential covariates in each multivariate model.

Results: Sixty-four healthy older adults (mean (SD) age 69.8 (7.5) years; 59.4% female) participated. Rectus abdominis size was associated with 6MWT(r=0.27;p=0.029), FRT(r=0.30;p=0.014), BRT(r=0.45;p<0.001), CST(r=0.33;p=0.007) and SRT(r=0.29;p=0.018). Lumbar multifidus thickness was associated with TUG(r=0.26;p=0.037) and FSST(r=0.24;p=0.048). Total lateral abdominal muscle thickness (r=0.43;p<0.001) and composite trunk muscle size (r=0.33;p=0.007) were associated with BRT. Composite trunk strength was associated with 6MWT(r=0.35;p=0.004), CST(r=0.30;p=0.016), SRT(r=0.40,p=0.001), BBS(r=0.29;p=0.017), FRT(r=0.36;p=0.003), and BRT(r=0.28;p=0.021). Composite trunk muscle size was correlated with composite trunk strength(r=0.42;$p<0.001$). After controlling for covariates, rectus abdominis size was associated with 6MWT(β=-0.27;p=0.050), SRT(β=0.33;$p<0.01$) and BRT (β=0.43;p=0.013), while lumbar multifidus thickness was associated with FSST(β=0.21;p=0.048). Trunk flexion strength was associated with FRT (β=0.27;p=0.01), while composite trunk strength was associated with SRT(β=0.34;$p<0.01$). Rectus abdominis size was associated with trunk flexion (β=0.45;$p<0.01$) and composite trunk strength (β=0.34;$p<0.01$), while total lateral abdominal muscles size was associated with trunk flexion strength (β=0.29;$p<0.01$).

Conclusion: This study revealed strong associations between, trunk muscle strength and functional ability as well as trunk muscle size and functional ability. These findings identify the trunk muscles as potentially important targets for exercise programs designed to improve balance, mobility and function in older adults.

Introduction

Age-related decreases in skeletal muscle size are accompanied by diminished muscle strength and function [1, 2]. These muscle changes are associated with reduced quality of life [3] and increased risk of falls [4]. Falls are a major health concern among older adults, in terms of injury, disability, socioeconomic burden, and mortality [5].

Previous studies investigating the relationship between muscle strength and functional outcomes in older adults have focused on peripheral musculature through examining handgrip strength and knee extensor strength [6]. However, more recent research has begun to focus on age-related changes in the trunk musculature (i.e. the abdominal muscles, and muscles attaching to the lumbar spine) [4, 7-9] due to the important role of these muscles in performing activities of daily living, balance, mobility, and falls prevention in older adults [10-12].

Recently, a systematic review conducted by Granacher et al [12] sought to examine if trunk muscle strength/composition was associated with balance, functional ability, and risk of falls in older adults. First, based on the findings of the cross-sectional studies included in Granacher et al [12]'s systematic review, there was a low but significant association between trunk muscle strength/muscle attenuation (i.e., higher fat infiltration) and balance, functional ability, and risk of falls in older adults. The authors [12] additionally identified that there was high levels of heterogeneity in terms of type of participants (e.g. clinical, healthy) and the applied testing methodology across the cross-sectional studies included in their systematic review. The authors [12] thus recommended that future research should specifically focus on additional well-designed cross sectional studies to investigate the relationship between measures of trunk muscle strength/composition, balance, and functional ability in older adults.

In light of previous findings and recommendations above, the primary aim of this study was to examine the associations between trunk muscle morphology (size), strength, and functional ability in healthy older adults. We first hypothesized that there will be a positive relationship between trunk muscle morphology and functional ability, and trunk muscle strength and functional ability in older adults. The secondary aim of this study was to investigate the association between trunk muscle morphology and strength in healthy older adults. We thus hypothesized that there will be a positive relationship between trunk muscle morphology and strength in healthy older adults.

Methods

We conducted a cross-sectional study to examine the associations between trunk muscle morphology, strength, and functional ability (functional outcome measures categorised into either functional mobility or balance outcome measures) in healthy older adults. The Murdoch University Human Research Ethics Committee approved the study protocol (No. 2013/140), and all participants provided written informed consent prior to enrolment.

Participants

We recruited males and females aged 60 years and older, from the local community and from aged care facilities. Participants were excluded from study participation if they i) had undergone lumbar spine surgery, ii) had any medical condition or were taking prescribed medication, which may have precluded safe participation in an exercise program according to a standardized adult pre-exercise screening tool (30) and, iii) were unable to communicate and respond to the questionnaires in English. In some cases, the study's supervisory panel (TJF, MH, JJH) requested participants to provide an additional medical clearance to participate in the study.

Testing materials

Anthropometric and demographic characteristics

Participants provided self-reported physical activity levels via filling in a demographic questionnaire. We measured body weight using a digital scale (Scales Plus, Perth, WA, Australia) and height (standing and seated) using a wall-mounted stadiometer (Surgical Medical Supplies Pvt Ltd, Adelaide, SA, Australia). Seated height (the length of the trunk) refers to the distance from the highest point on the head to the base sitting surface, and was measured using a wall-mounted stadiometer. The body mass index (BMI) was calculated as the body mass divided by the square of the body height.

Functional mobility

Functional mobility was assessed using the Six Minute Walk Test (6MWT) [13], the 30-second Chair Stand Test (CST) [14], and the Sitting and Rising Test (SRT) [15].

The Six Minute Walk Test (6MWT) [13] is one of the most widely-used cardiopulmonary functional tests. The 6MWT assesses distance walked over 6 minutes, as a submaximal test of aerobic capacity (endurance). Walking is an indicator of overall physical wellbeing, due to its strong influences on independent living, which in turn contributes to accomplishment in many activities of daily living [16]. A lower score (reflecting less distance covered in 6 minutes) indicates worse functioning (poorer aerobic capacity). The six minute walk distance in healthy older adults with good aerobic capacities has been reported to range from 400m to 700m [17].

The 30-Second Chair Stand Test (CST) [14] is an important functional test because it measures lower body strength. Age-related decline in lower body strength is associated with balance problems and risk of falls in older adults [14]. Performance in the CST also decreases with aging and low levels of activity [14]. Older individuals who completed the CST scores (mean (SD) repetitions) are classified into two categories. The first category involves age, and is divided into three subcategories: 60-69 y.o. (14.0 (2.4) repetitions), 70-79 y.o. (12.9 (3.0) repetitions), and 80-89 y.o. (11.9 (3.6) repetitions). The second category is based on physical activity levels, and is divided into two subcategories: high active older individuals (13.3 (2.8) repetitions) and low active older individuals (10.8 (3.6) repetitions) [14].

The ability to sit and rise from the floor unassisted (represented in the Sitting and Rising Test; SRT) has been identified as being predictive of all-cause mortality and is an important functional measure in older adults [15]. The SRT measures the individual's ability to sit and rise unassisted from the floor. Partial scores are assigned for each of the two required actions of sitting (5 points) and rising (5 points) from the floor (sit to rise). The final composite SRT point/s, varying from 0 to 10, is obtained by adding sitting and rising points. Each point increase in the SRT is associated with a 21% reduction in all-cause mortality [15].

Balance

Balance was assessed using the Berg Balance Scale (BBS) [18] , the Multi-Directional Reach Test (MDRT) [19], the Timed Up and Go Test (TUG) [20], and the Four Square Step Test (FSST) [21]. The results from the Multi-Directional Reach Test are presented as Forward Reach Test (FRT); Backward Reach Test (BRT); Right Reach Test (RRT); and Left Reach Test (LRT). The Berg Balance Scale (BBS) [18] is a widely used clinical test of static and dynamic balance abilities, both of which are good predictors of risk of falls in older adults. The BBS comprises 14 items of static and dynamic balance tasks, with a maximum score of 56, and a cut-off score of 45 is an established criterion to identify older adults with high risk of falls [18]. A change of 4 points is needed, to be 95% confident that "genuine" change has occurred if a patient scores within 45-56 initially [22].

The Multi-Directional Reach Test (MDRT) [19] was used to measure the limits of postural stability in four directions: forward, backward, leftward and rightward. Performance on the MDRT can be predictive of recurrent falls (individuals at high risk of falls with two or more eligible falls in the past 6-months) [23]. Newton [19] reported that the mean distances on the MDRT achieved by healthy older adults with good (normal) postural stability (FRT = 22.58 (8.63) cm, BRT = 11.78 (7.79) cm, RRT = 15.62 (7.59) cm, and LRT = 16.78 (7.31) cm) can be applied as norms for clinical populations with limited postural stability.

The Timed Up and Go Test (TUG) [20] is highly correlated with functional mobility, gait speed, and risk of falls in older adults. Longer TUG times are associated with decreased mobility and may accurately predict risk of falls [20]. Older individuals who completed the TUG in < 10 seconds are regarded as independent with good physical mobility; older individuals who completed TUG in < 20 seconds are described as having good mobility and can walk and go out alone without a gait aid. However, older individuals who completed the TUG in ≥30 seconds are described as being unable to go outside alone, may require a gait aid and have high risk of falls [20].

The Four Step Square Test (FSST) [21] is a reliable, easy to score, and quick to administer clinical test, to predict risk of falls in older adults [21]. The FSST is a timed agility test used to measure dynamic standing balance, quick stepping, and coordination in four different directions [21]. A cut-off score of 15 serves as the criterion to predict risk of falls in older adults. Participants with scores >15 seconds are considered as multiple fallers with greater risk of falls, and those with scores ≤ 15 seconds regarded as non-multiple fallers with less risk of falls [21].

Trunk muscle morphology

A SonoSite M-Turbo (SonoSite™, Bothell, WA, USA) ultrasound unit with a 60 mm broadband curved array (5-2 MHz) was used to measure the size of the rectus abdominis (RA), internal oblique (IO), external oblique (EO), transversus abdominis (TrA) and lumbar multifidus (LM) muscles. Previous studies using ultrasound imaging to measure trunk muscle size in older adults have demonstrated high inter-rater and intra-rater reliability (ICC ≥0.86) [24, 25].

Images of the lumbar multifidus (LM) were obtained at the L4-5 level (L4/L5) with the participant in the prone position using methods described in previous studies [26]. The transducer was positioned lateral to the L4 and L5 spinous process and angled slightly medial until the L4-5 facet joint could be identified. Lumbar multifidus thickness measurements were made between the posterior most portion of the L4-5 facet joint and the plane between the superficial muscle and subcutaneous tissue.

Rectus abdominis (RA) thickness and cross-sectional area (CSA), as well as transversus abdominis (TrA), internal oblique (IO) and external oblique (EO) thickness was measured with participants in the supine, hook-lying position. For acquisition of the TrA, IO and EO muscles, the transducer was positioned transversely over the anterolateral aspect of the abdominal wall, superior to the iliac crest and perpendicular to the mid-axillary line. The images were captured with the middle of the muscle belly centered in the field of view and at the end of a normal exhalation to control for the influence of respiration [26]. For acquisition of the RA, the inferior border of the transducer was placed immediately above the umbilicus and moved laterally from the midline until the muscle cross-section was centered in the image [27]. A single assessor performed image acquisition three times bilaterally and exported the images for offline analysis using Image J (National Institutes of Health, version 1.41). The same assessor averaged all measures across the three repetitions to reduce measurement error [26].

We created a composite trunk muscle size variable by summing the thickness of TrA, IO, and EO (total lateral abdominal muscles; TLAM), as well as other trunk muscles (rectus abdominis and lumbar multifidus muscles sizes). Composite trunk muscle size comprised the thickness of bilateral lateral abdominal muscles, rectus abdominis, lumbar multifidus at lumbar spinal level L4/L5 (L4/L5) (the average of of right/left) and lumbar multifidus at lumbar spinal level L5/S1 (L5/S1) (the average of right and left). The formula of composite trunk muscle size is as follows; [Composite trunk muscle size = TLAM + RA + LM (L4/L5) + LM (L5/S1)].

Trunk muscle strength

We measured maximal isometric strength in trunk flexion, extension, and lateral flexion using the Humac NORM Isokinetic dynamometer (Humac NORM, Computer Sports Medicine, Stoughton, MA, USA) with the trunk extension–flexion (TEF) modular component Isokinetic dynamometry, which has been reported to be a reliable and valid method for measuring trunk muscle strength [28, 29]. The footplate height was adjusted to align the participant's vertical anatomical axis (L5/S1 level) with the machine axis. Horizontal alignment was approximately 3.5 cm below the top of iliac crest at L5/S1 and vertical alignment was at the approximate intersection of the mid-axillary line and L5/S1 [30]. The lumbar pad was positioned to obtain a slightly flexed knee position (15º) and all other pads and belts secured in accordance with manufacturer instructions. The strength testing was performed in the same order each time: trunk flexion, extension and then lateral flexion (right, left).

Prior to testing, participants performed a standardised warm-up consisting of one set (10 repetitions) of range of motion exercises and up to five practice trials. For maximal efforts, contractions were held for 3 seconds and the peak torque from two attempts recorded. A familiarisation trial preceded each measure and the participant rested for 45 seconds between each repetition [31]. Verbal encouragement was provided during each effort. Maximum isometric trunk torque (Nm) data was normalised by adjusting for trunk height (cm) and converting the peak torque to maximum force (N) [Maximum force= Peak torque/ Moment arm (trunk height)]. Therefore, all data on trunk muscle strength are presented as maximum force. Similar to the muscle size measures, we calculated a composite trunk strength score by summing the maximum force outcomes from flexion, extension, lateral flexion right and lateral flexion left. The formula of composite trunk strength is as follows; [Composite trunk strength = Maximum force flexion+ Maximum force extension+ Maximum force lateral flexion].

Data Analysis

All data management and statistical analyses were performed using IBM SPSS version 21.0 software (IBM Corp, Armonk, NY). Descriptive statistics were computed as means and standard deviation for continuous variables, or as number and percentages for categorical variables.

The relationships between trunk muscle morphology, trunk muscle strength and functional outcome measures; and trunk muscle morphology and strength were examined with univariate and multivariate analyses. We first explored these relations with Pearson's correlation coefficients (r) for continuous independent variables or point-biserial coefficients for dichotomous independent variables. Independent variables demonstrating significant correlations ($p \leq 0.05$) with the outcome measures (dependant variables) were then included in separate multivariate linear regression models for each corresponding outcome measure. When only one muscle predictor was identified at the univariate step, it was force entered into the model along with any significant demographic covariates. When more than one muscle predictor was identified by the univariate analysis, they were entered into step one of a hierarchical model. The muscle predictor explaining the greatest variance in the outcome measures was then included in step two with the significant demographic covariates. If more than three variables qualified for entry into the model (e.g., a combination of two demographic variables and two potential predictors), then we selected the strongest demographic variable only, to ensure appropriate power in each model.

Standardized beta coefficients (*β*) were generated for each of the variables retained in the final model and adjusted R^2 values were calculated at each step. The level of significance was set at $p \leq 0.05$.

Results

Sixty-four participants (38 female) with a mean (SD) age of 69.8 (7.5) years and BMI of 27.3 (4.7) kg/m^2, participated in this study. Additional descriptive data are presented in Table 1. Univariate and multivariate outcomes are presented in Tables 2-4, and Tables 5-7, respectively.

Univariate associations between trunk muscle morphology and functional outcome measures

Table 2 includes the results of the univariate analysis. TLAM was positively correlated with BRT (r=0.43, p<0.001) outcome. Larger RA CSA was associated with improved 6MWT (r=0.27, p=0.029), CST (r=0.33, p=0.007), SRT (r=0.29, p=0.018), FRT (r=0.30, p=0.014) and BRT (r=0.45, p<0.001) outcomes. LM-L5/S1 thickness was positively correlated with TUG (r=0.26, p=0.037) and FSST (r=0.24, p=0.048) outcomes. Similarly, LM-L4/L5 thickness was positively correlated with FSST (r=0.25, p=0.043) outcome. Composite trunk muscle size was positively correlated with BRT (r=0.33, p=0.007) outcome.

Univariate associations between trunk muscle strength and functional outcome measures

Table 3 includes the results of the univariate analysis. Increased trunk flexion strength was associated with improved FRT (*r*=0.36, *p*=0.003) and BRT (*r*=0.31, *p*=0.013) outcomes. Increased trunk extension strength was correlated with better 6MWT (*r*=0.35, *p*=0.004), SRT (*r*=0.38, *p*=0.002) and BBS (*r*=0.25, *p*=0.042) outcomes. Similarly, lateral flexion strength was associated with improved 6MWT (*r*=0.33, *p*=0.007), CST (*r*=0.32, *p*=0.010), SRT (*r*=0.40, *p*=0.001), BBS (*r*=0.32, *p*=0.007), FRT (*r*=0.32, *p*=0.008), BRT (*r*=0.25, *p*=0.025) and, LRT (*r*=0.28, *p*=0.020) outcomes. Composite trunk strength was associated with improved 6MWT (*r*=0.35, *p*=0.004), CST (*r*=0.30, *p*=0.016), SRT (*r*=0.40, *p*=0.001), BBS (*r*=0.29, *p*=0.017), FRT (*r*=0.36, *p*=0.003), and BRT (*r*=0.28, *p*=0.021) outcomes.

Univariate associations between trunk muscle morphology and strength

Table 4 includes the results of the univariate analysis. Larger TLAM thickness was associated with increased trunk flexion (*r*=0.70, *p*<0.001), extension (*r*=0.38, *p*=0.002), lateral flexion (*r*=0.42, *p*=0.001), and composite trunk strength (*r*=0.60, *p*<0.001). Larger RA CSA was associated with increased trunk flexion strength (*r*=0.80, *p*<0.001), extension strength (*r*=0.51, *p*<0.001), lateral flexion strength (*r*=0.46, *p*<0.001), as well as the composite trunk strength measure (*r*=071, *p*<0.001). LM-L4/L5 thickness was positively correlated with trunk flexion strength (*r*=0.27, *p*=0.026). Composite trunk muscles size was positively correlated with trunk flexion (*r*=0.54, *p*<0.001), extension (*r*=0.33, *p*=0.006), and composite trunk strength (*r*=0.42, *p*<0.001).

Univariate associations between descriptive characteristics (age, sex and BMI), trunk muscle morphology, trunk muscle strength, and functional outcome measures

Table 2 includes the results of the univariate analysis. Older age was negatively associated with 6MWT (r=-0.67, p<0.001), CST (r=-0.48, p<0.001, SRT (r=-0.59, p<0.001, BBS (r=-0.71, p<0.001), FRT (r=-0.43, p<0.001), RRT (r=-0.44, p<0.001) and LRT (r=-0.43, p<0.001) outcomes. Older age was associated with slower speed in TUG (r=0.75, p<0.001) and FSST (r=0.52, p<0.001). Sex was positively associated with 6MWT (r=0.33, p=0.006), SRT (r=0.32, p=0.010) and BRT (r=0.34, p=0.005) outcomes. A higher BMI was associated with reduced performance in the SRT (r=-0.33, p=0.009).

Table 2 includes the results of the univariate analysis. Older age was negatively associated with right TLAM thickness (r=-0.25, p=0.042) and RA CSA (r=-0.28, p=0.023). Males had larger TLAM (mean right and left) (r=0.48, p<0.001), LM-L4/L5 (r=0.29, p=0.020), composite trunk muscle size (r=0.46, p<0.001) and RA CSA (r=0.73, p<0.001), than females. A higher BMI was positively associated with TLAM (mean right and left) (r=0.49, p<0.001), LM-L4/L5 (r=0.41, p=0.001), LM-L5/S1 (r=0.40, p=0.001), composite trunk muscle thickness (r=0.52, p<0.001) and RA CSA (r=0.37, p=0.002).

Table 3 includes the results of the univariate analysis. Older age was negatively associated with lateral flexion strength (r=-0.27, p=0.019) and composite trunk strength (r=-0.28, p=0.022). Males had greater trunk flexion (r=0.67, p<0.001), extension (r=0.64, p<0.001), lateral flexion strength (r=0.48, p<0.001) and composite trunk strength (*r*=0.71, *p*<0.001), than females. A higher BMI was positively associated with trunk flexion strength (r=0.47, *p*<0.001).

Multivariate associations between trunk muscle morphology and functional outcome measures

Table 5 includes the results of the multivariate analysis. After controlling for age and sex, RA CSA was associated with 6MWT (*β*=-0.27; *p*=0.050) outcome, while RA CSA was associated with SRT (β=0.33; *p*<0.001) outcome, after controlling for age and BMI. RA CSA was also associated with with BRT (*β*=0.43; *p*=0.013) outcome, after controlling for sex. LM-L4/L5 thickness, after controlling for age, was associated with FSST (*β*=0.21; *p*=0.048) outcome.

RA CSA was associated with BRT (*β*=0.45; *p*<0.001) outcome, while LM-L5/S1 thickness was associated with TUG (*β*=0.26, *p*=0.037) outcome and LM-L4/L5 thickness was associated with FSST (β=0.25, *p*=0.043) outcome.

Multivariate associations between trunk muscle strength and functional outcome measures

Table 6 includes the results of the multivariate analysis. After controlling for age, trunk flexion strength was associated with with FRT (*β*= 0.27; *p*=0.01) outcome, while composite trunk strength was associated with SRT (*β*=0.34; *p*<0.001) outcome, after controlling for age and BMI.

Trunk flexion strength was associated with FRT (*β*=0.36; *p*=0.003) and BRT (*β*=0.31; *p*= *p*=0.013) outcomes, while trunk extension strength was associated with 6MWT (*β*=0.35; *p*=0.004) outcome. Trunk right lateral flexion strength was associated with BBS (*β*=0.33; *p*=0.007) outcome, trunk left lateral flexion strength was associated with LRT (*β*=0.30; *p*=0.016) outcome and trunk lateral flexion strength (mean right/left) was associated with CST (*β*=0.32; *p*=0.008) outcome. Composite trunk strength was associated with SRT (*β*=0.40; *p*=0.001) outcome.

Multivariate associations between trunk muscle morphology and strength

Table 7 includes the results of the multivariate analysis. After controlling for sex, RA CSA was associated with trunk flexion strength (*β*=0.45; *p*=0.001), while RA CSA was associated with composite trunk strength (*β*=0.34; *p*=0.007) after controlling for age and sex. TLAM (mean right and left) thickness, after controlling for sex, was associated with trunk flexion strength (*β*=0.29; *p*=0.003).

RA CSA was associated with trunk flexion (*β*=0.60; *p*<0.001), extension (*β*=0.52; *p*<0.001), lateral flexion (mean right/left) (*β*=0.46; *p*<0.001) and composite trunk strength (*β*=0.56; *p*<0.001). TLAM thickness was associated with trunk flexion strength (*β*=0.28; *p*=0.005).

Discussion

This study aimed to identify the associations between trunk muscle morphology, strength, and functional ability in healthy older adults. The most important outcomes of this study were that: i) univariate analyses revealed small-moderate positive correlations between trunk muscle morphology, strength, and various functional outcome measures. More specifically, larger RA CSA was most consistently associated with better 6MWT, FRT, BRT, CST, and SRT outcomes. LM thickness was associated with better TUG and FSST outcomes, while TLAM thickness and composite trunk muscle size were associated with better BRT outcome. Increased composite trunk strength was consistently associated with better 6MWT, CST, SRT, BBS, FRT, and BRT outcomes. TLAM thickness and RA CSA were consistently and positively associated with all trunk muscle strength measures (flexion, extension, lateral flexion, and composite trunk strength). LM thickness was positively associated with trunk flexion strength, while composite trunk muscle size was positively associated with flexion, extension, and composite trunk strength. ii) After controlling for covariates (age, sex, and /or BMI), multivariate analyses revealed larger RA CSA was associated with lower 6MWT outcome, while larger RA CSA was associated with better SRT, and BRT outcomes. LM thickness was associated with better FSST outcome. Trunk flexion strength was associated with better FRT outcome, while composite trunk strength was associated with better SRT outcome. RA CSA was positively associated with trunk flexion and composite trunk strength, while TLAM thickness was positively associated with trunk flexion strength. iii) In addition to the above main findings, age, sex, and /or BMI had strong influences on performance in various functional tasks.

In the present study, we found that RA CSA (β = 0.33; Table 5) was retained in the model (R^2 = 0.60) for SRT outcome, along with age and BMI. At present, only one previous cross-sectional study conducted by Hicks et al [11] has explored the relationship between trunk muscle morphology (lumbar paraspinal, lateral abdominal, and rectus abdominis muscles) and performance on functional tasks. Similar to the findings of the present study, Hicks et al [11] found that after controlling for covariates (age, sex, race, height, total body fat and thigh muscle composition), the average trunk muscle area was not associated (All $p>0.10$) with performance in the Health ABC Physical Performance Battery (usual and narrow walk, chair stands, and standing balance) in healthy older adults (70-79 y.o.). However, Hicks et al [11] also revealed that higher fat infiltration, measured by reduced muscle attenuation in Computed Tomography (CT) images, was significantly and negatively associated with performance in the Health ABC Physical Performance Battery ($p<0.05$), explaining about 13% of the variance in performance, while thigh muscle attenuation explained only 5.5% of the variance. In other words, Hicks et al [11] indicated that fat infiltration in trunk muscles (a measure of muscle quality) was predictive of functional performance in older adults, while trunk muscle morphology explained little of the observed variance in performance in these functional tasks.

Second, composite trunk strength ($\beta = 0.34$; Table 6) was retained in the model ($R^2 = 0.60$) for the SRT, along with age and BMI. The associations between trunk muscle strength and functional tasks (BBS and TUG) have previously been explored in two studies [7, 10]. First, Suri et al [10] investigated associations between trunk muscle strength/endurance and mobility/balance in healthy older adults with mobility limitations. The authors [10] identified that isometric trunk extension strength was moderately correlated with the BBS ($r = 0.41$, $p<0.05$), and this is consistent with our findings ($r=0.25$, $p<0.05$). Additionally, Granacher et al [7] reported no significant correlations between measures of trunk muscle strength (i.e., flexion, extension, lateral flexion, rotation) and performance on the TUG. Similarly, the findings in the current study indicated that there were no correlations between all trunk muscle strength measures (flexion, extension, lateral flexion, and composite trunk strength) and TUG (All p>0.1).

In addition to the findings above, this study demonstrated strong positive correlations between trunk muscle morphology (size) and trunk muscle strength (Table 4). Specifically, RA CSA (β = 0.45; Table 7) was retained in the model (R^2 = 0.70) for trunk flexion strength, along with sex. TLAM thickness (β = 0.29; Table 7) was retained in the model (R^2 = 0.70) for trunk flexion strength, along with sex. RA CSA (β = 0.34; Table 7) was retained in the model (R^2 = 0.58) for composite trunk strength, along with age and sex. The results of the current study are in line with the findings of Andersen et al. [32], who examined the association between CT (trunk muscle cross-sectional area; attenuation) and trunk strength in older adults (≥65 y.o.). Andersen et al. [32] demonstrated that trunk muscle attenuation was associated with absolute strength, however, the association between trunk muscle cross-sectional area and absolute strength was stronger across all studied muscles (anterior abdominal muscles; posterior abdominal muscles; paraspinal muscles; combined). Generally, these are consistent with the role abdominal muscles play in providing stability in the trunk region [33] and not specifically as a prime mover.

The finding that age and sex strongly correlate with trunk muscle morphology and strength (Tables 2 and 3) is also consistent with previous studies [32, 34, 35]. It has been previously established that age-related declines in muscle morphology and strength indicate impaired physical function and increased risk of disability and injury in older adults [1, 6, 36], however, these findings were based on measures of peripheral musculature. Subsequently, additional studies have identified the importance of trunk muscle morphology and strength with function in cohorts with similar age ranges [7, 10, 11, 32]. In summary, these studies suggested that there are low but significant associations between trunk muscle morphology and strength with balance and functional performance among older adults. The findings of these cross-sectional studies may be important for the identification of trunk muscle exercise-components, which can be included into an exercise program aiming to improve balance and functional performance in older adults.

The study presented herein had several strengths, including i) this was the first study that comprehensively examined the associations of trunk muscle morphology, strength, and functional ability in healthy older adults; ii) the maximum isometric trunk torque (Nm) data was normalised by adjusting for trunk height (cm) which served as the surrogate measures for the moment arm, therefore providing greater confidence when comparing across study participants in this cohort [37, 38].

This study was limited by several factors. While the number of participants (n=64) was sufficient to conduct the specific analyses, the number of predictor variables we were able to enter in the models (i.e., multivariate linear regression) was limited. Secondly, the participants in this study were healthy and moderately active older adults. Therefore, the results may not generalize to other populations (e.g., sedentary, overweight/obese, frail/at high risk of falls older individuals, frail older individuals at high risk of falls, neuromuscular, mobility/balance limited patients). Additionally, the results are specific to the testing methodology used to assess trunk muscle morphology, strength and functional ability in the current study. Furthermore, the outcome measures may not represent all components of trunk muscle morphology, strength, mobility, and balance. Likewise, although ultrasound imaging is a reliable and valid technique to assess trunk muscle morphology, it may not accurately capture important intrinsic changes in muscle quality (e.g. intermuscular fat infiltration) and muscle volume that accompany aging. Finally, this study utilized a cross-sectional study design, and thus the findings of this study do not reflect longitudinal changes in trunk muscle morphology, strength muscle and functional ability in older adults as a result of potential factors such as aging, lack of physical activity, special exercise training and detraining.

In summary, this study provides valuable insight into the relationships between trunk muscle morphology (size), strength, and functional ability. Specifically our findings demonstrated that trunk muscle morphology and strength appeared to play important roles in functional performance, albeit that strength demonstrates more robust associations with functional ability. The findings of the current study demonstrate a potentially important role for training the trunk musculature in older adults.

Acknowledgements

The authors would like to thank Dr Golnaz Shahtahmassebi for her statistical advice.

Disclosure Statement

The authors have no conflicts of interest that are directly relevant to the content of this study.

Table 1. Descriptive characteristics (n=64)

Characteristics	Measure
Age (years)	69.8 (7.5)
Sex n (%) female	38 (59.4)
Body mass index (kg/m^2)	27.3 (4.7)
History of falls over past 12 months	
No falls	82%
Falls	18%
Self-reported physical activity	
Moderately active (exercise training one or twice per week)	53.1%
Very active (exercise training 3x times per week)	43.8%
Not very active (rarely leaves house)	3.1%
Right total lateral abdominal muscles, cm	1.6 (0.45)
Left total lateral abdominal muscles, cm	1.6 (0.39)
Total lateral abdominal muscles (mean right/left), cm	1.6 (0.41)
Rectus abdominis, cm^2	4.1 (1.41)
Lumbar multifidus L4/L5, cm	3.1 (0.45)
Lumbar multifidus L5/S1, cm	3.0 (0.49)
Composite trunk muscle size, cm	8.5 (1.16)
Trunk flexion strength, N	125.0
Trunk extension strength, N	89.4 (44.9)
Trunk right lateral flexion strength, N	65.7 (29.6)
Trunk left lateral flexion strength, N	57.3 (26.0)
Trunk lateral flexion strength (mean right/left), N	61.5 (26.5)
Composite trunk strength	337.5
Six Minute Walk Test, m	559.8
30-Second Chair Stand Test, reps	16.2 (4.4)
Sitting and Rising Test, points	5.7 (2.1)
Berg Balance Scale	52.0 (4.5)
Forward Reach Test, cm	28.2 (4.8)
Backward Reach Test, cm	16.0 (3.6)
Right Reach Test, cm	19.5 (4.9)
Left Reach Test, cm	19.0 (4.6)
Timed Up and Go Test, s	7.4 (1.9)
Four Step Square Test, s	8.3 (1.6)

Values are presented as mean (standard deviation; SD) or as number and percentages
L4/L5 lumbar spinal level L4/L5***, L5/S1*** lumbar spinal level L5/S1, ***reps*** repetitions

Table 2. Univariate analysis of associations between functional measures, descriptive characteristics (age, sex and BMI) and trunk muscle morphology

	Age, y	**Sex**	**BMI (kg/m^2)**	**Rectus abdominis , cm^2**	**Lumbar multifidus, cm**		**Total lateral abdominal muscles, cm**			**Composite trunk muscle size, cm**
				CSA	**L4/L5**	**L5/S1**	**Right**	**Left**	**Mean**	
Six Minute Walk Test, m	**-0.67** **(<0.001)**	**0.33** **(0.006)**	-0.20 (0.101)	**0.27** **(0.029)**	-0.05 (0.682)	-0.10 (0.431)	0.23 (0.057)	0.16 (0.195)	0.21 (0.093)	0.06 (0.616)
30-Second Chair Stand Test, reps	**-0.48** **(<0.001)**	0.20 (0.107)	-0.12 (0.321)	**0.33** **(0.007)**	-0.22 (0.076)	-0.22 (0.071)	0.23 (0.062)	0.15 (0.227)	0.20 (0.106)	-0.07 (0.558)
Sitting and Rising Test, points	**-0.59** **(<0.001)**	**0.32** **(0.010)**	**-0.33** **(0.009)**	**0.29** **(0.018)**	-0.14 (0.266)	-0.20 (0.104)	0.20 (0.109)	0.15 (0.229)	0.18 (0.143)	-0.02 (0.848)
Berg Balance Scale	**-0.71** **(<0.001)**	0.12 (0.341)	-0.13 (0.272)	0.20 (0.105)	-0.19 (0.118)	-0.21 (0.091)	0.23 (0.067)	0.18 (0.141)	0.21 (0.085)	-0.04 (0.699)
Forward Reach Test, cm	**-0.43** **(<0.001)**	0.14 (0.265)	0.10 (0.403)	**0.30** **(0.014)**	-0.03 (0.797)	-0.00 (0.989)	0.24 (0.051)	0.14 (0.240)	0.20 (0.100)	0.09 (0.455)
Backward Reach Test, cm	-0.16 (0.188)	**0.34** **(0.005)**	0.13 (0.292)	**0.45** **(<0.001)**	0.15 (0.216)	0.15 (0.221)	**0.42** **(<0.001)**	**0.41** **(0.001)**	**0.43** **(<0.001)**	**0.33** **(0.007)**
Right Reach Test, cm	**-0.44** **(<0.001)**	0.17 (0.357)	-0.008 (0.947)	0.14 (0.250)	0.01 (0.921)	0.03 (0.782)	0.22 (0.080)	0.14 0.250	0.19 (0.128)	(0.09) (0.468)
Left Reach Test, cm	**-0.43** **(<0.001)**	0.10 (0.424)	0.01 (0.903)	0.13 (0.285)	0.05 (0.683)	0.03 (0.780)	0.165 (0.194)	0.12 (0.325)	0.15 (0.233)	0.09 (0.478)
Timed Up and Go Test, s	**0.75** **(<0.001)**	-0.08 (0.512)	0.10 (0.431)	-0.14 (0.248)	0.24 (0.055)	**0.26** **(0.037)**	-0.17 (0.169)	-0.16 (0.184)	-0.17 (0.162)	0.12 (0.342)
Four Step Square Test, s	**0.52** **(<0.001)**	0.03 (0.805)	0.11 (0.355)	-0.05 (0.694)	**0.25** **(0.043)**	**0.24** **(0.048)**	-0.10 (0.411)	-0.06 (0.595)	-0.09 (0.478)	0.14 (0.247)
Age, y	-	-	-	**-0.28** **(0.023)**	0.08 (0.527)	0.14 (0.244)	**-0.25** **(0.042)**	-0.21 (0.087)	-0.24 (0.051)	-0.02 (0.819)
Sex	-	-	-	**0.73** **(<0.001)**	**0.29** **(0.020)**	0.20 (0.101)	**0.46** **(<0.001)**	**0.47** **(<0.001)**	**0.48** **(<0.001)**	**0.46** **(<0.001)**
BMI (kg/m^2)	-	-	-	**0.37** **(0.002)**	**0.41** **(0.001)**	**0.40** **(0.001)**	**0.44** **(<0.001)**	**0.51** **(<0.001)**	**0.49** **(<0.001)**	**0.52** **(<0.001)**

Values are presented are Pearson correlation coefficients, except sex was presented by point biserial correlation (exact *p* values)
Bolded estimates are statistically significant at $p \leq 0.05$ and $p \leq 0.01$
BMI body mass index, ***CSA*** cross sectional area, ***L4/L5*** lumbar spinal level L4/L5, ***L5/S1*** lumbar spinal level L5/S1, ***Composite trunk muscle size*** comprised the thickness of bilateral lateral abdominal muscles, rectus abdominis, lumbar multifidus L4/L5, lumbar multifidus L4/L5, ***n*** number of participants, ***reps*** repetitions, ***s*** seconds

Table 3. Univariate analysis of associations between functional measures, descriptive characteristics (age, sex and BMI) and trunk muscle strength

	Trunk strength, N		Trunk Lateral Flexion strength, N			Composite trunk strength, N
	Flexion	Extension	Right	Left	Mean	
Six Minute Walk Test, m	0.23 (0.059)	**0.35 (0.004)**	**0.29 (0.018)**	**0.28 (0.025)**	**0.33 (0.007)**	**0.35 (0.004)**
30-Second Chair Stand Test, reps	0.19 (0.128)	0.22 (0.072)	**0.30 (0.016)**	**0.32 (0.009)**	**0.32 (0.010)**	**0.30 (0.016)**
Sitting and Rising Test, points	0.22 (0.076)	**0.38 (0.002)**	**0.40 (0.001)**	**0.33 (0.007)**	**0.40 (0.001)**	**0.40 (0.001)**
Berg Balance Scale	0.17 (0.175)	**0.25 (0.042)**	**0.33 (0.007)**	**0.27 (0.030)**	**0.32 (0.007)**	**0.29 (0.017)**
Forward Reach Test, cm	**0.36 (0.003)**	0.24 (0.056)	**0.28 (0.022)**	**0.31 (0.013)**	**0.32 (0.008)**	**0.36 (0.003)**
Backward Reach Test, cm	**0.31 (0.013)**	0.14 (0.268)	**0.26 (0.038)**	0.23 (0.068)	**0.25 (0.025)**	**0.28 (0.021)**
Right Reach Test, cm	0.167 (0.187)	0.14 (0.261)	0.145 (0.251)	0.191 (0.130)	0.192 (0.129)	0.194 (0.124)
Left Reach Test, cm	0.18 (0.147)	0.10 (0.398)	**0.25 (0.045)**	**0.30 (0.016)**	**0.28 (0.020)**	0.23 (0.060)
Timed Up and Go Test, s	-0.14 (0.248)	-0.14 (0.268)	-0.17 (0.169)	-0.18 (0.148)	-0.19 (0.127)	-0.19 (0.132)
Four Step Square Test, s	-0.06 (0.621)	0.004 (0.973)	-0.22 (0.070)	-0.13 (0.290)	-0.19 (0.133)	-0.10 (0.402)
Age, y	-0.24 (0.056)	-0.20 (0.111)	**-0.27 (0.027)**	-0.24 (0.057)	**-0.27 (0.019)**	**-0.28 (0.022)**
Sex	**0.67 (<0.001)**	**0.64 (<0.001)**	**0.44 (<0.001)**	**0.48 (<0.001)**	**0.48 (<0.001)**	**0.71 (<0.001)**
BMI (kg/m^2)	**0.47 (<0.001)**	0.004 (0.974)	0.06 (0.622)	0.08 (0.499)	0.07 (0.509)	0.22 (0.070)

Values are presented are Pearson correlation coefficients, except sex was presented by point biserial correlation (exact *p* values)
Bolded estimates are statistically significant at ***p* ≤ 0.05** and ***p* ≤ 0.01**
BMI body mass index, ***Composite trunk strength*** comprised trunk strength flexion, extension and lateral flexion (the average of right and left)

Table 4. Univariate analysis of associations between trunk muscle morphology and strength

	Rectus abdominis, cm^2	Lumbar multifidus, cm		Total lateral abdominal muscles, cm			Composite trunk muscle size, cm
	CSA	L4/L5	L5/S1	Right	Left	Mean	
Trunk flexion strength, N	**0.80 (<0.001)**	**0.27 (0.026)**	0.21 (0.086)	**0.68 (<0.001)**	**0.68 (<0.001)**	**0.70 (<0.001)**	**0.54 (<0.001)**
Trunk extension strength, N	**0.51 (<0.001)**	0.20 (0.106)	0.13 (0.284)	**0.40 (0.001)**	**0.33 (0.007)**	**0.38 (0.002)**	**0.33 (0.006)**
Trunk right lateral flexion strength, N	**0.44 (<0.001)**	-0.01 (0.884)	-.060 (0.637)	**0.38 (0.002)**	**0.41 (0.001)**	**0.41 (0.001)**	0.17 (0.164)
Trunk left lateral flexion strength, N	**0.44 (<0.001)**	-0.00 (0.988)	-0.04 (0.700)	**0.37 (0.002)**	**0.38 (0.002)**	**0.39 (0.001)**	0.18 (0.152)
Trunk lateral flexion strength (mean right/left), N	**0.46 (<0.001)**	-0.01 (0.929)	-0.05 (0.651)	**0.40 (0.001)**	**0.41 (0.001)**	**0.42 (0.001)**	0.18 (0.138)
Composite trunk strength, N	**0.71 (<0.001)**	0.18 (0.148)	0.11 (0.374)	**0.59 (<0.001)**	**0.58 (<0.001)**	**0.60 (<0.001)**	**0.42 (<0.001)**

Values are presented are Pearson correlation coefficients (exact *p* values)
Bolded estimates are statistically significant at $p \leq 0.05$ and $p \leq 0.01$
BMI body mass index, ***CSA*** cross sectional area**,** ***Composite trunk muscle size*** comprised the thickness of bilateral lateral abdominal muscles, rectus abdominis, lumbar multifidus L4/L5, lumbar multifidus L5/S1, ***Composite trunk strength*** comprised trunk strength flexion, extension and lateral flexion (the average of right and left), ***n*** number of participants, ***N*** newton

Table 5. Multiple linear regression analysis of the relationship between trunk muscle morphology and functional measures

Variable		**Adjusted R^2**	**R^2 change significance**	**Standardised β coefficient**	**β coefficient significance**
Six Minute Walk Test, m					
Model	Age Sex Rectus abdominis CSA, cm^2	0.53	<0.001	-0.70 0.46 -0.27	<0.001 <0.001 0.050
30-Second Chair Stand Test, sec					
Model	Age Rectus abdominis CSA, cm^2	0.25	<0.001	-0.42 0.21	<0.001 0.064
Sitting and Rising Test, points					
Model	Age BMI Rectus abdominis CSA, cm^2	0.60	<0.001	-0.57 -0.52 0.33	<0.001 <0.001 <0.001
Forward Reach Test, cm					
Model	Age Rectus abdominis CSA, cm^2	0.20	<0.001	-0.38 0.20	0.002 0.099
Backward Reach Test, cm					
Model 1	Rectus abdominis CSA, cm^2	0.19	<0.001	0.45	<0.001
Model 2	Sex Rectus abdominis CSA, cm^2	0.18	0.001	0.03 0.43	0.857 0.013
Timed Up and Go Test, cm					
Model 1	Lumbar multifidus L5/S1, cm	0.05	0.037	0.26	0.037
Model 2	Age Lumbar multifidus L5/S1, cm	0.58	<0.001	0.58	<0.001 0.068
Four Step Square Test, cm					
Model 1	Lumbar multifidus L4/L5, cm	0.04	0.043	0.25	0.043
Model 2	Age Lumbar multifidus L4/L5, cm	0.30	<0.001	0.50 0.21	<0.001 0.048

Levels of significance are at $\boldsymbol{p \leq 0.05}$ and $\boldsymbol{p \leq 0.01}$

BMI body mass index, ***CSA*** cross sectional area, ***L4/L5*** lumbar spinal level L4/L5, ***L5/S1*** lumbar spinal level L5/S1, ***n*** number of participants, ***reps*** repetitions, ***s*** seconds

Table 6. Multiple linear regression analysis of the relationship between trunk muscle strength and functional measures

Variable		Adjusted R^2	R^2 change significance	Standardised β coefficient	β coefficient significance
Six Minute Walk Test, m					
Model 1	Trunk extension strength, N	0.113	0.004	0.35	0.004
Model 2	Age Sex Trunk extension strength, N	0.508	<0.001	-0.63 0.21 0.08	<0.001 0.063 0.449
30-Second Chair Stand Test, reps					
Model 1	Trunk lateral flexion strength (mean right/left), N	0.09	0.008	0.32	0.008
Model 2	Age Trunk lateral flexion strength (mean right/left), N	0.25	<0.001	-0.42 0.21	<0.001 0.066
Sitting and Rising Test, points					
Model 1	Composite trunk strength, N	0.14	0.001	0.40	0.001
Model 2	Age BMI Composite trunk strength, N	0.60	<0.001	-0.56 -0.47 0.34	<0.001 <0.001 <0.001
Berg Balance Scale, cm					
Model 1	Trunk right lateral flexion strength, N	0.09	0.007	0.33	0.007
Model 2	Age Trunk right lateral flexion strength, N	0.52	<0.001	-0.67 0.14	<0.001 0.112
Forward Reach Test, cm					
Model 1	Trunk flexion strength, N	0.11	0.003	0.36	0.003
Model 2	Age Trunk flexion strength, N	0.23	<0.001	-0.37 0.27	0.002 0.01
Backward Reach Test, cm					
Model 1	Trunk flexion strength, N	0.08	0.013	0.31	0.013
Model 2	Sex Trunk flexion strength, N	0.10	0.014	0.25 0.13	0.121 0.396

Table 6 continued

Variable		Adjusted R^2	R^2 change significance	Standardised β coefficient	β coefficient significance
Left Reach Test, cm					
Model 1	Trunk left lateral flexion strength, N	0.07	0.016	0.30	0.016
Model 2	Age Trunk left lateral flexion strength, N	0.20	<0.001	-0.38 0.20	0.002 0.077

The levels of significance are set at $\boldsymbol{p \leq 0.05}$ and $\boldsymbol{p \leq 0.01}$
BMI body mass index, ***Composite trunk strength*** comprised trunk strength flexion, extension and lateral flexion (the average of right and left)**,** ***n*** number of participants, ***N*** newton, ***reps*** repetitions

Table 7. Multiple linear regression analysis of the relationship between trunk muscle morphology and strength

Variable		**Adjusted R^2**	**R^2 change significance**	**Standardised β coefficient**	**β coefficient significance**
Trunk flexion strength, N					
Model 1	Rectus abdominis CSA, cm^2 Total lateral abdominal muscles (mean right/left), cm	0.68	<0.001	0.60 0.28	<0.001 0.005
Model 2	Sex Rectus abdominis CSA, cm^2 Total lateral abdominal muscles (mean right/left), cm	0.70	<0.001	0.19 0.45 0.29	0.060 0.001 0.003
Trunk extension strength, N					
Model 1	Rectus abdominis CSA, cm^2	0.25	<0.001	0.52	<0.001
Model 2	Sex Rectus abdominis CSA, cm^2	0.40	<0.001	0.56 0.10	<0.001 0.469
Trunk right lateral flexion strength, N					
Model 1	Rectus abdominis CSA, cm^2	0.18	<0.001	0.44	<0.001
Model 2	Age Sex Rectus abdominis CSA, cm^2	0.18	<0.001	-0.19 0.29 0.17	0.096 0.082 0.326
Trunk left lateral flexion strength, N					
Model 1	Rectus abdominis CSA, cm^2	0.18	<0.001	0.44	<0.001
Model 2	Sex Rectus abdominis CSA, cm^2	0.22	<0.001	0.35 0.18	0.035 0.264
Trunk lateral flexion strength (mean right/left), N					
Model 1	Rectus abdominis CSA, cm^2	0.20	<0.001	0.46	<0.001
Model 2	Sex Age Rectus abdominis CSA, cm^2	0.25	<0.001	0.35 -0.19 0.14	0.032 0.096 0.383

Table 7 continued

Variable		**Adjusted R^2**	**R^2 change significance**	**Standardised *β* coefficient**	***β* coefficient significance**
Composite trunk strength, N					
Model 1	Rectus abdominis CSA, cm^2	0.52	<0.001	0.56	<0.001
	Total lateral abdominal muscles (mean right/left), cm			0.21	0.079
Model 2	Age	0.58	<0.001	-0.14	0.100
	Sex			0.44	0.001
	Rectus abdominis CSA, cm^2			0.34	0.007

The levels of significance are set at $\boldsymbol{p \le 0.05}$ and $\boldsymbol{p \le 0.01}$
BMI body mass index, ***CSA*** cross sectional area, ***Composite trunk strength*** comprised trunk strength flexion, extension and lateral flexion (the average of right and left), ***n*** number of participants, ***N*** newton

References

1. Goodpaster, B.H., et al., *The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study.* J Gerontol A Biol Sci Med Sci, 2006. **61**(10): p. 1059-64.

2. Metter, E.J., et al., *Age-associated loss of power and strength in the upper extremities in women and men.* J Gerontol A Biol Sci Med Sci, 1997. **52**(5): p. B267-76.

3. Heathcote, G., *Autonomy, health and ageing: transnational perspectives.* Health Educ Res, 2000. **15**(1): p. 13-24.

4. Kasukawa, Y., et al., *Relationships between falls, spinal curvature, spinal mobility and back extensor strength in elderly people.* J Bone Miner Metab, 2010. **28**(1): p. 82-7.

5. Sartini, M., et al., *The epidemiology of domestic injurious falls in a community dwelling elderly population: an outgrowing economic burden.* Eur J Public Health, 2010. **20**(5): p. 604-6.

6. Martien, S., et al., *Is knee extension strength a better predictor of functional performance than handgrip strength among older adults in three different settings?* Arch Gerontol Geriatr, 2015. **60**(2): p. 252-8.

7. Granacher, U., et al., *Relationships between trunk muscle strength, spinal mobility, and balance performance in older adults.* J Aging Phys Act, 2014. **22**(4): p. 490-8.

8. Pfeifer, M., et al., *Vitamin D status, trunk muscle strength, body sway, falls, and fractures among 237 postmenopausal women with osteoporosis.* Exp Clin Endocrinol Diabetes, 2001. **109**(2): p. 87-92.

9. Sakari-Rantala, R., et al., *Associations of sensory-motor functions with poor mobility in 75- and 80-year-old people.* Scand J Rehabil Med, 1998. **30**(2): p. 121-7.

10. Suri, P., et al., *Trunk muscle attributes are associated with balance and mobility in older adults: a pilot study.* PM R, 2009. **1**(10): p. 916-24.

11. Hicks, G.E., et al., *Cross-sectional associations between trunk muscle composition, back pain, and physical function in the health, aging and body composition study.* J Gerontol A Biol Sci Med Sci, 2005. **60**(7): p. 882-7.

12. Granacher, U., et al., *The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: a systematic review.* Sports Med, 2013. **43**(7): p. 627-41.

13. Lipkin, D.P., et al., *Six minute walking test for assessing exercise capacity in chronic heart failure.* Br Med J (Clin Res Ed), 1986. **292**(6521): p. 653-5.

14. Jones, C.J., R.E. Rikli, and W.C. Beam, *A 30-s chair-stand test as a measure of lower body strength in community-residing older adults.* Res Q Exerc Sport, 1999. **70**(2): p. 113-9.

15. Brito, L.B.B.d., et al., *Ability to sit and rise from the floor as a predictor of all-cause mortality.* Eur J Prev Cardiol, 2014. **21**(7): p. 892-8.

16. Makizako, H., et al., *Cognitive functioning and walking speed in older adults as predictors of limitations in self-reported instrumental activity of daily living: prospective findings from the Obu Study of Health Promotion for the Elderly.* Int J Env Res Pub He, 2015. **12**(3): p. 3002-3013.

17. Enright, P.L., et al., *The 6-min walk test: a quick measure of functional status in elderly adults.* Chest, 2003. **123**(2): p. 387-98.

18. Berg, K.O., et al., *Measuring balance in the elderly: validation of an instrument.* Can J Public Health, 1992. **83 Suppl 2**: p. S7-11.

19. Newton, R.A., *Validity of the multi-directional reach test: a practical measure for limits of stability in older adults.* J Gerontol A Biol Sci Med Sci, 2001. **56**(4): p. M248-52.

20. Podsiadlo, D. and S. Richardson, *The timed "Up & Go": a test of basic functional mobility for frail elderly persons.* J Am Geriatr Soc, 1991. **39**(2): p. 142-8.

21. Dite, W. and V.A. Temple, *A clinical test of stepping and change of direction to identify multiple falling older adults.* Arch Phys Med Rehabil, 2002. **83**(11): p. 1566-71.

22. Donoghue, D. and E.K. Stokes, *How much change is true change? The minimum detectable change of the Berg Balance Scale in elderly people.* J Rehabil Med, 2009. **41**(5): p. 343-6.

23. Duncan, P.W., et al., *Functional reach: predictive validity in a sample of elderly male veterans.* J Gerontol, 1992. **47**(3): p. M93-8.

24. Sions, J.M., et al., *Ultrasound imaging: intraexaminer and interexaminer reliability for multifidus muscle thickness assessment in adults aged 60 to 85 years versus younger adults.* J Orthop Sports Phys Ther, 2014. **44**(6): p. 425-34.

25. Stetts, D.M., et al., *A rehabilitative ultrasound imaging investigation of lateral abdominal muscle thickness in healthy aging adults.* J Geriatr Phys Ther, 2009. **32**(2): p. 60-6.

26. Koppenhaver, S.L., et al., *Reliability of rehabilitative ultrasound imaging of the transversus abdominis and lumbar multifidus muscles.* Arch Phys Med Rehabil, 2009. **90**(1): p. 87-94.

27. Teyhen, D.S., et al., *Rehabilitative ultrasound imaging of the abdominal muscles.* J Orthop Sports Phys Ther, 2007. **37**(8): p. 450-66.

28. Kienbacher, T., et al., *Reliability of isometric trunk moment measurements in healthy persons over 50 years of age.* J Rehabil Med, 2014. **46**(3): p. 241-9.

29. Guilhem, G., et al., *Validity of trunk extensor and flexor torque measurements using isokinetic dynamometry.* J Electromyogr Kinesiol, 2014. **24**(6): p. 986-93.

30. Karatas, G.K., F. Gogus, and J. Meray, *Reliability of isokinetic trunk muscle strength measurement.* Am J Phys Med Rehabil, 2002. **81**(2): p. 79-85.

31. Van Damme, B.B.L., et al., *Velocity of isokinetic trunk exercises influences back muscle recruitment patterns in healthy subjects.* J Electromyogr Kinesiol, 2013. **23**(2): p. 378-86.

32. Anderson, D.E., et al., *Computed tomography-based muscle attenuation and electrical impedance myography as indicators of trunk muscle strength independent of muscle size in older adults.* Am J Phys Med Rehabil, 2014. **93**(7): p. 553-61.

33. Cholewicki, J., K. Juluru, and S.M. McGill, *Intra-abdominal pressure mechanism for stabilizing the lumbar spine.* J Biomech, 1999. **32**(1): p. 13-7.

34. Anderson, D.E., et al., *Variations of CT-based trunk muscle attenuation by age, sex, and specific muscle.* J Gerontol A Biol Sci Med Sci, 2013. **68**(3): p. 317-23.

35. Singh, D.K., M. Bailey, and R. Lee, *Decline in lumbar extensor muscle strength the older adults: correlation with age, gender and spine morphology.* BMC Musculoskelet Disord, 2013. **14**: p. 215.

36. Clark, B.C. and T.M. Manini, *What is dynapenia?* Nutrition, 2012. **28**(5): p. 495-503.

37. Kocjan, A. and N. Sarabon, *Assessment of isometric trunk strength - the relevance of body position and relationship between planes of movement.* J Sports Sci Med, 2014. **13**(2): p. 365-70.

38. Asaka, M., et al., *Elderly oarsmen have larger trunk and thigh muscles and greater strength than age-matched untrained men.* Eur J Appl Physiol, 2010. **108**(6): p. 1239-45.

Chapter 5

The effect of a 12-week multimodal exercise program on trunk muscle morphology, strength, and functional ability in healthy older adults: A randomized controlled trial

Submission planned for

Medicine & Science in Sports & Exercise (MSSE)

The effect of a 12-week multimodal exercise program on trunk muscle morphology, strength, and functional ability in healthy older adults: A randomized controlled trial

Authors: Behnaz Shahtahmassebi[1], Jeffrey J. Hebert[1], Mark Hecimovich[1, 2], Timothy Fairchild[1]

Institutional affiliation: [1]School of Psychology and Exercise Science, Murdoch University, Perth, WA, Australia; [2]School of Health, Physical Education and Leisure Services University of Northern Iowa, Iowa, United States

Correspondence: Timothy Fairchild

School of Psychology and Exercise Science, Murdoch University

Room 2.042, Social Sciences Building, 90 South Street

Murdoch WA 6150

Email: T.Fairchild@murdoch.edu.au

Tel +61 8 9360 2959

ABSTRACT

Background: Age-related decrements in trunk muscle morphology and strength are associated with decreased balance and increased falls risk. Previously, balance and/or resistance training of the peripheral musculature have demonstrated good efficacy for falls prevention in older adults. However, little is known about the effect of exercise programs on trunk musculature, strength, and functional ability in older adults. Therefore**,** we aimed to explore the effectiveness of an exercise program on trunk muscles morphology (size), strength, and functional ability in healthy older adults. **Methods:** We conducted a single-blinded parallel group randomized clinical trial to investigate the effectiveness of a 12-week exercise program on trunk muscle morphology, strength and functional ability in healthy older adults. Sixty-four individuals (mean(SD) age: 69.8 (7.5) years; 59.4% female) were randomized to receive a multimodal exercise program comprising walking and balance exercises with or without trunk strengthening/motor control exercises. Trunk muscle morphology and strength were assessed using ultrasound imaging and HUMAC NORM isokinetic dynamometer, respectively. Functional and balance outcomes were assessed using Six-Minute Walk Test, 30 seconds Chair Stand Test, Sitting and Rising Test, Berg Balance Scale, Multi-Directional Reach Test, Timed Up and Go Test, and Four Square Step Test. **Results:** Participants in the trunk strengthening exercise group experienced larger increases (mean difference [95%CI]) in trunk muscle hypertrophy (1.6[1.0,2.2]cm) and composite trunk strength (172.6[100.8,244.5]N), as well as 30-Second Chair Stand Test(5.9[3.3,8.4]repetitions), Sitting and Rising Test (1.2[0.22,2.2]points), Forward Reach Test (4.2[1.8,6.6]cm), Backward Reach Test (2.4[0.22,4.5]cm), and Timed Up and Go Test (-0.74[-1.4,-0.03]seconds) outcomes, compared to the walking-balance exercise group. **Conclusion:** These findings support the inclusion of trunk strengthening/motor control exercises as part of a multimodal exercise program in older adults. **Key words:** FALLS, EXERCISE, WALKING, BALANCE, CORE, TRAINING

The age-associated degenerative loss in skeletal muscle size is typically accompanied by a decrease in muscle strength and function (12). Consequently, these degenerative changes are associated with an increased risk of falls (18), which are a leading cause of injury and permanent disability (21), as well as being associated with high rates of mortality (38) in older adults. Improved falls prevention strategies are thus a primary health care target for older adults (35).

Multimodal exercise programs incorporating balance and resistance-based training have been well established to reduce both the rate and risk of falls in older adults (16, 46). While earlier studies in resistance training have focused on exercises for peripheral musculature (11), more recent studies on older adults suggest an important role for strengthening the trunk musculature (13), due to the importance of these muscles in performing activities of daily living, balance and mobility (15, 44). More specifically, a systematic review (13) reported that including trunk strengthening exercises into exercise programs improved trunk muscle strength, balance and functional ability in older adults; however, the benefits of incorporating trunk strengthening exercises on function and balance in older adults require further investigation (13). A recently completed systematic review (39) identified that the largest changes in trunk muscle morphology resulted from exercise programs combining motor control exercises with non-machine-based resistance exercises.

Therefore, we aimed to explore the effectiveness of a 12-week supervised multimodal exercise program comprising of walking and balance exercises, with or without trunk strengthening/motor control exercises on trunk muscle morphology (size), strength, and functional ability in healthy older adults.

METHODS

Participants. This study sought to recruit individuals aged 60 years and older, who were able to participate in a 12-week exercise program, and who met the eligibility requirements of the study. More specifically, participants were excluded from study participation if they i) had undergone lumbar surgery, ii) had any medical condition or were taking prescribed medication, which may have precluded safe participation in an exercise program according to a standardized adult pre-exercise screening tool (30) and, iii) were unable to communicate and respond to the questionnaires in English. In some cases, the study's supervisory panel (TJF, MH, JJH) requested participants to provide an additional medical clearance to participate in the study. The recruitment process first involved posting flyers in public areas (e.g., shopping malls, library) and institutions (e.g. aged care facilities, universities), making announcements through electronic news outlets, as well as attendance at a seminar hosted at a local retirement village. Participants who responded to the advertisements then provided written informed consent, to be involved in the study. This study has been approved by the Murdoch University Research Ethics Committee (No. 2013/140).

Study design. This study adopted a single-blinded parallel group randomized clinical trial design [ACTRN12613001176752] with a 12-week multimodal exercise program. Participant randomization occurred from a block randomisation list (https://www.randomizer.org/) with variable block sizes of 6-2-4. Sequentially numbered, opaque envelopes containing the participant's group assignment were prepared by research staff not affiliated with delivery of the exercise program. Each envelope was opened, and participants were randomly allocated to one of two independent exercise groups after completion of baseline assessments by the exercise trainer. Sixty-four individuals (mean (SD) age: 69.8 (7.5) years; 59.4% female) were randomized into two exercise groups. The first group received a multimodal exercise program comprising of walking and balance exercises with trunk strengthening/motor control exercises (trunk strengthening exercise group). The second group received only walking and balance exercises (walking-balance exercise group). The outcomes of allocation for each group were not disclosed to participants until study completion. Anthropometric, demographic characteristics and all outcome measures were assessed at baseline. The outcome measures were reassessed at week 6 and immediately (within 2 weeks) following completion of the 12-week exercise program.

Exercise programs. All exercise training sessions were conducted and supervised at Murdoch University. Each training session lasted approximately 60 minutes, and there were three training sessions per week, with exercises being gradually progressed over 12 weeks (total of 36 sessions) (see details of the protocols below). Participants were considered compliant if they attended at least 80% of the exercise sessions over the 12-week training period.

Trunk strengthening exercise program. This study made use of a multimodal exercise program comprising of 30 minutes of trunk strengthening/motor control exercises (28) (e.g., abdominal bracing, front bridge pose), 15 minutes of Otago balance exercises (10) (e.g., toe raises, figure 8 walking), and 15 minutes of continuous walking at approximately 60% of maximum heart rate using the age-based prediction formula (220-age). Resting, maximum, and post heart rates of each individual were checked before, halfway through, and at the end of the walking session, respectively. The participant-to-instructor ratio was kept small (14) (1 main instructor (B.S) with 2 additional assistants for 8 participants) throughout the program. All trunk strengthening/motor control exercises were conducted on gym mats using unstable training equipment (e.g., Airex mats, Bosu ball), but without the use of resistance machines. Throughout the trunk strengthening/motor control exercises, participants were always in supine, prone, quadruped and side-lying positions on the gym mats to avoid continuous position changes (from standing to lying/sitting and vice versa), which are often uncomfortable for older adults (14). Training intensity was progressively and individually increased over the 12-week exercise program by changing the lever lengths, range of motion, movement velocity (isometric, dynamic) and the level of stability/instability.

Walking-balance exercise program. Participants in this group performed the same Otago balance exercises (10) for 15 minutes as above and 45 minutes of continuous walking at approximately 60% of their maximum heart rate using the age-based prediction formula (220-age). Resting, maximum, and post heart rates of each individual were checked before, halfway through, and at the end of the walking session, respectively.

Measurements

Anthropometric and demographic characteristics. Self-reported physical activity was collected through a demographic questionnaire. We measured body weight using a digital scale (Scales Plus, Perth, WA, Australia) and height (standing and seated) using a wall-mounted stadiometer (Surgical Medical Supplies Pvt Ltd, Adelaide, SA, Australia).

Functional mobility. Functional mobility was assessed using the Six Minute Walk Test (27), the 30-second Chair Stand Test (19), and the Sitting and Rising Test (3).

Balance. Balance was assessed using the Berg Balance Scale (2) , the Multi-Directional Reach Test (29), the Timed Up and Go Test (34), and the Four Square Step

Test (6). The results from the Multi-Directional Reach Test are presented as Forward Reach Test; Backward Reach Test; Right Reach Test; and Left Reach Test.

Trunk muscle morphology. A high resolution and portable ultrasound unit with a 60 mm broadband curved array ultrasound transducer probe (5-2 MHz) (SonoSite M-Turbo, SonoSite™, Bothell, WA, USA) was used to measure the size of the rectus abdominis (RA), internal oblique (IO), external oblique (EO), transversus abdominis (TrA), and lumbar multifidus (LM). Previous studies using ultrasound imaging to measure trunk muscle size in older adults have demonstrated high inter-rater and intra-rater reliability (ICC ≥0.86) (42, 43).

Images of the lumbar multifidus (LM) were obtained at the L4-5 level with the participant in the prone position using methods described in a previous study (25). The transducer was positioned lateral to the L4 and L5 spinous process and angled slightly medial until the L4-5 facet joint could be identified. Lumbar multifidus thickness measurements were made between the posterior most portion of the L4-5 facet joint and the plane between the superficial muscle and subcutaneous tissue.

Rectus abdominis (RA) thickness and cross-sectional area (CSA), as well as transversus abdominis (TrA), internal oblique (IO) and external oblique (EO) thickness was measured with participants in the supine, hook-lying position. For acquisition of the TrA, IO and EO muscles, the transducer was positioned transversely over the anterolateral aspect of the abdominal wall, superior to the iliac crest and perpendicular to the mid-axillary line. The images were captured with the middle of the muscle belly centered in the field of view, and at the end of a normal exhalation to control for the influence of respiration (25). For acquisition of the rectus abdominis CSA, the inferior border of the transducer was placed immediately above the umbilicus and moved laterally from the midline until the muscle cross-section was centered in the image (45).

A single assessor performed image acquisition three times bilaterally and exported the images for offline analysis using Image J (National Institutes of Health, version 1.41). The same assessor averaged all measures across the three repetitions to reduce measurement error (25).

We created a composite trunk muscle size variable by summing the thickness of TrA, IO, and EO (total lateral abdominal muscles), as well as other trunk muscles (rectus abdominis and lumbar multifidus muscles). Composite trunk muscle size comprised the thickness of bilateral lateral abdominal muscles, rectus abdominis, lumbar multifidus at lumbar spinal level L4/L5 (the average of of right/left) and lumbar multifidus at lumbar spinal level L5/S1 (the average of right and left). The formula of composite trunk muscle size is as follows; [Composite trunk muscle size = TLAM + RA + LM (L4/L5) + LM (L5/S1)].

Trunk muscle strength. We measured maximal isometric strength in trunk flexion, extension, and lateral flexion using the Humac NORM Isokinetic dynamometer (Humac NORM, Computer Sports Medicine, Stoughton, MA, USA) with the trunk extension–flexion (TEF) modular component. Isokinetic dynamometry has previously been reported to be a reliable and valid method for measuring trunk muscle strength (17, 23). Horizontal alignment was approximately 3.5 cm below the top of iliac crest at L5/S1 and vertical alignment was the approximate intersection of the mid-axillary line and L5/S1 (22). The lumbar pad was positioned to obtain a slightly flexed knee position (15º) and all other pads and belts secured in accordance with manufacturer instructions. The strength testing was performed in the same order each time: trunk flexion, extension and then lateral flexion (right, left).

Prior to testing, participants performed a standardised warm-up consisting of one set (10 repetitions) of range of motion exercises and up to five practice trials. For maximal efforts, contractions were held for 3 seconds and the peak torque from two attempts recorded. A familiarisation trial preceded each measure and the participant rested for 45 seconds between each repetitions (47).

Verbal encouragement was provided during each effort. Maximum isometric trunk torque (Nm) data was normalised by adjusting for trunk height (cm) and converting the peak torque to maximum force (N) [Maximum force= Peak torque/ Moment arm (trunk height)]. Therefore, all data on trunk muscle strength are presented as maximum force. A composite trunk strength score was calculated by summing the maximum force outcomes from flexion, extension, lateral flexion right and lateral flexion left. The formula of composite trunk strength is as follows; [Composite trunk strength = Maximum force flexion+ Maximum force extension+ Maximum force lateral flexion

Power and sample size. An *a priori* power analysis using G*Power revealed 64 participants (i.e., 32 participants per group) would be required to detect an effect of 0.16 (with type I error: 0.05; type II error: 0.80) between 2 groups with 3 repeated measurements and an anticipated 20% dropout rate. The small-moderate effect size (f=0.16) was computed from changes in trunk muscle morphology following a randomized controlled exercise training intervention conducted by Critchley et al. (5) and which was identified as high-quality in a recent systematic review (39).

Statistical analyses. Data management and statistical analyses were performed using IBM SPSS version 22.0 software (IBM Corp, Armonk, NY). Treatment effects were estimated using separate, random-intercept linear mixed models for each outcome variable. Time (baseline, 6 weeks, 12 weeks) and exercise group (trunk strengthening, walking-balance) were modeled as fixed effects. The hypothesis of interest was the time by group interaction, which we examined with pairwise comparisons of the estimated marginal means. Consistent with the intention-to-treat principle, the linear mixed models estimated values for missing data based on the available scores; therefore, all participants were included in the analyses. The level of significance was set at $p \leq 0.05$. Data are presented as the mean and standard deviation.

RESULTS

Participant characteristics and retention. Between February 2014 and November 2015, 105 participants were screened for study inclusion. Sixty-four participants met the inclusion criteria and 32 participants were randomised to the trunk strengthening exercise group, and 32 to the walking-balance exercise group. The participant flow, reasons for exclusion and loss to follow-up are presented in Figure 1. Exercise compliance was high (trunk strengthening: 90% and walking-balance: 91.5%) with low rates of dropout (trunk strengthening: 12.5% and walking-balance: 3.1%). None of the participants reported any training or test-related injuries. Baseline characteristics of participants and baseline outcome measures are presented in Table 1. There were no significant between-group differences at baseline for any outcome measures (all $p > 0.05$) (Table 1).

Trunk muscle morphology. There were significant time by group interactions for trunk muscle size at week 6 and 12 (Table 2). Specifically, participants in the trunk strengthening exercise group demonstrated greater hypertrophy (mean difference [95% CI]) in the total lateral abdominal muscles (mean of right and left; 0.63 [0.40 to 0.85] cm), the CSA of rectus abdominis muscle (2.08 [1.28 to 2.89] cm^2), lumbar multifidus muscles at L4/L5 (0.38 [0.16 to 0.61] cm) and L5/S1 (0.31 [0.07 to 0.55] cm), and composite trunk muscles (1.6 [1.0 to 2.2] cm) at week 12 compared with participants in the walking-balance exercise group (Table 2). Additionally, significant within-group muscle hypertrophy in all trunk muscles except composite trunk muscles at week 12 were found in the trunk strengthening exercise group while participants in the walking-balance exercise group showed no muscle hypertrophy in all trunk muscles size (Table 2).

Trunk muscle strength. A significant time by group interaction was identified for all trunk strength outcomes at week 6 and 12, except trunk flexion and extension strength which showed changes only by week 12 (Table 3). Specifically, participants in the trunk strengthening exercise group experienced larger increases (mean difference [95% CI]) in trunk flexion (30.0 [4.1 to 55.9] N), trunk extension (38.4 [15.0 to 61.7] N), trunk lateral flexion (52.8 [36.7 to 69.0] N), and composite trunk strength (172.6 [100.8 to 244.5] N) at week 12 compared with participants in the walking-balance exercise group (Table 3). Additionally, significant within-group increases in trunk flexion, extension, lateral flexion and composite strength measures were found in the trunk strengthening exercise group while participants in the walking-balance exercise group showed no increases in trunk strength (Table 3).

Functional mobility and balance. At six weeks, only the performance in the 30-Second Chair Stand Test (3.1 [0.68 to 5.5] repetitions) was significantly different between groups (Table 4). After 12 weeks of the exercise program, participants in the trunk strengthening exercise group showed significant improvements (mean difference [95% CI]) in the 30-Second Chair Stand Test (5.9 [3.3 to 8.4] repetitions), Sitting and Rising Test (1.2 [0.22 to 2.2] points), Forward Reach Test (4.2 [1.8 to 6.6] cm), Backward Reach Test (2.4 [0.22 to 4.5] cm) and Timed Up and Go Test (-0.74 [-1.4 to -0.03] seconds) outcomes, when compared to the walking-balance exercise group (Table 4). Additionally, significant within-group improvements in all balance and functional tasks were found following both trunk strengthening and walking-balance exercise programs (Table 4).

DISCUSSION

This study investigated the effect of supplementing a 12-week walking and balance exercise program with trunk strengthening/motor control exercises on trunk muscle size, trunk muscle strength, and functional ability in healthy older adults. The primary outcomes of this study were that: i) inclusion of trunk strengthening/motor control exercises into the exercise program was associated with significant increases in trunk muscle morphology and strength; and ii) inclusion of trunk strengthening/motor control exercises was associated with significant improvements in functional outcome measures, including the 30-Second Chair Stand Test, Sitting and Rising Test, Forward Reach Test, Backward Reach Test, and Timed Up and Go Test. Overall, the inclusion of trunk strengthening/motor control exercises into the exercise program was efficacious across a number of outcome measures, when compared to a time-matched walking and balance exercise program, and was not associated with any deleterious outcomes.

Our findings of increased trunk muscle size (CSA and thickness) following the trunk strengthening exercise program are consistent with the findings of a recent systematic review (39). It is noteworthy that almost all trunk muscles (excluding lumbar multifidus L5/S1; Table 2) demonstrated significant hypertrophy by week 6 of the trunk strengthening exercise program, which is consistent with findings in studies focusing on peripheral musculature (quadriceps muscle groups) of older men (9) and women (33). Indeed, the extent of trunk muscle hypertrophy (as measured by CSA or thickness; 18.5% using composite muscle scores) by week 6 is comparable or greater than that typically observed in the peripheral musculature (9, 33), which may be indicative of some level of atrophy in these muscles at baseline despite the relatively high physical activity levels and capacities of our cohort (1, 20). In comparison to another study (24) investigating the trunk musculature (24), the extent of hypertrophy (thickness) of lumbar multifidus muscle (10.93% and 17.04% by week 6 and 12, respectively) as a consequence of the trunk strengthening exercise program was comparable (25.78% and 68.35% by week 16 and 32, respectively), albeit a little lower, even when considering the time periods. In the current study, lumbar multifidus muscle thickness increased by 1.82% and 1.42% per week when considering the total percentage increase over 6 weeks and 12 weeks respectively; while Kliziene et al (24) reported 1.61% and 2.14% increases in the CSA of the lumbar multifidus muscle, over 16 weeks and 32 weeks respectively. As expected, there were no increases in trunk muscle size following the walking-balance exercise program, which is in accordance with findings of Ryan et al. (36).

The current study demonstrated a significant increase in all measures of trunk strength by week 12 of the trunk strengthening exercise program (Table 3). These results are in agreement with the outcomes of a recent systematic review (13). Although large within-group increases in trunk flexion (13.87%) and extension strength (24.15%) were observed by week 6 of the trunk strengthening exercise program, between-group differences were not apparent. The absence of significant between-group differences is likely due to the large variances observed within the individual groups (Table 3). The increases in trunk flexion and extension strength with the trunk strengthening exercise program are consistent with two previous studies (32, 41). In the first study, Petrofsky et al (32) reported significant increases in trunk flexion (36%) and extension strength (33%) following a 4-week single-arm exercise program. The use of an exercise program and machine designed to specifically target the abdominal and lower back muscles (6 Second Abs machine) in the study of Petrofsky et al (32) potentially contributed to this large increase in trunk muscle strength (32). In the second study, Sinaki et al (41) demonstrated a significant increase in trunk extension (37.5%) following a 4-week single-arm Spinal Proprioceptive Extension Exercise Dynamic (SPEED) program in osteoporotic-kyphotic older adults. The large increase in trunk muscle strength in the study of Sinaki et al (41) over a 4-week exercise program is likely attributed to the use of an exercise program designed to specifically target the trunk extensor muscles of osteoporotic-kyphotic older adults.

The trunk strengthening exercise program resulted in significant improvements in functional tests of strength, including the 30-Second Chair Stand Test and the Sitting and Rising Test (Table 4). The significant improvement in the 30-Second Chair Stand Test following the trunk strengthening exercise program in our study is consistent with findings from previous studies (13, 26, 33). The 30-Second Chair Stand Test (19) is an important functional test because it measures lower body strength, which is associated with balance problems and falls in older adults (19). Performance in the 30-Second Chair Stand Test also decreases with aging and low levels of activity (19). In the current study, participants in the trunk strengthening exercise group and participants in the walking-balance exercise group performed 16.2 (4.2) repetitions and 16.3 (4.9) repetitions respectively, and the number of repetitions are higher than those previously (19) reported for a similar aged-cohort (i.e. 60-69 y.o.: 14.0 (2.4) repetitions; 70-79 y.o.: 12.9 (3.0)). Despite the high baseline scores in the 30-Second Chair Stand Test, participants in the trunk strengthening exercise group significantly improved (36.4%), completing 25.1 (5.5) repetitions after the 12-week exercise program.

The ability to sit and rise from the floor unassisted (represented in the Sitting and Rising Test) has been identified as being predictive of all-cause mortality (3). The Sitting and Rising Test measures the individual’s ability to sit and rise unassisted from the floor. Partial scores are assigned for each of the two required actions of sitting (5 points) and rising (5 points) from the floor (sit to rise). The final composite Sitting (0-5) and Rising (0-5) Test results ranges from 0 to 10 points and is obtained by adding the sitting and rising points. Each point increase in the Sitting and Rising Test is associated with a 21% reduction in all-cause mortality (3). Notably, our study showed that the trunk strengthening exercise group led to significant improvements in the Sitting and Rising Test performance, and this had not been previously examined in the extant literature. Specifically, the trunk strengthening exercise group showed significant improvements (46.98%) in Sitting and Rising Test outcome (mean (SD)) from 5.3 (1.8) to 7.8 (1.1) points), and the walking-balance exercise group showed smaller improvements (10%) in Sitting and Rising Test outcomes (mean (SD)) from 6.1 (2.2) to 6.6 (2.5) points). Thus, although participants in this study were mostly healthy and active older individuals (classified into the second and third Sitting and Rising Test points category) (3), the trunk strengthening/motor control exercises still resulted in a significant improvement in Sitting and Rising Test results.

The trunk strengthening exercise program also resulted in significant improvements in functional tests of balance, including the Multi-Directional Reach Test (forward and backward). This increase in Multi-Directional Reach Test performance following the trunk strengthening exercise program was in agreement with previous studies (13, 14, 26). Significant within and between-group changes were observed for the forward and backward reach tests, while only within-group changes were identified for the Functional Reach Test sideways (right/left) tests, following 6 and 12 weeks of both exercise programs (Table 4). Individuals unable to reach 6 or more inches (≤15.24 cm) forward have previously been identified as being at high risk of falls (8). The distance achieved in the Multi-Directional Reach Test by this study cohort is comparable to those previously published in a similarly aged healthy cohort (Mean scores of Forward Reach Test = 22.58 (8.63) cm, Backward Reach Test = 11.78 (7.79) cm, Right Reach Test = 15.62 (7.59) cm, and Left Reach Test = 16.78 (7.31) cm (29)). Although all participants in this study cohort achieved scores above clinical cut-off points at baseline (Table 4) the participants in the trunk strengthening exercise group still demonstrated significant improvements in Forward and Backward Reach Test (both ~15%) after 12 weeks of the exercise program.

The significant improvements in participants' performance in the Timed Up and Go Test following the trunk strengthening exercise program was also in agreement with previous studies (14, 26). Longer Timed Up and Go test times are associated with decreased mobility and may predict falls in older adults (34). Older individuals who completed the Timed Up and Go test in less than 10 seconds (independent individuals in physical mobility) are classified into the first category of Timed Up and Go Test scores (34). All the participants in the current study were classified into the first category with good functional performance at baseline (mean (SD)) (trunk strengthening 7.5 (1.2) seconds, walking-balance exercise 7.3 (2.1) seconds). However, participants in the trunk strengthening exercise group demonstrated significant improvements in Timed Up and Go Test performance, whereas the walking-balance exercise group's performance in this test did not significantly improve.

Although there were no significant between-group differences in Berg Balance Scale performance, there were significant (3-6.7%) within group changes observed following both exercise programs. Previous findings have identified that the Berg Balance Scale is a good predictor of falls in a cohort of older adults (40). A cut-off score of 45 is an established criterion to identify older adults with high risk of falls. However, the Berg Balance Scale might not be sensitive enough for identifying risk of falls among healthy and physically active older individuals with higher scores (48 to 56 points), such as the participants in the present study, due to presence of ceiling effect (37). A change of 4 points is needed to be 95% confident that "genuine" change has occurred if an older adult scores within 45-56 initially (7). In this current study, although no significant differences were found between exercise groups, both groups demonstrated within-group differences after 12 weeks of training, and achieved the genuine change of

4 points (mean (SD)) [trunk strengthening exercise group; at baseline 51.7 (4.1), at week 12; 55.2 (0.87)] and [walking-balance exercise group at baseline; 52.3 (4.0), at week 12; 54.3 (2.6)].

The Four Step Square Test is a reliable, easy to score, and quick to administer clinical test, used to predict risk of falls in older adults (6). A cut-off score of 15 seconds is the criterion used to distinguish older adults with a history of multiple falls (>15 seconds) from individuals with no history of falls (≤15 seconds) (6). Participants in the trunk strengthening exercise group scored (mean (SD) seconds) (8.5 (1.6) seconds) and participants in the walking-balance exercise group scored (8.0 (1.4) seconds). There were statistically significant (7-25.4%) within-group changes following 12 weeks of both exercise programs, but no significant between-group differences.

With respect to Six Minute Walk Test performance, although there were no significant between-group differences, there were large (11.2-16.4%) within-group changes following both exercise programs (table 4). This is not surprising that the two groups were not significantly different in Six Minute Walk Test performance, since this study recruited an active control group which walked. The distance achieved in the six minutes by this study cohort is comparable to those previously published in a similarly aged healthy cohort (4). An increase of 20 m and 50 m in older adults has previously been identified as being a small and substantial meaningful change in six minute walk distance, respectively (31).

The study presented herein had multiple strengths, including i) adoption of a randomized controlled design that comprehensively examined the efficacy of a 12-week multimodal exercise program using an intention-to-treat analysis; ii) the current exercise design contributed to high exercise compliance and low dropout rates, as seen from participants' feedback. More specifically, participants indicated that the current exercise program was easy to access, exercises were easy to learn (data not shown; Rating of

Perceived Exertion), required no specific equipment, and was completely free of charge over 12 weeks. In other words, participants' feedback lent support to the vicinity and proximity of the current exercise program. Most importantly, participants reported that the professional, friendly and encouraging exercise training atmosphere motivated them to be personally committed to accomplish this exercise training; iii) the current exercise program incorporated unstable elements (i.e., balance pads, Swiss balls) as part of trunk strengthening and improving balance; v) adoption of well validated and reliable outcome measures.

Despite these strengths, the findings of the current study should be considered in light of several limitations. The participants included in this study were healthy and moderately active older adults. Therefore, the results of our study may not generalize to other populations (e.g., sedentary, overweight/obese, frail/at high risk of falls older individuals, frail older individuals at high risk of falls, neuromuscular, mobility/balance limited patients). In addition, the results of this study are specific to the testing methodology used to assess trunk muscle morphology, strength, balance, and functional performance. Our outcome measures may not represent all the components of trunk muscle morphology, strength, mobility, and balance; therefore, the findings of our study should be generalised with caution to other experimental assessment techniques (i.e., MRI imaging, isokinetic trunk strength, force-plate for balance and postural sway measurements).

The results of this study indicate that inclusion of trunk strengthening/motor control exercises into a 12-week supervised multimodal exercise program confers additional benefits to balance and walking training in healthy older adults. Future research should focus on longitudinal changes in falls risk and subsequent rate of falls following specific multimodal exercise programs. In addition, the benefits of this type of exercise program in clinical populations (i.e., sedentary, frail older adults, obese/overweight, musculoskeletal disorders) require further investigation.

CONCLUSION

Age-related decrements in trunk muscle morphology, strength and function are associated with decreased balance and increased risk of falls. The findings of this randomised controlled trial demonstrated that 12 weeks of trunk strengthening exercise program may significantly increase both muscle size and strength of trunk musculature, with many of these benefits evident within 6 weeks of training. Whilst translation of these benefits to functional tasks was limited by week 6, there were significant within-group changes associated with the trunk strengthening exercise program. The week 12 results revealed important between-group differences in some clinically important functional tasks, specifically the 30-Second Chair Stand Test; Sitting and Rising Test; Multidirectional Reach tests; and Timed Up and Go Test. Within-group differences were additionally observed in all functional tasks by week 12. Overall, the inclusion of trunk strengthening/motor control exercises into a walking-balance exercise program was shown to be safe (no training-related injuries), feasible (high attendance rates of >90%) and inexpensive (minimal equipment), and was associated with improvements in trunk size, strength, and multiple components of functional ability in healthy older adults.

The authors would like to thank Dr Golnaz Shahtahmassebi for statistical advice. The authors declare no conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

REFERENCES

1. Anderson DE, D'Agostino JM, Bruno AG, Demissie S, Kiel DP, Bouxsein ML. Variations of CT-based trunk muscle attenuation by age, sex, and specific muscle. *J Gerontol A Biol Sci Med Sci*. 2013;68(3):317-23.
2. Berg KO, Wood-Dauphinee SL, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. *Can J Public Health*. 1992;83 Suppl 2:S7-11.
3. Brito LBBd, Ricardo DR, Araujo DSMSd, Ramos PS, Myers J, Araujo CGSd. Ability to sit and rise from the floor as a predictor of all-cause mortality. *Eur J Prev Cardiol*. 2014;21(7):892-8.
4. Camarri B, Eastwood PR, Cecins NM, Thompson PJ, Jenkins S. Six minute walk distance in healthy subjects aged 55-75 years. *Respir Med*. 2006;100(4):658-65.
5. Critchley DJ, Pierson Z, Battersby G. Effect of pilates mat exercises and conventional exercise programmes on transversus abdominis and obliquus internus abdominis activity: pilot randomised trial. *Man Ther*. 2011;16(2):183-9.
6. Dite W, Temple VA. A clinical test of stepping and change of direction to identify multiple falling older adults. *Arch Phys Med Rehabil*. 2002;83(11):1566-71.
7. Donoghue D, Stokes EK. How much change is true change? The minimum detectable change of the Berg Balance Scale in elderly people. *J Rehabil Med*. 2009;41(5):343-6.
8. Duncan PW, Studenski S, Chandler J, Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. *J Gerontol*. 1992;47(3):M93-8.
9. Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, Evans WJ. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol (1985)*. 1988;64(3):1038-44.
10. Gardner MM, Buchner DM, Robertson MC, Campbell AJ. Practical implementation of an exercise-based falls prevention programme. *Age Ageing*. 2001;30(1):77-83.
11. Gillespie LD, Robertson MC, Gillespie WJ et al. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev*. 2012;9:CD007146.

12. Goodpaster BH, Park SW, Harris TB et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci*. 2006;61(10):1059-64.
13. Granacher U, Gollhofer A, Hortobagyi T, Kressig RW, Muehlbauer T. The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: a systematic review. *Sports Med*. 2013;43(7):627-41.
14. Granacher U, Lacroix A, Muehlbauer T, Roettger K, Gollhofer A. Effects of core instability strength training on trunk muscle Strength, spinal mobility, dynamic balance and functional mobility in older adults. *Gerontology*. 2013;59(2):105-13.
15. Granacher U, Lacroix A, Roettger K, Gollhofer A, Muehlbauer T. Relationships between trunk muscle strength, spinal mobility, and balance performance in older adults. *J Aging Phys Act*. 2014;22(4):490-8.
16. Granacher U, Zahner L, Gollhofer A. Strength, power, and postural control in seniors: Considerations for functional adaptations and for fall prevention. *Eur J Sport Sci*. 2008;8(6):325-40.
17. Guilhem G, Giroux C, Couturier A, Maffiuletti NA. Validity of trunk extensor and flexor torque measurements using isokinetic dynamometry. *J Electromyogr Kinesiol*. 2014;24(6):986-93.
18. Heathcote G. Autonomy, health and ageing: transnational perspectives. *Health Educ Res*. 2000;15(1):13-24.
19. Jones CJ, Rikli RE, Beam WC. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Res Q Exerc Sport*. 1999;70(2):113-9.
20. Kanehisa H, Miyatani M, Azuma K, Kuno S, Fukunaga T. Influences of age and sex on abdominal muscle and subcutaneous fat thickness. *Eur J Appl Physiol*. 2004;91(5-6):534-7.
21. Kannus P, Sievanen H, Palvanen M, Jarvinen T, Parkkari J. Prevention of falls and consequent injuries in elderly people. *Lancet*. 2005;366(9500):1885-93.
22. Karatas GK, Gogus F, Meray J. Reliability of isokinetic trunk muscle strength measurement. *Am J Phys Med Rehabil*. 2002;81(2):79-85.
23. Kienbacher T, Paul B, Habenicht R et al. Reliability of isometric trunk moment measurements in healthy persons over 50 years of age. *J Rehabil Med*. 2014;46(3):241-9.

24. Klizienė I, Sipavičienė S, Imbrasienė D, Klizas Š, Inokaitis H. Effect of core stability exercise on cross sectional area of lumbar multifidus muscle and physical capacity. *Educ Phys Train Sport*. 2011;83:9-15.
25. Koppenhaver SL, Hebert JJ, Fritz JM, Parent EC, Teyhen DS, Magel JS. Reliability of rehabilitative ultrasound imaging of the transversus abdominis and lumbar multifidus muscles. *Arch Phys Med Rehabil*. 2009;90(1):87-94.
26. Lacroix A, Kressig RW, Muehlbauer T et al. Effects of a supervised versus an unsupervised combined balance and strength training program on balance and muscle power in healthy older adults: a randomized controlled trial. *Gerontology*. 2015.
27. Lipkin DP, Scriven AJ, Crake T, Poole-Wilson PA. Six minute walking test for assessing exercise capacity in chronic heart failure. *Br Med J (Clin Res Ed)*. 1986;292(6521):653-5.
28. McGill SM, Karpowicz A. Exercises for spine stabilization: motion/motor patterns, stability progressions, and clinical technique. *Arch Phys Med Rehabil*. 2009;90(1):118-26.
29. Newton RA. Validity of the multi-directional reach test: a practical measure for limits of stability in older adults. *J Gerontol A Biol Sci Med Sci*. 2001;56(4):M248-52.
30. Norton K, Norton L. Pre-exercise Screening. In: Exercise and Sports Science Australia, Fitness Australia and Sports Medicine Australia;; 2011.
31. Perera S, Mody SH, Woodman RC, Studenski SA. Meaningful change and responsiveness in common physical performance measures in older adults. *J Am Geriatr Soc*. 2006;54(5):743-9.
32. Petrofsky JS, Cuneo M, Dial R, Pawley AK, Hill J. Core strengthening and balance in the geriatric population. *J Appl Res.* 2005;5(3):423.
33. Pinto RS, Correa CS, Radaelli R, Cadore EL, Brown LE, Bottaro M. Short-term strength training improves muscle quality and functional capacity of elderly women. *Age (Dordr)*. 2014;36(1):365-72.
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.
35. Rubenstein LZ, Josephson KR. Falls and their prevention in elderly people: what does the evidence show? *Med Clin North Am*. 2006;90(5):807-24.

36. Ryan AS, Harduarsingh-Permaul AS. Effects of weight loss and exercise on trunk muscle composition in older women. *Clin Interv Aging*. 2014;9:395-402.
37. Santos GM, Souza AC, Virtuoso JF, Tavares GM, Mazo GZ. Predictive values at risk of falling in physically active and no active elderly with Berg Balance Scale. *Rev Bras Fisioter*. 2011;15(2):95-101.
38. Sartini M, Cristina ML, Spagnolo AM et al. The epidemiology of domestic injurious falls in a community dwelling elderly population: an outgrowing economic burden. *Eur J Public Health*. 2010;20(5):604-6.
39. Shahtahmassebi B, Hebert JJ, Stomski NJ, Hecimovich M, Fairchild TJ. The effect of exercise training on lower trunk muscle morphology. *Sports Med*. 2014;44(10):1439-58.
40. Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Phys Ther*. 2000;80(9):896-903.
41. Sinaki M, Brey RH, Hughes CA, Larson DR, Kaufman KR. Significant reduction in risk of falls and back pain in osteoporotic-kyphotic women through a Spinal Proprioceptive Extension Exercise Dynamic (SPEED) program. *Mayo Clin Proc*. 2005;80(7):849-55.
42. Sions JM, Velasco TO, Teyhen DS, Hicks GE. Ultrasound imaging: intraexaminer and interexaminer reliability for multifidus muscle thickness assessment in adults aged 60 to 85 years versus younger adults. *J Orthop Sports Phys Ther*. 2014;44(6):425-34.
43. Stetts DM, Freund JE, Allison SC, Carpenter G. A rehabilitative ultrasound imaging investigation of lateral abdominal muscle thickness in healthy aging adults. *J Geriatr Phys Ther*. 2009;32(2):60-6.
44. Suri P, Kiely DK, Leveille SG, Frontera WR, Bean JF. Trunk muscle attributes are associated with balance and mobility in older adults: a pilot study. *Pm R*. 2009;1(10):916-24.
45. Teyhen DS, Gill NW, Whittaker JL, Henry SM, Hides JA, Hodges P. Rehabilitative ultrasound imaging of the abdominal muscles. *J Orthop Sports Phys Ther*. 2007;37(8):450-66.
46. Tofthagen C, Visovsky C, Berry DL. Strength and balance training for adults with peripheral neuropathy and high risk of fall: current evidence and implications for future research. *Oncol Nurs Forum*. 2012;39(5):E416-24.

47. Van Damme BBL, Stevens VK, Van Tiggelen DE, Duvigneaud NNP, Neyens E, Danneels LA. Velocity of isokinetic trunk exercises influences back muscle recruitment patterns in healthy subjects. *J Electromyogr Kinesiol*. 2013;23(2):378-86.

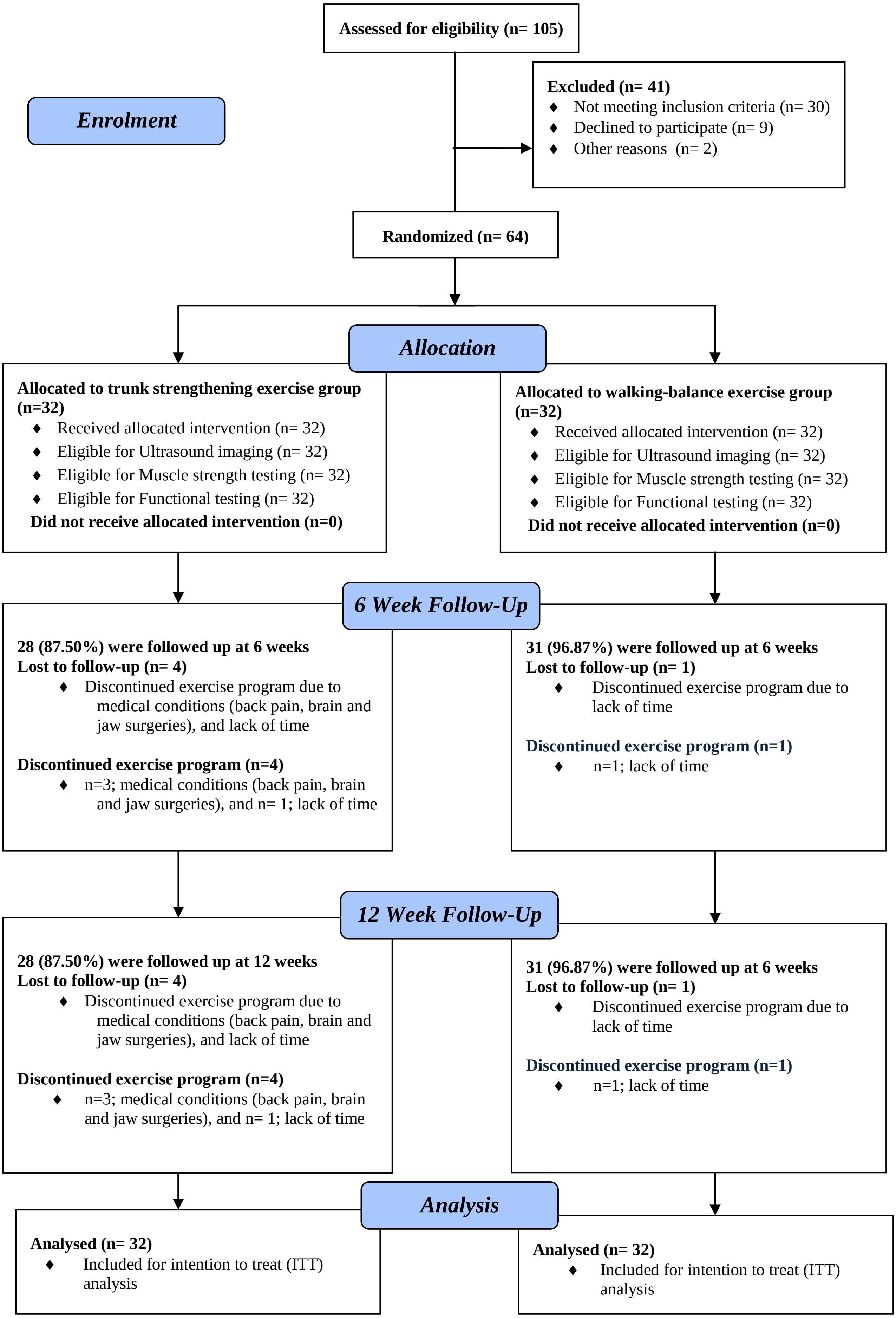


Figure 1. Study flow diagram

Table 1. Baseline characteristics of study's participants stratified by exercise group

Characteristics	All (n=64)	Trunk strengthening (n=32)	Walking-balance (n=32)
Age, years	69.8 ±7.5	70.1 (7.7)	69.4 (7.3)
Sex n (%) female	38 (59.4)	18 (56.3)	20 (62.5)
BMI, kg/m^2	27.3 ± 4.7	26.6 (3.2)	28.1 (5.8)
Sitting height, cm	80.5 ± 5.0	81.5 (4.9)	79.5 (4.9)
Living status			
Lived with one or more than one persons (%)	28.1	28.1	28.1
Lived alone (%)	71.9	71.9	71.9
History of falls over past one month			
Falls (%)	9.4	6.3	12.5
History of falls over past 12 months			
Falls (%)	18.8	18.8	18.8
Medications			
1-2 medications (%)	42.2	43.7	40.6
3 medications or more (%)	12.5	31.3	37.6
No medications (%)	23.4	25.0	21.8
Self-reported physical activity			
Moderately active (×1 or 2 wkly) (%)	53.1	43.7	62.5
Very active (×3 wkly) (%)	43.8	50.0	37.5
Not very active (rarely leaves house) (%)	3.1	6.3	0

Values are presented as mean (SD) or as number and percentage.
No group baseline differences were detected (all $p \geq 0.05$).
×1 wkly once weekly, ***×2 wkly*** twice weekly, ***×3 wkly*** three times weekly

Table 2. Changes[a] in trunk muscle morphology in response to exercise program

Outcome measures	Trunk strengthening exercise group (n=32)	Walking-balance exercise group (n=32)	Mean between-group difference (95% CI)	*P*-values
Right total lateral abdominal muscles, cm				
Baseline	1.61 (0.38)	1.72 (0.51)	-0.10 (-0.36 to 0.14)	0.40
6 weeks	2.19 (0.47)	1.75 (0.52)	0.44 (0.19 to 0.68)	<0.001
12 weeks	2.42 (0.46)	1.78 (0.52)	0.63 (0.39 to 0.88)	<0.001
Mean difference (95% CI): Baseline vs. week 6	0.58 (0.50 to 0.66)	0.03 (-0.04 to 0.10)	-	-
Mean difference (95% CI): Baseline vs. week 12	0.81 (0.73 to 0.88)	0.06 (-0.00 to 0.13)	-	-
Left total lateral abdominal muscles, cm				
Baseline	1.59 (0.34)	1.66 (0.43)	-0.06 (-0.28 to 0.15)	0.55
6 weeks	2.12 (0.39)	1.68 (0.42)	0.43 (0.23 to 0.64)	<0.001
12 weeks	2.34 (0.46)	1.72 (0.42)	0.62 (0.40 to 0.83)	<0.001
Mean difference (95% CI): Baseline vs. week 6	0.53 (0.46 to 0.59)	0.02 (-0.03 to 0.08)	-	-
Mean difference (95% CI): Baseline vs. week 12	0.75 (0.67 to 0.83)	0.06 (-0.01 to 0.13)	-	-
Total lateral abdominal muscles (mean right/left), cm				
Baseline	1.60 (0.33)	1.69 (0.47)	-0.08 (-0.32 to 0.14)	0.46
6 weeks	2.16 (0.42)	1.72 (0.46)	0.43 (0.21 to 0.65)	<0.001
12 weeks	2.38 (0.45)	1.75 (0.46)	0.63 (0.40 to 0.85)	<0.001
Mean difference (95% CI): Baseline vs. week 6	0.55 (0.49 to 0.62)	0.03 (-0.03 to 0.09)	-	-
Mean difference (95% CI): Baseline vs. week 12	0.78 (0.71 to 0.85)	0.06 (-0.00 to 0.13)	-	-
Rectus abdominis CSA, cm^2				
Baseline	4.04 (1.3)	4.22 (1.5)	-0.17 (-1.0 to 0.65)	0.67
6 weeks	6.06 (1.7)	4.32 (1.5)	1.73 (0.94 to 2.53)	<0.001
12 weeks	6.50 (1.7)	4.41 (1.5)	2.08 (1.28 to 2.89)	<0.001
Mean difference (95% CI): Baseline vs. week 6	2.02 (1.80 to 2.23)	0.10 (-0.09 to 0.31)	-	-
Mean difference (95% CI): Baseline vs. week 12	2.46 (2.23 to 2.68)	0.19 (-0.02 to 0.41)	-	-

Table 2 continued

Outcome measures	**Trunk strengthening exercise group (n=32)**	**Walking-balance exercise group (n=32)**	**Mean between-group difference (95% CI)**	***P*-values**
Lumbar multifidus L4/L5, cm				
Baseline	3.11 (0.45)	3.23 (0.42)	-0.12 (-0.35 to 0.10)	0.29
6 weeks	3.46 (0.50)	3.23 (0.40)	0.23 (0.00 to 0.46)	0.04
12 weeks	3.65 (0.45)	3.26 (0.41)	0.38 (0.16 to 0.61)	<0.001
Mean difference (95% CI): Baseline vs. week 6	0.34 (0.30 to 0.39)	-0.00 (-0.04 to 0.03)	-	-
Mean difference (95% CI): Baseline vs. week 12	0.53 (0.49 to 0.57)	0.02 (-0.01 to 0.06)	-	-
Lumbar multifidus L5/S1, cm				
Baseline	2.98 (0.49)	3.17 (0.44)	-0.18 (-0.43 to 0.05)	0.13
6 weeks	3.33 (0.52)	3.15 (0.42)	0.17 (-0.07 to 0.42)	0.16
12 weeks	3.52 (0.48)	3.20 (0.43)	0.31 (0.07 to 0.55)	0.01
Mean difference (95% CI): Baseline vs. week 6	0.342 (0.29 to 0.39)	-0.021 (-0.06 to 0.02)	-	-
Mean difference (95% CI): Baseline vs. week 12	0.53 (0.49 to 0.57)	0.03 (-0.00 to 0.06)	-	-
Composite trunk muscle size, cm				
Baseline	8.36 (1.1)	8.77 (1.2)	-0.40 (-1.0 to 0.20)	0.18
6 weeks	9.91 (1.2)	8.79 (1.1)	1.11 (0.51 to 1.70)	<0.001
12 weeks	10.62 (1.2)	8.93 (1.1)	1.68 (1.09 to 2.27)	<0.001
Mean difference (95% CI): Baseline vs. week 6	1.54 (1.41 to 1.67)	0.02 (-0.09 to 0.15)	-	-
Mean difference (95% CI): Baseline vs. week 12	2.25 (2.13 to 2.38)	0.16 (0.05 to 0.28)	-	-

[a]All differences are adjusted for the baseline value of the outcome variables.
CSA cross sectional area, ***L4/L5*** lumbar spinal level L4/L5, ***L5/S1*** lumbar spinal level L5/S1

Table 3. Changes[a] in trunk muscle strength in response to exercise program

Outcome measures	Trunk strengthening exercise group (n=32)	Walking-balance exercise group (n=32)	Mean between-group difference (95% CI)	*P*-values
Trunk flexion strength, N				
Baseline	120.38 (48.6)	129.72 (53.4)	-9.3 (-34.4 to 15.7)	0.46
6 weeks	137.09 (52.0)	128.09 (51.14)	8.9 (-16.1 to 34.1)	0.47
12 weeks	157.20 (54.5)	127.14 (45.3)	30.0 (4.1 to 55.9)	0.02
Mean difference (95% CI): Baseline vs. week 6	16.70 (10.38 to 23.03)	-1.62 (-7.64 to 4.39)	-	-
Mean difference (95% CI): Baseline vs. week 12	36.81 (29.15 to 44.48)	-2.57 (-9.96 to 4.82)	-	-
Trunk extension strength, N				
Baseline	91.5 (48.4)	87.2 (41.8)	4.2 (-20.2 to 28.8)	0.73
6 weeks	113.9 (47.0)	93.8 (42.1)	18.4 (-3.7 to 40.6)	0.10
12 weeks	130.8 (52.4)	90.6 (39.9)	38.4 (15.0 to 61.7)	<0.001
Mean difference (95% CI): Baseline vs. week 6	22.10 (12.40 to 31.80)	7.91 (-1.40 to 17.23	-	-
Mean difference (95% CI): Baseline vs. week 12	38.98 (27.91 to 50.06)	4.84 (-5.83 to 15.51)	-	-
Trunk right lateral flexion strength, N				
Baseline	65.65 (28.5)	65.75 (31.2)	-0.09 (-18.8 to 18.6)	0.99
6 weeks	96.36 (42.6)	64.43 (17.6)	31.9 (16.1 to 47.7)	<0.001
12 weeks	116.64 (46.5)	63.38 (19.9)	53.2 (36.4 to 70.1)	<0.001
Mean difference (95% CI): Baseline vs. week 6	30.702 (21.34 to 40.06)	-1.31 (-10.35 to 7.73)	-	-
Mean difference (95% CI): Baseline vs. week 12	50.98 (40.72 to 61.24)	-2.370 (-12.31 to 7.57)	-	-
Trunk left lateral flexion strength, N				
Baseline	57.7 (25.9)	57.0 (26.4)	0.70 (-14.4 to 15.8)	0.92
6 weeks	85.8 (36.07)	58.9 (23.6)	24.8 (10.5 to 39.1)	<0.001
12 weeks	114.4 (44.8)	61.7 (20.2)	52.6 (36.1 to 69.0)	<0.001
Mean difference (95% CI): Baseline vs. week 6	26.15 (18.25 to 34.06)	1.97 (-5.61 to 9.56)	-	-
Mean difference (95% CI): Baseline vs. week 12	56.73 (46.89 to 66.58)	4.83 (-4.70 to 14.36)	-	-

Table 3 continued

Outcome measures	Trunk strengthening exercise group (n=32)	Walking-balance exercise group (n=32)	Mean between-group difference (95% CI)	*P*-values
Trunk lateral flexion strength (mean right/left), N				
Baseline	61.6 (26.4)	61.3 (27.1)	0.30 (-16.5 to 17.1)	0.97
6 weeks	90.0 (38.2)	61.6 (19.5)	28.3 (13.7 to 42.9)	<0.001
12 weeks	115.4 (45.1)	62.5 (18.4)	52.8 (36.7 to 69.0)	<0.001
Mean difference (95% CI): Baseline vs. week 6	28.367 (20.47 to 36.25)	0.344 (-7.26 to 7.95)	-	-
Mean difference (95% CI): Baseline vs. week 12	53.79 (44.45 to 63.14)	1.21 (-7.82 to 10.26)	-	-
Composite trunk strength				
Baseline	339.3 (130.0)	339.7 (120.7)	-4.4 (-76.0 to 67.1)	0.90
6 weeks	429.8 (160.3)	347.1 (116.8)	82.6 (14.9 to 150.3)	0.01
12 weeks	517.7 (184.2)	345.0 (97.6)	172.6 (100.8 to 244.5)	<0.001
Mean difference (95% CI): Baseline vs. week 6	94.52 (71.90 to 117.15)	7.41 (-14.23 to 29.05)	-	-
Mean difference (95% CI): Baseline vs. week 12	182.38 (153.78 to 210.99)	5.26 (-22.26 to 32.79)	-	-

[a] All differences are adjusted for the baseline value of the outcome variables.

Table 4. Changes[a] in functional mobility and balance in response to exercise program

Outcome measures	Trunk strengthening exercise group (n=32)	Walking-balance exercise group (n=32)	Mean between-group difference (95% CI)	*P*-values
Six Minute Walk Test, m				
Baseline	567.5 (93.0)	552.1 (79.9)	15.3 (-46.1 to 76.9)	0.62
6 weeks	612.1 (98.2)	591.4 (103.9)	20.7 (-31.6 to 73.1)	0.43
12 weeks	660.9 (107.6)	613.6 (108.7)	47.2 (-5.8 to 100.3)	0.08
Mean difference (95% CI): Baseline vs. week 6	44.56 (17.19 to 71.94)	39.24 (12.82 to 65.66)	-	-
Mean difference (95% CI): Baseline vs. week 12	93.351 (65.29 to 121.41)	61.48 (34.34 to 88.62)	-	-
30-Second Chair Stand Test, reps				
Baseline	16.2 (4.2)	16.3 (4.9)	-0.09 (-2.5 to 2.3)	0.93
6 weeks	21.0 (5.1)	17.9 (5.1)	3.1 (0.68 to 5.5)	0.01
12 weeks	25.1 (5.5)	19.2 (5.4)	5.9 (3.3 to 8.4)	<0.001
Mean difference (95% CI): Baseline vs. week 6	4.78 (3.70 to 5.85)	1.56 (0.51 to 2.60)	-	-
Mean difference (95% CI): Baseline vs. week 12	8.93 (7.73 to 10.14)	2.91 (1.76 to 4.06)	-	-
Sitting and Rising Test, points				
Baseline	5.3 (1.8)	6.1 (2.2)	-0.62 (-1.6 to 0.44)	0.24
6 weeks	7.2 (1.2)	6.3 (2.2)	0.89 (-0.09 to 1.8)	0.07
12 weeks	7.8 (1.1)	6.6 (2.5)	1.2 (0.22 to 2.2)	0.01
Mean difference (95% CI): Baseline vs. week 6	1.81 (1.30 to 2.33)	0.29 (-0.21 to 0.79)	-	-
Mean difference (95% CI): Baseline vs. week 12	2.49 (1.93 to 3.05)	0.61 (0.07 to 1.15)	-	-
Berg Balance Scale				
Baseline	51.7 (4.1)	52.3 (4.0)	-0.59 (-2.5 to 1.3)	0.54
6 weeks	54.8 (1.4)	53.9 (3.0)	0.84 (-0.40 to 2.1)	0.18
12 weeks	55.2 (0.87)	54.3 (2.6)	0.91 (-0.31 to 2.1)	0.13
Mean difference (95% CI): Baseline vs. week 6	3.02 (1.79 to 4.26)	1.58 (0.36 to 2.80)	-	-
Mean difference (95% CI): Baseline vs. week 12	3.48 (2.28 to 4.68)	1.97 (0.79 to 3.15)	-	-

Table 4 continued

Outcome measures	Trunk strengthening exercise group (n=32)	Walking-balance exercise group (n=32)	Mean between-group difference (95% CI)	*P*-values
Forward Reach Test, cm				
Baseline	27.5 (4.5)	28.9 (4.9)	-1.3 (-3.8 to 1.1)	0.28
6 weeks	31.9 (3.7)	29.8 (4.4)	2.0 (-0.02 to 4.0)	0.06
12 weeks	34.9 (4.7)	30.7 (4.8)	4.2 (1.8 to 6.6)	<0.001
Mean difference (95% CI): Baseline vs. week 6	4.37 (2.97 to 5.77)	0.98 (-0.38 to 2.35)	-	-
Mean difference (95% CI): Baseline vs. week 12	7.44 (5.77 to 9.11)	1.83 (0.22 to 3.45)	-	-
Backward Reach Test, cm				
Baseline	15.2 (2.5)	16.9 (4.0)	-0.17 (-3.8 to 0.37)	0.10
6 weeks	18.8 (2.7)	17.4 (4.2)	1.3 (-0.49 to 3.2)	0.14
12 weeks	21.0 (3.7)	18.6 (5.0)	2.4 (0.22 to 4.5)	0.03
Mean difference (95% CI): Baseline vs. week 6	3.61 (2.49 to 4.74)	0.52 (-0.57 to 1.62)	-	-
Mean difference (95% CI): Baseline vs. week 12	5.85 (4.45 to 7.25)	1.73 (0.38 to 3.07)	-	-
Right Reach Test, cm				
Baseline	19.4 (4.8)	19.5 (4.7)	-0.15 (-2.7 to 2.4)	0.90
6 weeks	23.5 (3.7)	21.7 (4.2)	1.8 (-0.22 to 3.8)	0.08
12 weeks	25.2 (3.7)	23.9 (4.3)	1.3 (-0.876 to 3.5)	0.23
Mean difference (95% CI): Baseline vs. week 6	4.10 (2.63 to 5.57)	2.12 (0.68 to 3.57)	-	-
Mean difference (95% CI): Baseline vs. week 12	5.84 (4.26 to 7.43)	4.37 (2.83 to 5.91)	-	-
Left Reach Test, cm				
Baseline	18.5 (4.8)	19.6 (4.5)	-1.0 (-3.4 to 1.3)	0.37
6 weeks	22.7 (4.5)	21..9 (4.2)	0.80 (-1.3 to 2.9)	0.45
12 weeks	25.6 (3.7)	23.0 (4.0)	1.6 (-0.45 to 3.7)	0.12
Mean difference (95% CI): Baseline vs. week 6	4.27 (2.82 to 5.72)	2.39 (.97 to 3.81)	-	-
Mean difference (95% CI): Baseline vs. week 12	7.07 (5.64 to 8.50)	4.35 (2.96 to 5.74)	-	-
Timed Up and Go Test, sec				
Baseline	7.5 (1.2)	7.3 (2.1)	0.11 (-0.75 to 0.97)	0.79
6 weeks	6.1 (1.0)	6.4 (1.1)	-0.30 (-0.95 to 0.34)	0.34
12 weeks	5.6 (0.98)	6.3 (1.3)	-0.74 (-1.4 to -0.03)	0.04
Mean difference (95% CI): Baseline vs. week 6	-1.36 (-1.84 to -0.88)	-0.94 (-1.41 to -0.47)	-	-
Mean difference (95% CI): Baseline vs. week 12	-1.88 (-2.40 to -1.35)	-1.02 (-1.53 to -0.51)	-	-

Table 4 continued

Outcome measures	**Trunk strengthening exercise group (n=32)**	**Walking-balance exercise group (n=32)**	**Mean between-group difference (95% CI)**	***P*-values**
Four Step Square Test, sec				
Baseline	8.5 (1.6)	8.0 (1.4)	0.50 (-0.29 to 1.31)	0.21
6 weeks	6.8 (1.1)	7.4 (1.3)	-0.59 (-1.2 to 0.08)	0.08
12 weeks	6.4 (1.1)	6.8 (1.1)	-0.47 (-1.1 to 0.18)	0.15
Mean difference (95% CI): Baseline vs. week 6	-1.70 (-2.15 to -1.25)	-0.60 (-1.03 to -0.16)	-	-
Mean difference (95% CI): Baseline vs. week 12	-2.16 (-2.59 to -1.73)	-1.18 (-1.60 to -0.76)	-	-

[a]All differences are adjusted for the baseline value of the outcome variables.

Chapter 6

General Discussion

Overview

Age-related declines in skeletal muscle size are accompanied by diminished muscle strength and function [1, 2], which are in turn associated with reduced quality of life [3] and increased risk of falls [4]. Falls are a major health concern in older adults worldwide. One-third of older adults experience one or more falls per year [5]. Falls can result in serious injuries (e.g., hip fractures and head trauma), which greatly amplify risk of permanent disability, socioeconomic burden and risk of early mortality in older adults [6]. Improved falls prevention strategies are thus a primary health care target for older adults [7].

Earlier studies investigating the associations between age-related decrements in muscle strength and functional outcomes in older adults have focused mainly on peripheral musculature, through examining handgrip strength and knee extensor strength [8, 9]. These studies have provided empirical support to the benefits of multimodal exercise programs incorporating balance and resistance-based training to target peripheral musculature, and in reducing both the rate and risk of falls in older adults [10, 11]. More recent research has now also focused on age-related changes in the trunk musculature [4, 12-14] due to the important role of these muscles in performing activities of daily living, balance, mobility, and falls prevention in older adults [15-17]. A systematic review by Granacher et al [17] identified low, but significant associations between trunk muscle composition, strength, functional ability and risk of falls in older adults; however, the studies they reported had high levels of heterogeneity in subject cohorts and testing methodology. The authors [17] thus called on additional research to investigate these associations in in older adults. Additionally, the authors [17] reported that including trunk strengthening exercises into exercise programs improved trunk muscle strength, balance and functional ability in older adults; however, they also acknowledged that the benefits of incorporating trunk strengthening exercises on function and balance in older adults require further investigation.

Therefore, the overarching aims of this dissertation were to explore the relationships between trunk muscle morphology (size), strength, and functional ability, and to then empirically determine the effects of an exercise program on these outcomes in healthy older adults. Specifically, we sought to i) systematically review the extant literature assessing the effectiveness of different types of exercise programs on trunk muscle morphology; ii) explore the associations between trunk muscle morphology, strength and functional ability in healthy older adults; iii) determine the effectiveness of a 12-week supervised multimodal exercise program comprising of walking and balance exercises, with or without trunk strengthening /motor control exercise on trunk muscle morphology, strength, and functional ability in healthy older adults. This dissertation comprises a systematic review, a cross sectional study, and a single-blinded parallel group randomized clinical trial.

Systematic Review (Chapter 2)

This study involved systematically reviewing the extant literature, to determine the effectiveness of different exercise programs on trunk muscle morphology [18]. We conducted a systematic search strategy in the following databases: Pub-Med, SportDiscus, CINAHL, the Cochrane Library and PEDro. We included full, peer-reviewed, prospective longitudinal studies, including randomized controlled trials and single-group designs, such as pre- to post-intervention and crossover studies, reporting on the effect of exercise training on trunk muscle morphology. Study quality was assessed with the Cochrane risk of bias tool. We classified each exercise program into four categories based on the primary exercise approach: motor control, machine-based resistance, non-machine-based resistance, or cardiovascular. Treatment effects were estimated using within-group standardized mean differences (SMDs).

Our systematic search identified 1,910 citations: 597 from SportDiscus, 595 from PubMed, 495 from CINAHL, 143 from CENTRAL and 80 from PEDro. Of these citations, 382 were duplicates, thus yielding 1,529 unique studies. The title and abstract screen resulted in 122 potentially relevant studies being identified and retained for full-text review. Ultimately, 29 studies met our selection criteria and were analysed. The main findings of this review were: i) Of the 29 included studies, 14 (48 %) reported positive changes in trunk muscle morphology following participation in an exercise training program; ii) Exercise programs comprising motor control exercises combined with non-machine-based resistance exercises, as well as machine-based resistance exercise programs, demonstrated the largest effects (medium to large) on trunk muscle morphology while cardiovascular exercise programs had no effect on trunk muscle morphology; iii) there was substantial risk of bias and suboptimal reporting of exercise details in the included studies. As a result of the clinical heterogeneity related to differences in the sample populations, exercise modes, exercise prescriptions, outcome muscles, and methods of muscle measurement amongst the included studies, it was not possible to complete a meta-analysis.

To summarize, this systematic review identified that exercise programs comprising motor control exercises combined with non-machine-based resistance exercises, as well as machine-based resistance exercise programs, demonstrated positive effects on trunk muscle morphology. However, the systematic review has also revealed that many of the included studies suffered from numerous methodological limitations. In light of this, there was a clear need for high-quality randomized controlled trials to identify the response in trunk muscle morphology to an exercise program (s) targeting this region.

Cross-Sectional Study (Chapter 4)

The relationships between trunk muscle morphology, strength, and functional ability in healthy older adults were not clear. Therefore, this study first involved exploring the associations between trunk muscle morphology (size), strength, and functional ability in healthy older adults.

This analysis was completed on the baseline data of our Randomized Controlled Trial (Chapter 5). Briefly, we recruited healthy older adults, aged 60 years or older, with no history of lumbar surgery and no medical conditions precluding safe participation in an exercise program. Trunk muscle morphology and strength (flexion, extension, and lateral flexion) were assessed using ultrasound imaging and the HUMAC NORM isokinetic dynamometer, respectively. Functional and balance outcomes were assessed using Six-Minute Walk Test (6MWT), 30-second Chair Stand Test (CST), Sitting and Rising Test (SRT), Berg Balance Scale (BBS), Forward, Backward, Right and Left Reach Tests (FRT, BRT, RRT, and LRT respectively), Timed Up and Go Test (TUG), and Four Square Step Test (FSST). Univariate and multivariate analyses were performed with correlation and linear regression, and reported with correlation coefficients (r) and standardized beta coefficients (β) respectively. Age, sex, and BMI were considered as potential covariates in each multivariate model.

Sixty-four healthy older adults (mean (SD) age 69.8 (7.5) years; 59.4% female) participated in our cross-sectional study.The most important outcomes of this study were that: i) univariate analyses revealed small-moderate positive correlations between trunk muscle morphology, strength, and various functional outcome measures. More specifically, larger RA CSA was most consistently associated with better 6MWT, FRT, BRT, CST, and SRT outcomes. LM thickness was associated with better TUG and FSST outcomes, while TLAM thickness and composite trunk muscle size were associated with better BRT outcome. Increased composite trunk strength was consistently associated with better 6MWT, CST, SRT, BBS, FRT, and BRT outcomes. TLAM thickness and RA CSA were consistently and positively associated with all trunk muscle strength measures (flexion, extension, lateral flexion, and composite trunk strength). LM thickness was positively associated with trunk flexion strength, while composite trunk muscle size was positively associated with flexion, extension, and composite trunk strength. ii) After controlling for covariates (age, sex, and /or BMI), multivariate analyses revealed larger RA CSA was associated with lower 6MWT outcome, while larger RA CSA was associated with better SRT, and BRT outcomes. LM thickness was associated with better FSST outcome. Trunk flexion strength was associated with better FRT outcome, while composite trunk strength was associated with better SRT outcome. RA CSA was positively associated with trunk flexion and composite trunk strength, while TLAM thickness was positively associated with trunk flexion strength. iii) In addition to the above main findings, age, sex, and /or BMI had strong influences on performance in various functional tasks.

The findings of important relationships between trunk muscle morphology and strength with functional ability in older adults corroborated the need to assess whether balance and functional performance could be improved by training the trunk musculature.

Randomized Controlled Trial (Chapter 5)

The third and most significant study of this dissertation involved a single-blinded parallel group randomized controlled trial investigating the effectiveness of a 12-week supervised multimodal exercise program on trunk muscle morphology (size), strength, and functional ability in healthy older adults. Specifically, this study investigated the effect of supplementing a 12-week walking and balance exercise program with trunk muscle strengthening /motor control exercises on trunk muscle morphology, strength, and functional ability in healthy older adults; to address the short-comings previously outlined by Granacher et al [17]. Sixty four individuals (mean (SD) age 69.8 (7.5) years; 59.4% female) underwent a series of baseline assessments (see above cross-sectional study), and were eventually randomised to receive a multimodal exercise program comprising various walking and balance exercises with or without trunk muscle strengthening/motor control exercises. Trunk muscle morphology and strength (flexion, extension, and lateral flexion) were assessed in this study at week 6 and 12, using the same equipment outlined in the cross-sectional study. The same functional outcome measures from the cross-sectional study were also utilized in this study, and were administered at week 6 and 12. Consistent with the intention-to-treat principle, all data was analyzed using a linear mixed model, and the main effects of exercise group and the exercise group by time interactions explored.

The most important outcomes of this study were that: i) inclusion of trunk strengthening/motor control exercises was associated with significant increases in trunk muscle morphology and strength; ii) inclusion of trunk strengthening/motor control exercises was associated with significant improvements in functional outcome measures, including the 30-Second Chair Stand Test, Sitting and Rising Test, Forward Reach Test, Backward Reach Test, and Timed Up and Go Test. Overall, the inclusion of trunk strengthening/motor control exercises into the exercise program was efficacious across a number of outcome measures when compared to a time-matched walking and balance exercise program, and was not associated with any deleterious outcomes.

Apart from utilizing a randomized controlled design to comprehensively examine the efficacy of a 12-week multimodal exercise program via intention-to-treat analyses; this study had other notable strengths. First, the current exercise program's design contributed to high exercise compliance with low rates of dropout. Specifically, participants perceived the exercise program as easy to access, wherein exercises were simple to learn and required no specific equipment. Despite these strengths, the findings of the current study should be considered in light of several limitations. The participants included in this study were healthy and moderately active older adults. Therefore, the results of our study should be generalized only with caution to other populations (e.g., sedentary, overweight/obese, frail/at high risk of falls older adults, frail older adults at high risk of falls, neuromuscular, mobility/balance limited patients). In addition, the results of this study are specific to the testing methodology used to assess trunk muscle morphology, strength and functional performance balance performance. Our outcome measures may not represent all the components of trunk muscle morphology, strength, mobility, and balance; therefore, the findings of our study should be generalised with caution to other experimental assessment techniques (i.e., MRI imaging, isokinetic trunk strength, force-plate for balance and postural sway measurements).

Clinical Implications

These findings have important clinical implications for practitioners and clinicians. First, these findings emphasize the importance in evaluating age-related changes in trunk muscle morphology, strength, and functional ability and implement appropriate exercise programs to enhance these clinical outcomes. Second, based on the findings of this study, it is recommended that multimodal trunk strengthening exercise programs should be implemented as an alternate form of rehabilitation, to improve trunk muscle morphology, strength, functional ability among older adults. Targeting these aspects may consequently combat age-related decrements in trunk muscle morphology, strength, and functional ability.

Future Directions

Future research should focus on the strengthening of the anterior, lateral abdominal and posterior trunk muscles which are positively associated with functional ability in older adults. Future research also should investigate the longitudinal changes in falls risk and subsequent rate of falls following trunk strengthening exercise program among healthy and clinical populations (i.e., sedentary, frail older adults, obese/overweight, musculoskeletal disorders, neuromuscular, mobility/balance limited patients). Additionally, high quality randomised control trials could be designed to examine the effectiveness of trunk strengthening exercise program on trunk muscle size, strength and functional ability in clinical populations (i.e., sedentary, frail older adults, obese/overweight, musculoskeletal disorders, neuromuscular, mobility/balance limited patients), athletic population /injury prevention, longer training length (i.e., 6 or 12 months), and following a detraining phase. Furthermore, future studies should examine functional and physical effects of the current study's trunk strengthening exercise program in comparison with different types of gentle and free weights exercise programs (i.e., yoga, Pilates, Tai chi, BodyBalance).

References

1. Goodpaster, B.H., et al., *The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study.* J Gerontol A Biol Sci Med Sci, 2006. **61**(10): p. 1059-64.
2. Metter, E.J., et al., *Age-associated loss of power and strength in the upper extremities in women and men.* J Gerontol A Biol Sci Med Sci, 1997. **52**(5): p. B267-76.
3. Heathcote, G., *Autonomy, health and ageing: transnational perspectives.* Health Educ Res, 2000. **15**(1): p. 13-24.
4. Kasukawa, Y., et al., *Relationships between falls, spinal curvature, spinal mobility and back extensor strength in elderly people.* J Bone Miner Metab, 2010. **28**(1): p. 82-7.
5. Campbell, A.J., et al., *Falls in old age: a study of frequency and related clinical factors.* Age Ageing, 1981. **10**(4): p. 264-70.
6. Sartini, M., et al., *The epidemiology of domestic injurious falls in a community dwelling elderly population: an outgrowing economic burden.* Eur J Public Health, 2010. **20**(5): p. 604-6.
7. Rubenstein, L.Z. and K.R. Josephson, *Falls and their prevention in elderly people: what does the evidence show?* Med Clin North Am, 2006. **90**(5): p. 807-824.
8. Martien, S., et al., *Is knee extension strength a better predictor of functional performance than handgrip strength among older adults in three different settings?* Arch Gerontol Geriatr, 2015. **60**(2): p. 252-8.
9. Bohannon, R.W., *Hand-grip dynamometry predicts future outcomes in aging adults.* J Geriatr Phys Ther, 2008. **31**(1): p. 3-10.
10. Tofthagen, C., C. Visovsky, and D.L. Berry, *Strength and balance training for adults with peripheral neuropathy and high risk of fall: current evidence and implications for future research.* Oncol Nurs Forum, 2012. **39**(5): p. E416-24.
11. Granacher, U., L. Zahner, and A. Gollhofer, *Strength, power, and postural control in seniors: Considerations for functional adaptations and for fall prevention.* Eur J Sport Sci, 2008. **8**(6): p. 325-340.

12. Granacher, U., et al., *Relationships between trunk muscle strength, spinal mobility, and balance performance in older adults.* J Aging Phys Act, 2014. **22**(4): p. 490-8.
13. Pfeifer, M., et al., *Vitamin D status, trunk muscle strength, body sway, falls, and fractures among 237 postmenopausal women with osteoporosis.* Exp Clin Endocrinol Diabetes, 2001. **109**(2): p. 87-92.
14. Sakari-Rantala, R., et al., *Associations of sensory-motor functions with poor mobility in 75- and 80-year-old people.* Scand J Rehabil Med, 1998. **30**(2): p. 121-7.
15. Suri, P., et al., *Trunk muscle attributes are associated with balance and mobility in older adults: a pilot study.* PM R, 2009. **1**(10): p. 916-24.
16. Hicks, G.E., et al., *Cross-sectional associations between trunk muscle composition, back pain, and physical function in the health, aging and body composition study.* J Gerontol A Biol Sci Med Sci, 2005. **60**(7): p. 882-7.
17. Granacher, U., et al., *The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: a systematic review.* Sports Med, 2013. **43**(7): p. 627-41.
18. Shahtahmassebi, B., et al., *The effect of exercise training on lower trunk muscle morphology*. Sports Med, 2014. **44**(10): p. 1439-58.

Appendices

Appendix A

(Recruitment materials; Ethics, Study Flyer, Information Letter, Consent Form, Demographic Questionnaire, Medical Clearance Form, and Adult Pre-Exercise Screening Tool)

Murdoch
UNIVERSITY

www.murdoch.edu.au

Research Ethics Office
Division of Research and Development

Chancellery Building
South Street
MURDOCH WA 6150
Telephone: 9360 6677
Facsimile: 9360 6686
human.ethics@murdoch.edu.au
www.research.murdoch.edu.au/ethics

Thursday, 14 November 2013

Dr Timothy Fairchild
School of Psychology and Exercise Science
Murdoch University

Dear Timothy,

Project No. 2013/140
Project Title Assessing the psychological and physiological efficacy of an exercise intervention in aged individuals: Is there a role for core-stability training?

Thank you for addressing the conditions placed on the above application to the Murdoch University Human Research Ethics Committee. On behalf of the Committee, I am pleased to advise the application now has:

OUTRIGHT APPROVAL

Approval is granted on the understanding that research will be conducted according the standards of the ***National Statement on Ethical Conduct in Human Research*** **(2007), the** ***Australian Code for the Responsible Conduct of Research*** **(2007) and Murdoch University policies at all times. You must also abide by the Human Research Ethics Committee's standard conditions of approval (see attached). All reporting forms are available on the Research Ethics web-site.**

I wish you every success for your research.

Please quote your ethics project number in all correspondence.

Kind Regards,

Dr. Erich von Dietze
Manager of Research Ethics

cc: Dr Jeffrey Herbert, Dr Mark Hecimovich, Dr Helen Correia, Behnaz Shahtahmassebi and Jacinta Hatton

CRICOS Provider Code: 00125J
ABN 61 616 369 313

Murdoch University Human Research Ethics
Committee (Approval 2013/140)

Free supervised exercise training program

Are you 60 years or older?
Interested in improving your health and well-being?

The School of Psychology and Exercise Science is seeking eligible volunteers to participate in an exercise study.

We are seeking to recruit:

1. Individuals 60 years or older
2. Willing to participate in a supervised exercise program

Why is this exercise important?
Loss of strength and muscle often accompanies aging and may lead to a reduced quality of life. We aim to investigate how different types of exercise may enhance health and wellbeing.

What will be required?

1. Three supervised exercise sessions per week over the course of 18 weeks at Murdoch University.

2. Four assessments with the first being before you begin the exercise sessions, one at the end of the week 6, one at the end of the week 12 and the final testing will be at the end of the week 18. These assessments will be conducted at the Exercise Science laboratory at Murdoch University and include:
   i. Strength and muscle size
   ii. Balance
   iii. Quality of life
   iv. Mood

What are the benefits?

1- Free assessments on strength and balance
2- Free supervised exercise program running for 18 weeks; developed by Exercise Experts.

Interested to find out more?
If you are interested in participating and/or finding out more, please contact Miss Behnaz Shahtahmassebi or Miss Jacinta Hatton.

Behnaz Shahtahmassebi
B.Shahtahmassebi@murdoch.edu.au
Phone: 0434214532

Jacinta Hatton
Phone: 0412418712

Information Letter

Assessing the psychological and physiological efficacy of an exercise intervention in aged individuals: Is there a role for core-stability training?

We invite you to participate in a research study aiming to identify the effects of a 12-week exercise training program on physical (muscle strength and size) and psychological (mood) measures. We then aim to see whether those changes have a positive effect on your quality of life. This study is being conducted by Miss Behnaz Shahtahmassebi as part of her PhD, as well as Ms Jacinta Hatton and Ms Sarah Malley, as part of their postgraduate (Clinical Masters) training. The supervisors of the project include Dr. Timothy Fairchild, Dr. Jeffrey Hebert, Dr Helen Correia and Dr. Mark Hecimovich from the School of Psychology and Exercise Science at Murdoch University.

Nature and Purpose of the Study
Age-related loss of muscle size and strength leads to reduced engagement in physical activity, and difficulty in performing some daily tasks. This may then affect quality of life and have negative effects on mood and sleep. Here we aim to explore whether the usual benefits of participation in exercise such as improved health, strength and overall fitness may improve the multiple factors comprising quality of life.
If you consent to take part in this research study, it is important that you understand the purpose of the study and the procedures you will be asked to undertake. Please make sure that you ask any questions you may have, and that all your questions have been answered to your satisfaction before you agree to participate.

Eligibility criteria
Regarding the inclusion criteria of this study, we are seeking to engage individuals who are 60 years or older and are able to participate in a structured exercise program. We will ask you a series of questions regarding your health and at the end of these questions we may request that you seek clearance from your doctor prior to participation in this exercise program.

Please note that there may be circumstances where the doctor may not grant this clearance and we may then not be able to enrol you into the exercise training program.

Since this project includes assessment of strength and a training program which targets the lower back, we will need to exclude you from the evaluation and training program if you have any of the following:

1. A history of lumbar surgery
2. Any medical condition and prescribed medication, which may preclude safe participation in an exercise intervention
3. Unable to communicate and fill in the questionnaires in English

What the Study will Involve

If you decide to participate in this study, we will take a series of measurements at the start of the program including:

(i) The size of muscles in your lower back and stomach area with an ultrasound device
(ii) Assessing the strength of the muscles in your stomach and lower back using a purpose-built commercially available machine
(iii) Assess your balance

This testing is expected to take 45-60min.

We will also ask you to fill in a number of forms which will be used to assess:

(iv) Your falls-risk score, performance of activities of daily living, quality of life
(v) Your mood and well-being

This testing is expected to take 30-45min.

To measure your physical activity and sleep, we will also ask you to wear a device called an ActiGraph, for one week during the day and night. This small device measures your movement (but not your location), much like a step counter.

After this testing we will invite you to participate in an 18-week supervised exercise program which will include either walking or an indoor-based exercise training program. The researchers will assign you to one of these exercise programs. Each session will be held 3 times per week for 45 minutes per session. The measures and questionnaires mentioned above will then be repeated after 6-, 12- and 18-weeks. This testing will occur at Murdoch University.

What will happen with the information?

Once all the information has been received, we will then de-identify the data using a unique code (numbering system) prior to storing the data. This means that a random number will be assigned to you which we will then use through use throughout the study to be able to compare your scores from the start, to week 6, 12 and 18.

It also means that anyone who looks through the files will not know who the actual individual is. All analysis will then be performed on this data that has been de-identified. All information will then be released as group-data, so no one individual will be identifiable from the research findings.

Since we are collecting a large amount of information, it is important to note that we may use some of that information for some additional analysis at a later stage. There could for example, be some very important relationships between the strength of stomach muscles and back muscles with quality of life which we did not anticipate, but we feel is important to announce since it will be beneficial to the community.

Voluntary Participation and Withdrawal from the Study

Your participation in this study is entirely voluntary. You may withdraw at any time without discrimination or prejudice. All information is treated as confidential and no names or other details that might identify you will be used in any publication arising from the research. If you withdraw prior to data analysis, all information you have provided will be destroyed.

Benefits of the Study

Participants in our study will be provided with:

a) A free exercise training program (36 exercise sessions in total), supervised by exercise experts.
b) Accurate information regarding their dynamic and static balance, falls-risk scores, level of daily living activities and quality of life Accurate information regarding their dynamic and static balance, falls-risk scores, level of daily living activities and quality of life.
c) Information related to the benefits of exercise in aging; specifically related to musculoskeletal performance
d) A $20 reimbursement for participation

Possible Risks

There are some minor risks associated with the testing sessions, which include feelings of fatigue afterwards and feelings of muscular discomfort due to the level of exertion required during these sessions. We will minimize the risks by monitoring supervising you closely during the tests.

Furthermore, if you experience any feeling of great discomfort during the exercise conditions, it is important for you to understand that you can ask the investigator to stop the experiment at any stage without having to provide an explanation.

The risks associated with the exercise training are expected to be minor only since we will closely supervise you at all times.

If you have any questions about this project please feel free to contact either Miss Behnaz Shahtahmassebi (9360 6474; or 0434214532 ; or b.shahtahmassebi@murdoch.edu.au); or Ms Jacinta Hatton (31791875@student.murdoch.edu.au; or 0412418712) or one of the supervisors:
Dr Tim Fairchild (9360 2959; or t.fairchild@murdoch.edu.au)
Dr Jeffrey Hebert (9360 2566 or J.Hebert@murdoch.edu.au)
Dr Helen Correia (9360 2290 or h.correia@murdoch.edu.au)

Once we have analyzed the information from this study we will publish the results of the study on the Murdoch University School of Psychology and Exercise Science website: http://www.murdoch.edu.au/School-of-Psychology-and-Exercise-Science/Research/Exercise-Science-Research/.

We will also provide a talk at the completion of the study presenting a summary of the findings. You can expect to receive this feedback within a few months of completing the project and we expect the information to be available by December 2014.

If you are willing to consent to participation in this study, please complete the Consent Form. Thank you for your assistance with this research project.
Thank you for your assistance with this research project.

Sincerely,

Timothy Fairchild

This study has been approved by the Murdoch University Human Research Ethics Committee (Approval 2013/140). If you have any reservation or complaint about the ethical conduct of this research, and wish to talk with an independent person, you may contact Murdoch University's Research Ethics Office (Tel. 08 9360 6677 (for overseas studies, +61 8 9360 6677) or e-mail ethics@murdoch.edu.au). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Consent Form

Assessing the psychological and physiological efficacy of an exercise intervention in aged individuals: Is there a role for core-stability training?

1. I agree voluntarily to take part in this study.
2. I have read the Information Sheet provided and been given a full explanation of the purpose of this study, of the procedures involved and of what is expected of me. The researcher has answered all my questions and has explained the possible problems that may arise as a result of my participation in this study.
3. I understand I am free to withdraw from the study at any time without needing to give any reason.
4. I understand I will not be identified in any publication arising out of this study.
5. I understand that my name and identity will be stored separately from the data, and these are accessible only to the investigators. All data provided by me will be analysed anonymously using code numbers.
6. I understand that there may be some secondary analysis of data. This may be conducted to explore any unexpected research findings.
7. I understand that all information provided by me is treated as confidential and will not be released by the researcher to a third party unless required to do so by law.

Signature of Participant: ________________________ Date: ………./…….…../……….
(Name) (Day) (Month) (Year)

Signature of researcher: ________________________ Date: ………./…….…../……….
(Name) (Day) (Month) (Year)

Examiner Code: ……………………
Participant Code: …………………..
Date of assessment: ………../……..../………..
Day Month Year

Murdoch University
Perth Western Australia

Demographic Information Questionnaire
School of Psychology and Exercise Science

Please Provide the Following Information:
Title:………… **First name:**……………… **Surname**: ……………………
Address: …………………………………………………………………   …………………………………………………………………………
Telephone:……………………… **Mobile:** ……………………..………   **Email:**…………………………………………………………………........

Date of Birth: ……………../…………../……………
(Day) ***(Month)*** ***(Year)***

Please read each question carefully and cross the appropriate box (×)

1. **Gender:**
   - ☐ Male
   - ☐ Female

2. **Marital status:**
   - ☐ Never married
   - ☐ Married/Partnered
   - ☐ Separated/Divorced
   - ☐ Widowed

3. **Education Level**
   - ☐ No formal schooling
   - ☐ Primary school
   - ☐ Some secondary school
   - ☐ Completed secondary school
   - ☐ Bachelor's degree
   - ☐ Graduate degree/professional
   - ☐ Other (please specify) ……………………………………….

4. **Which of the following best describe your living status?**
   - ☐ Live alone
   - ☐ Living with one or more people

5. **Do you drive?**
   - ☐ Yes
   - ☐ No

6. **Do you Use a Walking Aid?**
   - ☐ Yes
   - ☐ No

7. **If you answered "Yes" to question <u>6</u> what type of Walking Aid do you use**?
   - ☐ Stick
   - ☐ Walking Frame
   - ☐ Other (please specify) ……………………………………………………………….

8. **Do you wear Glasses or Contact Lenses?**
   - ☐ No
   - ☐ Yes, if yes, have you noticed any symptoms of impaired vision, please specify any symptoms ……………………………………………………………………….

9. **Do you use any Hearing Aids?**
   - ☐ No
   - ☐ Yes, if yes, have you noticed any symptoms of impaired hearing, please specify any symptoms

     ……………………………………………………………………….

10. **Please list your occupation prior to retirement.**

    ………………………………………………………………………………………………

11. **Please list your current occupation or responsibilities.**

    ………………………………………………………………………………………………

– This question is about the time you spent being physically active days. Any physical activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation or sport.

12. Which of the following best describe your Physical Activity status?

☐ Very active (exercise 3 times per week)
☐ Moderately active (exercise once or twice per week)
☐ Not very active (rarely leaves the house)
☐ Inactive (rarely leaves one room of house)

History of falls

- A fall is defined as "An event such as slip", "trip", "faint" and "any other accident which results in coming to rest inadvertently on the ground or lower level".

13. Number of falls in the past month or past 12 months?

☐ No fall, if No, please answer question 16 and 17
☐ 1 fall
☐ 2 falls
☐ 3 falls or more (please specify)……………………………………………………..

14. Was an injury sustained in any of the fall/s in the past month or past 12 months?

☐ No
☐ Minor injury, did not require medical attention
☐ Minor injury, did require medical attention
☐ Severe injury (e.g., fractures, severe soft tissue injuries requiring suturing, or other injuries requiring you a see healthcare provider)

- please list all severe injuries:

……………………………………………………………………………………..…

…………………………………………………………………………………………

15. Describe the circumstances of the most recent fall in the <u>past month</u> or in the <u>past 12 months</u>? (please circle).

- **Time of fall**: AM / PM
- **Cause of fall:** trip / slip / loss of balance / knees gave way / fainted / feeling dizzy / alcohol or meds / fell out of bed / unknown

Medication

16. Number of prescription medications

☐ No medication
☐ 1-2 medications
☐ 3 medications
☐ 4 or more medications

17. List of all current medications and reasons for taking medications:

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

School of Psychology and Exercise Science

Murdoch University

Medical Clearance Form

Date:______________________________

Participant Name:______________________________ Age:_______________ Male/ Female

Telephone Number:____

Dear Dr ____________________

Your patient, ____________________ has recently been invited to participate in "a Supervised Exercise Program, 3 times per week over the course of 18 weeks at Murdoch University (including light to moderate core strengthening, balance, and walking exercises)". In addition, for measurement of the trunk muscle strength, your patient will be asked to perform maximum isometric voluntary contractions of trunk muscles that will be measured using an isokinetic system (Humac Norm Isokinetic Dynamometer System).
If you are in agreement with your patient joining our exercise program, would be so kind as to indicate this on the clearance form below and return it to your patient.

If you require more information about our exercise program, please do not hesitate to contact me.

Kind Regards

Timothy Fairchild PhD AEP
School of Psychology and Exercise Science, Murdoch University
Room 2.042, Social Sciences Building, 90 South Street
Murdoch WA 6150
Tel +61 8 9360 2959
Fax +61 8 9360 6878
Email: t.fairchild@murdoch.edu.au

I have examined____ and clear him/her of any obvious medical condition that may prevent his/her participation in "18 weeks of supervised exercise training, 3 times per week".

Based on my assessment, it is unlikely that light to moderate physical activity will pose a significant risk to this participant.

Name of Doctor/Specialist:_______________________________ Date:__________________________

ADULT PRE-EXERCISE SCREENING TOOL

Name: ______________________________

Date of Birth: ____________ Male ☐ Female ☐ Date: ____________

STAGE 1 (COMPULSORY)

AIM: to identify those individuals with a known disease, or signs or symptoms of disease, who may be at a higher risk of an adverse event during physical activity/exercise. This stage is self administered and self evaluated.

Please circle response

1.	Has your doctor ever told you that you have a heart condition or have you ever suffered a stroke?	Yes	No
2.	Do you ever experience unexplained pains in your chest at rest or during physical activity/exercise?	Yes	No
3.	Do you ever feel faint or have spells of dizziness during physical activity/exercise that causes you to lose balance?	Yes	No
4.	Have you had an asthma attack requiring immediate medical attention at any time over the last 12 months?	Yes	No
5.	If you have diabetes (type I or type II) have you had trouble controlling your blood glucose in the last 3 months?	Yes	No
6.	Do you have any diagnosed muscle, bone or joint problems that you have been told could be made worse by participating in physical activity/exercise?	Yes	No
7.	Do you have any other medical condition(s) that may make it dangerous for you to participate in physical activity/exercise?	Yes	No

IF YOU ANSWERED 'YES' to any of the 7 questions, please seek guidance from your GP or appropriate allied health professional prior to undertaking physical activity/exercise

IF YOU ANSWERED 'NO' to all of the 7 questions, and you have no other concerns about your health, you may proceed to undertake light-moderate intensity physical activity/exercise

I believe that to the best of my knowledge, all of the information I have supplied within this tool is correct.

Signature ______________________ Date ____________

EXERCISE INTENSITY GUIDELINES

INTENSITY CATEGORY	HEART RATE MEASURES	PERCEIVED EXERTION MEASURES	DESCRIPTIVE MEASURES
SEDENTARY	< 40% HRmax	Very, very light RPE# < 1	• Activities that usually involve sitting or lying and that have little additional movement and a low energy requirement
LIGHT	40 to <55% HRmax	Very light to light RPE# 1-2	• An aerobic activity that does not cause a noticeable change in breathing rate • An intensity that can be sustained for at least 60 minutes
MODERATE	55 to <70% HRmax	Moderate to somewhat hard RPE# 3-4	• An aerobic activity that is able to be conducted whilst maintaining a conversation uninterrupted • An intensity that may last between 30 and 60 minutes
VIGOROUS	70 to <90% HRmax	Hard RPE# 5-6	• An aerobic activity in which a conversation generally cannot be maintained uninterrupted • An intensity that may last up to about 30 minutes
HIGH	≥ 90% HRmax	Very hard RPE# ≥ 7	• An intensity that generally cannot be sustained for longer than about 10 minutes

= Borg's Rating of Perceived Exertion (RPE) scale, category scale 0-10

ADULT PRE-EXERCISE SCREENING TOOL

STAGE 2 (OPTIONAL)

Name: ______________________________

Date of Birth: ______________________ Date: ______________________

AIM: To identify those individuals with risk factors or other conditions to assist with appropriate exercise prescription. This stage is to be administered by a qualified exercise professional.

Question		RISK FACTORS
1. Age ____ Gender ____	≥ 45yrs Males or ≥ 55yrs Females +1 risk factor	
2. Family history of heart disease (eg: stroke, heart attack) Relative / Age / Relative / Age ☐ Father ____ ☐ Mother ____ ☐ Brother ____ ☐ Sister ____ ☐ Son ____ ☐ Daughter ____	If male < 55yrs = +1 risk factor If female < 65yrs = +1 risk factor Maximum of 1 risk factor for this question	
3. Do you smoke cigarettes on a daily or weekly basis or have you quit smoking in the last 6 months? Yes No If currently smoking, how many per day or week? ____	If yes, (smoke regularly or given up within the past 6 months) = +1 risk factor	
4. Describe your current physical activity/exercise levels: Sedentary ☐ Light ☐ Moderate ☐ Vigorous ☐ Frequency (sessions per week) ____ ____ ____ Duration (minutes per week) ____ ____ ____	If physical activity level < 150 min/ week = +1 risk factor If physical activity level ≥ 150 min/ week = -1 risk factor (vigorous physical activity/ exercise weighted x 2)	
5. Please state your height (cm) ____ weight (kg) ____	BMI = ____________ BMI ≥ 30 kg/m² = +1 risk factor	
6. Have you been told that you have high blood pressure? Yes No	If yes, = +1 risk factor	
7. Have you been told that you have high cholesterol? Yes No	If yes, = +1 risk factor	
8. Have you been told that you have high blood sugar? Yes No	If yes, = +1 risk factor	

Note: Refer over page for risk stratification.

STAGE 2 Total Risk Factors = ____

9.	Have you spent time in hospital (including day admission) for any medical condition/illness/injury during the last 12 months? Yes No	If yes, provide details
10.	Are you currently taking a prescribed medication(s) for any medical conditions(s)? Yes No	If yes, what is the medical condition(s)?
11.	Are you pregnant or have you given birth within the last 12 months? Yes No	If yes, provide details. I am ______ months pregnant or postnatal (circle).
12.	Do you have any muscle, bone or joint pain or soreness that is made worse by particular types of activity? Yes No	If yes, provide details

STAGE 3 (OPTIONAL)

AIM: To obtain pre-exercise baseline measurements of other recognised cardiovascular and metabolic risk factors. This stage is to be administered by a qualified exercise professional. (Measures 1, 2 & 3 – minimum qualification, Certificate III in Fitness; Measures 4 and 5 minimum level, Exercise Physiologist*).

	RESULTS		RISK FACTORS
1. BMI (kg/m²)		BMI ≥ 30 kg/m² = +1 risk factor	
2. Waist girth (cm)		Waist > 94 cm for men and > 80 cm for women = +1 risk factor	
3. Resting BP (mmHg)		SBP ≥140 mmHg or DBP ≥90 mmHg = +1 risk factor	
4. Fasting lipid profile*			
Total cholesterol		Total cholesterol ≥ 5.20 mmol/L = +1 risk factor	
HDL		HDL cholesterol >1.55 mmol/L = -1 risk factor	
		HDL cholesterol < 1.00 mmol/L = +1 risk factor	
Triglycerides		Triglycerides ≥ 1.70 mmol/L = +1 risk factor	
LDL		LDL cholesterol ≥ 3.40 mmol/L = +1 risk factor	
5 Fasting blood glucose*		Fasting glucose ≥ 5.50 mmol = +1 risk factor	
		STAGE 3 Total Risk Factors =	

RISK STRATIFICATION

Total stage 2
or
Total stage 3
Plus stage 2 (Q1 - Q4)

≥ 2 RISK FACTORS – MODERATE RISK CLIENTS
Individuals at moderate risk may participate in aerobic physical activity/exercise at a light or moderate intensity (Refer to the exercise intensity table on page 2)

< 2 RISK FACTORS – LOW RISK CLIENTS
Individuals at low risk may participate in aerobic physical activity/exercise up to a vigorous or high intensity (Refer to the exercise intensity table on page 2)

Note: If stage 3 is completed, identified risk factors from stage 2 (Q1-4) and stage 3 should be combined to indicate risk. If there are extreme or multiple risk factors, the exercise professional should use professional judgement to decide whether further medical advice is required.

Appendix B

(Materials for the Measurement Procedures)

Examiner Code:……………………
Participant Code: …………………..
Date of assessment: ………../……..../…………..
Day Month Year

Participant Code:

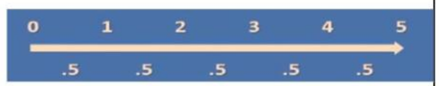
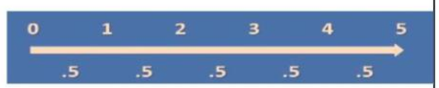
Weight (kg):

Height (cm):

Sitting height (cm):

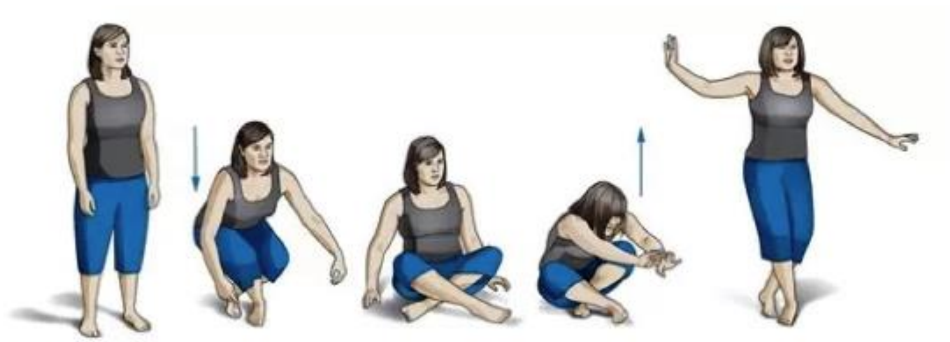
Dominant side:

Test	Scoring		Date	Comments
Berg Balance Test	**Position**	**Score**		
	Sitting to standing			
	Standing unsupported			
	Sitting unsupported			
	Standing to sitting			
	Transfers			
	Standing with eyes closed			
	Standing with feet together			
	Reaching forward with outstretched arm			
	Retrieving object from floor			
	Turning to look behind			
	Turning 360 degrees			
	Placing alternate foot on stool			
	Standing with one foot in front			
	Standing on one foot			
	Total score			
Reach-Multidirectional Test	**Direction**	**Distance (cm)**		
	Forward			
	Backward			
	Sideway to the right			
	Sideways to the left Reach			
30 Second Chair Stand Test	**Repetitions**			
Timed Up & Go Test	**Time (Sec)**			

Test	Scoring					Date	Comments
Four Square Step Test	**Trial 1 (Sec)**	**Trial 2 (Sec)**	**Average score**				
Sitting-Rising Test	**Testing position**	**Score**					
	Sitting						
							
	Standing						
							
Ultrasound Testing	**OI**	**EO**	**TrA**	**RA**	**LM**		
Right side							
Left Side							
Humac Norm (Trunk Strength Testing)	**Flexion**	**Extension**	**Lateral Flexion**	**Lateral Flexion**			

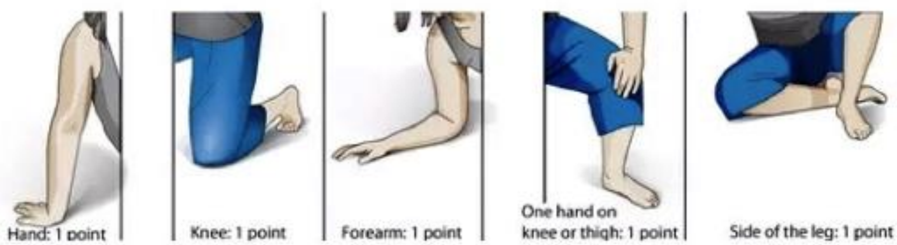
The Sitting and Rising Test (SRT)

This YouTube link "**https://www.youtube.com/watch?v=MCQ2WA2T2oA**" was adapted from "Brito, L.B.B.d., et al., Ability to sit and rise from the floor as a predictor of all-cause mortality. Eur J Prev Cardiol, 2014. 21(7): p. 892-8".



Try It

1. Stand in comfortable clothes in your bare feet, with clear space around you.
2. Without leaning on anything, lower yourself to a sitting position on the floor.
3. Now stand back up, trying not to use your hands, knees, forearms or sides of your legs.



Scoring

The two basic movements in the sitting-rising test — lowering to the floor and standing back up — are each scored on a 1-to-5 scale, with one point subtracted each time a hand or knee is used for support and 0.5 points subtracted for loss of balance; this yields a single 10-point scale.

GOOD 8 - 10　　FAIR 3.5 - 7.5　　POOR 0 - 3

Berg Balance Test

1- SITTING TO STANDING

INSTRUCTIONS: Please stand up. Try not to use your hand for support.
( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal aid to stand or stabilize
( ) 0 needs moderate or maximal assist to stand

2- STANDING UNSUPPORTED

INSTRUCTIONS: Please stand for two minutes without holding on.
( ) 4 able to stand safely for 2 minutes
( ) 3 able to stand 2 minutes with supervision
( ) 2 able to stand 30 seconds unsupported
( ) 1 needs several tries to stand 30 seconds unsupported
( ) 0 unable to stand 30 seconds unsupported

If a subject is **able to stand 2 minutes unsupported**, score full points for sitting unsupported. **Proceed to item #4**.

3- SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL

INSTRUCTIONS: Please sit with arms folded for 2 minutes.
( ) 4 able to sit safely and securely for 2 minutes
( ) 3 able to sit 2 minutes under supervision
( ) 2 able to able to sit 30 seconds
( ) 1 able to sit 10 seconds
( ) 0 unable to sit without support 10 seconds

4- STANDING TO SITTING

INSTRUCTIONS: Please sit down.
( ) 4 sits safely with minimal use of hands
( ) 3 controls descent by using hands
( ) 2 uses back of legs against chair to control descent
( ) 1 sits independently but has uncontrolled descent
( ) 0 needs assist to sit

5- TRANSFERS

INSTRUCTIONS: Arrange chair(s) for pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.
( ) 4 able to transfer safely with minor use of hands
( ) 3 able to transfer safely definite need of hands
( ) 2 able to transfer with verbal cuing and/or supervision
( ) 1 needs one person to assist
( ) 0 needs two people to assist or supervise to be safe

Berg Balance Scale continued…..

6- **STANDING UNSUPPORTED WITH EYES CLOSED**

INSTRUCTIONS: Please close your eyes and stand still for 10 seconds.
( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays safely
( ) 0 needs help to keep from falling

7- **STANDING UNSUPPORTED WITH FEET TOGETHER**

INSTRUCTIONS: Place your feet together and stand without holding on.
( ) 4 able to place feet together independently and stand 1 minute safely
( ) 3 able to place feet together independently and stand 1 minute with supervision
( ) 2 able to place feet together independently but unable to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 15 seconds feet together
( ) 0 needs help to attain position and unable to hold for 15 seconds

8- **REACHING FORWARD WITH OUTSTRETCHED ARM WHILE STANDING**

INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at the end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)
( ) 4 can reach forward confidently 25 cm (10 inches)
( ) 3 can reach forward 12 cm (5 inches)
( ) 2 can reach forward 5 cm (2 inches)
( ) 1 reaches forward but needs supervision
( ) 0 loses balance while trying/requires external support

9- **PICK UP OBJECT FROM THE FLOOR FROM A STANDING POSITION**

INSTRUCTIONS: Pick up the shoe/slipper, which is place in front of your feet.
( ) 4 able to pick up slipper safely and easily
( ) 3 able to pick up slipper but needs supervision
( ) 2 unable to pick up but reaches 2-5 cm(1-2 inches) from slipper and keeps balance independently
( ) 1 unable to pick up and needs supervision while trying
( ) 0 unable to try/needs assist to keep from losing balance or falling

10- **TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING**

INSTRUCTIONS: Turn to look directly behind you over toward the left shoulder. Repeat to the right. Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.
( ) 4 looks behind from both sides and weight shifts well
( ) 3 looks behind one side only other side shows less weight shift
( ) 2 turns sideways only but maintains balance
( ) 1 needs supervision when turning
( ) 0 needs assist to keep from losing balance or falling

Berg Balance Scale continued…..

11- TURN 360 DEGREES

INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

( ) 4 able to turn 360 degrees safely in 4 seconds or less
( ) 3 able to turn 360 degrees safely one side only 4 seconds or less
( ) 2 able to turn 360 degrees safely but slowly
( ) 1 needs close supervision or verbal cuing
( ) 0 needs assistance while turning

12- PLACE ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED

INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touch the step/stool four times.

( ) 4 able to stand independently and safely and complete 8 steps in 20 seconds
( ) 3 able to stand independently and complete 8 steps in > 20 seconds
( ) 2 able to complete 4 steps without aid with supervision
( ) 1 able to complete > 2 steps needs minimal assist
( ) 0 needs assistance to keep from falling/unable to try

13- STANDING UNSUPPORTED ONE FOOT IN FRONT

INSTRUCTIONS: (DEMONSTRATE TO SUBJECT) Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width.)

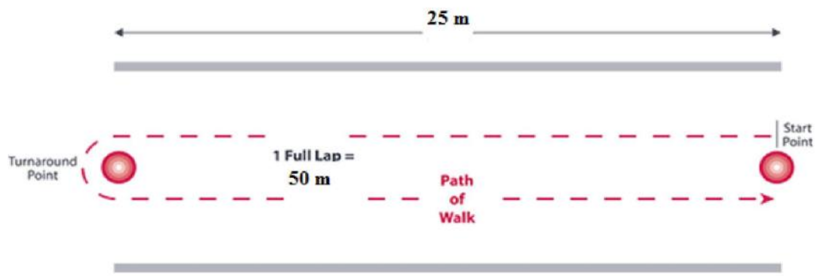
( ) 4 able to place foot tandem independently and hold 30 seconds
( ) 3 able to place foot ahead independently and hold 30 seconds
( ) 2 able to take small step independently and hold 30 seconds
( ) 1 needs help to step but can hold 15 seconds
( ) 0 loses balance while stepping or standing

14- STANDING ON ONE LEG

INSTRUCTIONS: Stand on one leg as long as you can without holding on.

( ) 4 able to lift leg independently and hold > 10 seconds
( ) 3 able to lift leg independently and hold 5-10 seconds
( ) 2 able to lift leg independently and hold ≥ 3 seconds
( ) 1 tries to lift leg unable to hold 3 seconds but remains standing independently.
( ) 0 unable to try of needs assist to prevent fall

Berg Balance Test (   ) TOTAL SCORE



6MWT-Baseline	Date/ Time	R HR	RBP	Max HR	BP	Post HR	Post PB	Distance	Steps	Laps	Borg	Gait deviation Y/N
Comments												

6MWT-Week 6	Date/ Time	R HR	RBP	Max HR	BP	Post HR	Post PB	Distance	Steps	Laps	Borg	Gait deviation Y/N
Comments												

6MWT-Week 12	Date/ Time	R HR	RBP	Max HR	BP	Post HR	Post PB	Distance	Steps	Laps	Borg	Gait deviation Y/N
Comments												

Appendix C

(Components of Both Exercise Programs)

Week	Trunk Strengthening/Motor Control Exercises				
1	Supine abdominal bracing* (Redondo ball between thighs)	Quadruped with Redondo ball between thighs (Four-point kneeling)	Modified beginner curl-up on the wedge (Redondo ball between thighs)	Supine supported bridge (Redondo ball between thighs)	Bent knees side bridge (Redondo ball between thighs)
Rep/Sec	6Rx3”	6Rx3”	6Rx3”	6Rx3”	6Rx3”
2	Supine abdominal bracing (Redondo ball between thighs)	Quadruped with Redondo ball between thighs (Four-point kneeling)	Modified beginner curl-up on the wedge (Redondo ball between thighs)	Supine supported bridge (Redondo ball between thighs)	Bent knees side bridge (Redondo ball between thighs)
Rep/Sec	6Rx6”	6Rx6”	6Rx6”	6Rx6”	6Rx6”
3	Supine abdominal bracing (Redondo ball between thighs)	Quadruped with Redondo ball between thighs with arm lifts	Modified beginner curl-up on the wedge (Redondo ball between thighs)	Supine supported bridge (Redondo ball between thighs)	Bent knees side bridge (Redondo ball between thighs)
Rep/Sec	8Rx6”	8Rx6”	8Rx6”	8Rx6”	8Rx6”
4	Supine abdominal bracing	Quadruped (Four-point kneeling with arm lifts)	Modified beginner curl-up	Supine supported bridge	Bent knees side bridge
Rep/Sec	8Rx8	8Rx8	8Rx8	8Rx8	8Rx8
5	Supine abdominal bracing with knee lift. alt	Quadruped (Four-point kneeling with arm lifts, leg or knee lifts	Modified beginner curl-up	Supine supported bridge on heels, toes up	Side bridge with one leg straight
Rep/Sec	8Rx6”	8Rx6”	8Rx6”	8Rx6”	8Rx6”
6	Supine abdominal bracing with knee lift. alt	Quadruped (Four-point kneeling with arm lifts, leg lifts	Modified beginner curl-up with elbows lift	Supine supported bridge on heels, toes up	Side bridge with one leg straight
Rep/Sec	8Rx8	8Rx8	8Rx8	8Rx8	8Rx8
7	Abdominal bracing with single straight leg raise **See below for explanation**	Quadruped opposite arm/leg lifts (Bride-Dog pose) **See below for explanation**	Modified intermediate curl-up with Airex Balance Pad under lower back **See below for explanation**	Supine bridging + with feet on Airex Balance Pad **See below for explanation**	Side bridge with one leg extended and forearm on Airex Balance Pad **See below for explanation**
Rep/Sec	8Rx6	8Rx6	8Rx6	8Rx6	8Rx6
8	Abdominal bracing with single straight leg raise	Quadruped opposite arm/leg lifts (Bride-Dog pose)	Modified intermediate curl-up with Airex Balance Pad under lower	Supine bridging + with feet on Airex Balance Pad	Side bridge with one leg extended and forearm on Airex Balance

			back		Pad
Rep/Sec	8Rx8	8Rx8	8Rx8	8Rx8	8Rx8
9	Abdominal bracing with single straight leg raise "on a deflated ball"	Quadruped opposite arm/leg lifts (Bride-Dog pose) "hands and knees on the Airex Balance Pads"	Curl-up with Airex Balance Pad under lower back "by placing hands behind ears" if they could otherwise "hands underneath their back"	Supine bridging + with feet on Airex Balance Pad "by placing heels on the blue"	Side bridge with one leg extended and forearm on Airex Balance Pad "both legs fully extended"
Rep/Sec	8Rx6	8Rx6	8Rx6	8Rx6	8Rx6
10	Abdominal bracing with single straight leg raise "on a deflated ball"	Quadruped opposite arm/leg lifts (Bride-Dog pose) "hands and knees on the Airex Balance Pads"	Curl-up with Airex Balance Pad under lower back "by placing hands behind ears" if they could otherwise hands underneath their back"	Supine bridging + with feet on Airex Balance Pad "by placing heels on the blue"	Side bridge with one leg extended and forearm on Airex Balance Pad "both legs fully extended"
Rep/Sec	8Rx8	8Rx8	8Rx8	8Rx8	8Rx8
11	Abdominal bracing with both legs raise "knees bent" "on a deflated ball" **See below for explanation**	Quadruped opposite arm/leg lifts (Bride-Dog pose) "on Swiss ball" **See below for explanation**	Curl-up with Airex Balance Pad under lower back "on Semi ball or Bosu ball" **See below for explanation**	Supine bridging "on Bosu ball or Swiss ball"	Side bridge with one leg extended and forearm "on Bosu ball or Swiss ball"
Rep/Sec	8Rx6	8Rx6	8Rx6	8Rx6	8Rx6
12	Abdominal bracing with both legs raise (knees bent" "on a deflated ball"	Quadruped opposite arm/leg lifts (Bride-Dog pose) "on Swiss ball"	Curl-up with Airex Balance Pad under lower back "on Semi ball or Bosu ball"	Supine bridging with feet "on Bosu ball or Swiss ball"	Side bridge with one leg extended and forearm "on Buso ball or Swiss ball"
Rep/Sec	8Rx8	8Rx8	8Rx8	8Rx8	8Rx8

Week 7

Abdominal bracing with single straight leg raise:

Instruct participants to brace and lift one leg towards them (bending from the hip and knee) extend out for 3 seconds and bring back in for 3 seconds. Do this with the participant for a total of four times, and instruct them to do it four more times independently.

Quadruped opposite hand to knee (Bird-Dog pose):

Participants get into the position for table pose (on hands and knees). For the warm up, ask participant to brace and lift each limb separately (arm, arm, leg, leg) before moving onto to bird dog (arm and opposite leg raise). Instruct participants to brace, lift, extend opposite arm/leg and hold for 6 seconds. Do this with the participant four times and instruct them to do four more independently.

Modified intermediate curl-up with Airex Balance Pad under lower back:

Participants lay flat on their back with a mat under their lower back, with their hands underneath their lower back for support and one knee up and the other extended (alternating). You must ensure participants are not curling up with their neck, and keeping their spine neutral. Instruct participants to brace and then curl up. Hold for 6 seconds.

Supine Bridging + with feet on Airex Balance Pad:

Participants are lying flat on their back with feet on Airex Balance Pad underneath their feet (uneven surface). Instruct participants to brace, lift their pelvis up. Hold for 6 seconds.

Side Bridge with one leg extended and forearm on Airex Balance Pad:

Participants lay on their side with the mat under their forearm, their top leg straight and the lower bent. Instruct participants to brace, and lift themselves up whilst saying that they have to keep their chest opened, back parallel to you (stand behind the participant) and elbow must be directly under their shoulder. Hold for 6 seconds.

Week 11

Abdominal bracing with both legs raise (knees bent):

Participants lay flat on a deflated ball. Instruct participants to brace and lift both legs towards them (bending from the knees and hips), hold for 6 seconds. Do this with the participant for a total of four times, and instruct them to do it a further four times independently.

Quadruped opposite arm/leg lifts (Bride-Dog pose) " on Swiss ball" :

Participants get into the position for table pose, which involves placing their chest or belly on the ball, and place hands and knees on the floor for support on top of a Swiss ball (Note: place two Airex Balance Pads in front and back of the ball, if the participants are unable to reach the floor by hands and knees). Warm up participants by getting them to brace for each limb separately before moving onto to bird dog (arm and opposite leg raise).

Curl-up with Airex Balance Pad under lower back " on Semi ball or Bosu ball (semi ball)":

Participants lay flat on their back on a semi ball and a mat under their head, with their hands underneath their lower back for support and one knee up and the other extended (alternating). Participants will be doing a curl up or sit up. You must ensure participants are not curling up with their neck, and keeping their spine neutral.

Supine bridging " on Bosu Ball or Swiss ball":

Participants are laying flat on their back with their feet placed on a Swiss ball. Instruct participants to brace and lift their pelvis up.

Side bridge with one leg extended and forearm "on Bosu Ball or Swiss ball":

Participants lay on their side with a semi ball under their forearm, with their legs straight out or one leg extended. They lean on their elbow, which must be directly under their shoulder. Instruct participants to brace, and lift themselves up whilst staying parallel.

Week	Balance exercises
1	**Seated-Chair:** - **Seated Heel lift and Toe lift (4x) 3 sec hold** Sitting upright on the edge of the chair with hands on thighs – alt. between raising heels hold 3sec – raising toes hold 3sec (2×) The participant is seated on the edge of their chair with their back straight, lift their heels off the ground and point their toes, and this is then held for 5 seconds. They then lower their feet, and lift their toes, hold for another 5 seconds, this is then repeated. The focus is on maintaining a straight back and posture. - **Seated Hip March (4x) 3 sec hold** alt. single leg lifts (2per leg) Sitting upright on the edge of the chair with hands on thighs. Ask participant to lift the leg with knee bent as far as is comfortable and hold it in the air 5 second. Then foot down with control. Repeat with the opposite leg. **Standing-Chair** - **Standing Heel lift and Toe lift (4x) alt. 3 sec hold** The participant stands behind a chair and places hands on the back of the chair (Remind participant not to lean on the chair because the chair is not a stable support, the chair is used only for maintaining their balance). They then lift their heels off the ground and maintain their balance on their toes, holding for 5 seconds, complete twice. Repeat with raising toes and standing on heels. - **Supported Heel/Toe lift Steps (2x)** **Toes:** The participant stands behind a chair and places hands on the back of the chair. They then lift their heels off the ground and take three steps to the side of the chair, maintain their balance on their toes, holding for around 5 seconds, and back to the centre and repeat on the other side of the chair, 5 second hold and back to the centre. **Heels:** Same as previous exercise but on heels. - **Leg lift (4x) (**2 per leg**)**: standing either side of chair 4x (alt. single leg lifts supported – holding for 3sec) - **Squats (4x):** feet shoulder width apart (behind the chair and hand on the top of the chair) **Sit to Stand (4X)** Sitting upright on the edge of the chair with hands on thighs. Ask participant to lean forward from their hips as much as they can and when ready, stand up. Once straight, they close their eyes for a 3-5 seconds, open their eyes to check for the chair behind (safety) and hands on thighs, slowly lowering through a squat onto the chair (tilt pelvis, bend through the knees) hold the squat for 5 seconds and control movement downwards to sit the chair.

2	**Seated-Chair:** - **Seated Heel lift and Toe lift (4x) 6 sec hold** Sitting upright on the edge of the chair with hands on thighs – alt. between raising heels hold 6 sec – raising toes hold 6sec (2×) Participant is seated on the edge of their chair with their back straight, lift their heels off the ground and point their toes, and this is then held for 5 seconds. They then lower their feet, and lift their toes, hold for another 5 seconds, this is then repeated. The focus is on maintaining a straight back and posture. - **Seated Hip March (4x) 6 sec hold** alt. single leg lifts (2per leg) Sitting upright on the edge of the chair with hands on thighs. Ask participant to lift the leg with knee bent as far as is comfortable and hold it in the air 6 second. Then foot down with control. Repeat with the opposite leg. **Standing-Chair** - **Standing Heel lift and Toe lift (4x) alt. 6 sec hold** The participant stands behind a chair and places hands on the back of the chair (Remind participant not to lean on the chair because the chair is not a stable support, the chair is used only for maintaining their balance). They then lift their heels off the ground and maintain their balance on their toes, holding for 6 seconds, complete twice. Repeat with raising toes and standing on heels. - **Supported Heel/Toe lift Steps (2x)** **Toes:** The participant stands behind a chair and places hands on the back of the chair. They then lift their heels off the ground and take three steps to the side of the chair, maintain their balance on their toes, holding for around 6 seconds, and back to the centre, closing eyes for a 6 seconds. They repeat on the other side of the chair, 6 seconds hold and back to the centre. **Heels:** Same as previous exercise but on heels. - **Leg lift (4x) (**2 per leg): Standing either side of chair 4x (alt. single leg lifts supported – holding for 6sec) - **Squats (4x)** with feet shoulder width apart (behind the chair and hand on the top of the chair)- holding for 6 second **Sit to Stand (4X)** Sitting upright on the edge of the chair with hands on thighs. Ask participant to lean forward from their hips as much as they can and when ready stand up. Once straight they close their eyes for a 6 seconds, open their eyes to check for the chair behind (safety) and hands on thighs, slowly lowering through a squat onto the chair (tilt pelvis, bend through the knees) hold the squat for 6 seconds and control movement downwards to sit on the chair.
3	**Seated-Chair (With holding a ball front of the body at shoulder level):** - **Seated Heel lift (2x) and Toe lift (2x) 6 sec hold** - **Seated Hip March (4x) 6 sec hold** **Table-Standing/Walking** - **Standing-walking Heel lift (2x) 6 sec hold**

	- Participant stands next to a table and places one hand on it – for support but not leaning on the table! They then lift their heels off the ground and walk around the table (6 steps). Now instruct participant "to stop, maintaining their balance on their toes for 6 seconds, then feet flat on the floor, eyes closed and stay for 6 seconds". Then ask them to open their eyes, and turn around and repeat this exercise again. - **Standing-walking Toe lift (2x) 6 sec hold:** same as previous exercise but on heels - **Standing-walking Heel to Toe (2x) 6 sec hold:** same as previous exercise but one foot in front of the other **Table- Leg lift** - **Table-Leg lift (4x) (2 per leg) 6 second hold** - Participants stand next to the table, hand placed on it for stability and lift each leg once. **Table- Leg squats** - **Squats (2x)** : Using the table for support 2× 6sec hold (with holding ball out in front on the table) - **Cross-legged squat (2x):** Squat with crossed legs using the table for support 2× 6secs hold (with holding ball out in front on the table) **Sit to Stand (4X)** Sitting upright on the edge of the chair with holding ball out in front. Ask participant to lean forward from their hips as much as they can and when ready, stand up. Once straight they close their eyes for a 6 seconds while holding ball out in front, open their eyes to check for the chair behind (safety), slowly lowering into a squat onto the chair (tilt pelvis, bend through the knees), hold the squat for 6 seconds and control movement downwards to sit on the chair.
4	**Seated-Chair (With holding a ball front of the body at shoulder level):** - **Seated Heel lift (2x) and Toe lift (2x) 8 sec hold** - **Seated Hip March (4x) 8 sec hold** **Table-Standing/Walking** - **Standing-walking Heel lift (2x) 8 sec hold** - The participant stands next to a table and places one hand on it and uses it to support not leaning on the table! They then lift their heels off the ground and walk the table (6 steps). Now instruct them, "to stop, maintaining their balance on their toes for 8 seconds, then feet flat on the floor, eyes closed" and stay for 8 seconds. Then ask them to open their eyes, and turn around and repeat this exercise again. - **Standing-walking Toe lift (2x) 8 sec hold:** same as previous exercise but on heels - **Standing-walking Heel to Toe (2x) 8 sec hold:** same as previous exercise but one foot in front of

the other

Table- Leg lift

- **Table-Leg lift (4x) (2 per leg) 8 second hold**
- Participants stand next to the table, hand placed on it for stability and lift each leg once.
- **Squats (2x)** : Using the table for support 2× 8sec hold (with holding ball out in front)
- **Cross-legged squat (2x):** Squat with crossed legs using the table for support 2× 8secs hold (with holding ball out in front)

Sit to Stand (4X)

Sitting upright on the edge of the chair with holding ball out in front. Ask participant to lean forward from their hips as much as they can and when ready stand up. Once straight they close their eyes for a 8 seconds with holding ball out in front , open their eyes to check for the chair behind (safety), slowly lowering through a squat onto the chair (tilt pelvis, bend through the knees) hold the squat for 8 seconds and control movement downwards to sit on the chair.

5

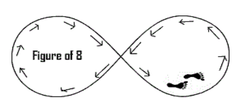
Seated-Chair (With holding a ball front of the body at shoulder level):

- **Seated Heel lift (2x) and Toe lift (2x) 8 sec hold**
- **Seated Hip March (4x) 8 sec hold**

Figure 8-Double Chair

Two chairs are placed on in front of the other, to allow participants to walk in a figure eight. Placing hands on the chair to allow for stability. Then ask participants do the following (slow and controlled)

- **2x regular walking**
- **2x on toes walking**
- **2x on heels walking**
- **2x heel to toe walking**



Note: Please note that participants must keep their backs straight, shoulders relaxed, chin parallel to the floor and pelvis tucked in during this exercise.

Chair- Leg lift

- **Chair-Leg lift (4x) (2 per leg) 8 second hold**

  Participants stand next to their chair, hand placed on it for stability and lift each leg once (if they feel they are stable, they can take the hand off the chair**).** Repeat on the other side.
- **Squats (2x)** : Using the table for support 2× 8sec hold (with holding ball out in front)
- **Cross-legged squat (2x):** Squat with crossed legs using the table for support 2× 8secs hold (with holding ball out in front)

<table>
<tr><td></td><td>

Sit to Stand (4X)

Sitting upright on the edge of the chair with holding ball out in front. Ask participant to lean forward from their hips as much as they can and when ready stand up. Once straight they close their eyes for a 8 seconds with holding ball out in front , open their eyes check for the chair behind (safety), slowly lowering through a squat onto the chair (tilt pelvis, bend through the knees) hold the squat for 8 seconds and control movement downwards to sit on the chair.

</td></tr>
<tr><td>

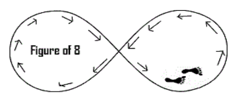
6

</td><td>

Seated-Chair (with holding arms in front of chest at shoulder level):

- **Seated Heel lift (2x) and Toe lift (2x) 10 sec hold**
- **Seated Hip March (4x) 10 sec hold**

Figure 8-Double Chairs



Two chairs are placed on in front of the other, to allow participants to walk in a figure 8. Placing hands on tthe chair to allow for stability. Then ask participants do the following (slow and controlled).

- **2x regular walking**
- **2x on toes walking**
- **2x on heels walking**
- **2x heel to toe walking**

Note: Please note that participants must keep their backs straight, shoulders relaxed, chin parallel to the floor and pelvis tucked in during this exercise.

Chair- Leg lift

- **Chair-Leg lift (4x) (2 per leg) 10 second hold**

  Participants stand next to their chair, hand placed on it for stability and lift each leg once (if they feel they are stable, they can take the hand off the chair**).** Repeat on the other side.

- **Squats (2x)** : Using the table for support 2× 10 sec hold (with holding arms in front of chest)
- **Cross-legged squat (2x):** Squat with crossed legs using the table for support 2× 10 secs hold (with holding arms in front of chest)

Sit to Stand (4X) with holding arms in front of chest at shoulder level

Sitting upright on the edge of the chair with arms in front. Ask participant to lean forward from their hips as much as they can and when ready stand up. Once straight they close their eyes for a couple of seconds with holding ball out in front , open their eyes to check for the chair behind (safety), slowly lowering through a squat onto the chair (tilt pelvis, bend through the knees) hold the squat for 10 seconds and control movement downwards to sit on the chair.

</td></tr>
<tr><td>

7

</td><td>

Seated-Chair (With blue mat underneath feet and arms crossed over chest)

</td></tr>
</table>

	- Seated Heel lift (2x) and Toe lift (2x) 6-7 sec hold - Seated Hip March (4x) 6-7 sec hold **Standing Heel lift and Toe lift (4x) alt. 6 sec hold** - The participant stands on the "blue mat" behind a chair and places hands on the back of the chair (Remind participant not to lean on the chair because the chair is not a stable support, the chair is used only for maintaining their balance). They then lift their heels off the ground and maintain their balance on their toes, holding for 6-7 seconds, complete twice. Repeat with raising toes and standing on heels. **Please note that if you think the participant needs" doubled chairs" during this exercise to maintain the balance, apply two chairs.** **Chair- Leg lift with Blue Mat** - **Chair-Leg lift (4x) (2 per leg) 6-7 second hold** Participant stands on the blue mat next to their chair; hands placed on top of the chair for stability and lift each leg once**.** Repeat on the other side. **Figure 8-Double Chairs (Place two chair closer, to make the exercise challenging)** - **2x on toes walking (R/L)** - **2x on heels walking (R/L)** - **2x heel to toe walking (R/L)** **Chair-Squats with Blue Mat underneath feet** - **Squats (2x)**: Blue mat placed underneath feet, squats with holding arms in front of chest or on the top of the chair (2× 6-7 sec hold) - **Cross-legged squat (2x):** Blue mat placed underneath feet, squat with crossed legs with holding arms in front of chest or on the top of the chair (2× 6-7 sec hold) **Sit to Stand (4X) with Blue Mat underneath feet** Sitting upright on the edge of the chair with blue mat underneath feet and arms in front or on thighs. Ask participant to lean forward from their hips as much as they can and when ready stand up. Once straight they close their eyes for a couple of seconds with holding ball out in front , open their eyes to check for the chair behind (safety), slowly lowering through a squat onto the chair (tilt pelvis, bend through the knees) hold the squat for 6-7 seconds and control movement downwards to sit on the chair.
8	**Swiss ball:** Toes, Heels and extended leg - Sitting on Swiss ball on toes/heels with holding hands on thighs 6 sec, 2x - Sitting on Swiss ball and leg lifts with hands on thighs 6 sec, 2x each side - Sitting on Swiss ball and arm raises 6 sec, 2x each side - Sitting on Swiss ball and opposite arm and leg raises-**Static** (8x, 2rep) - On Swiss ball bouncing up and down (6x, 2rep). - On Swiss ball, Pelvic tilting slowly side to side 6x, 2rep

	- On Swiss ball, Pelvic tilting slowly forward and backward 6x, 2rep **Figure 8-Cones (2):** Please note that to determine the distance between two cones, place the first cone on the floor and then ask your participant to take a big step forward and place the second cone in front of her/his front foot. - Normal walk forward and back along the cones (straight line) - Normal walking in figure 8 pattern around two cones (R/L) - Walking in figure 8 on toes around two cones (R/L) - Walking in figure 8 on heels around two cones (R/L) - Walking in figure 8 heel to toe pattern around two cones (R/L) **Unstable Airex Mat:** Preferably using the corridor edges, outside the lab. - Standing on the unstable mat, next to the wall and normal squats 6 sec 2x, - Standing on the unstable mat, next to the wall and cross legged squats 6 sec 2x
9	**Swiss ball:** Toes, Heels and extended leg - Sitting on Swiss ball on toes/heels with holding hands on thighs 8 sec, 2x - Sitting on Swiss ball and leg lifts with hands on thighs 8 sec, 2x each side - Sitting on Swiss ball and arm raises (punch) 8 sec, 2x each side - Sitting on Swiss ball and opposite arm and leg raises-**Static** (8x, 2rep) - On Swiss ball bouncing up and down (8x, 2rep) - Sitting on Swiss ball and opposite arm and leg raises-**Dynamic** (combined with bouncing on the ball) (8x, 2rep) - On Swiss ball, Pelvic tilting slowly side to side 8x, 2rep - On Swiss ball, Pelvic tilting slowly forward and backward 8x, 2rep **Figure 8-Cones (2):** To make the exercise more challenging, make the distance between the 2 cones shorter. - Walking in figure 8 on toes around two cones (R/L) - Walking in figure 8 on heels around two cones (R/L) - Walking in figure 8 heel to toe pattern around two cones (R/L) **Airex Balance Pad :** Preferably using the corridor edges, outside the lab.

	- Standing on the unstable mat, next to the wall using hand for support and normal squats 8 sec 2x, - Standing on the unstable mat, next to the wall using hand for support and cross legged squats 8 sec 2x - Standing on the unstable mat, next to the wall using hand for support on the edge and lifting opposite leg up x2 each leg (8 seconds).
10	**Swiss ball:** Toes, Heels and extended leg - Sitting on Swiss ball on toes/heels with arms bent by sides 10 sec, 2x - Sitting on Swiss ball and leg lifts with arms bent by sides 10 sec, 2x each side - Sitting on Swiss ball and arm raises 10 sec, 2x each side - Sitting on Swiss ball and opposite arm and leg raises-**Static** (10x, 2rep) - On Swiss ball bouncing up and down with arms bent to the sides (10x, 2rep) - Sitting on Swiss ball and opposite arm and leg raises-**Dynami**c (combined with bouncing on the ball) (10x, 2rep) - On Swiss ball, Pelvic tilting slowly side to side (with arms bent to the sides) (10x, 2rep) - On Swiss ball, Pelvic tilting slowly forward and backward 10x, 2rep - Sitting on Swiss ball and take three steps forward and backward, 2 rep **Double -Figure 8-Cones (4):** - Normal walk forward and back along the cones (straight line) - Walking in double figure 8 on toes around 4 cones (R/L) - Walking in double figure 8 on heels around 4 cones (R/L) - Walking in double figure 8 heel to toe pattern around 4 cones (R/L) **Airex Balance Pad:** - Standing on the unstable mat, far from the wall raising arms in front and normal squats 10 sec 2x, - Standing on the unstable mat, far from the wall raising arms in front and cross legged squats 10 sec 2x - Standing on the unstable mat, far from wall with raising arms in front and lifting opposite leg up x2 each leg (10 seconds).
11	**Swiss ball:** Toes, Heels and extended leg - Sitting on Swiss ball on toes/heels with arms straight out to sides at shoulder level, turn head to one side, then the other (look over right shoulder, then left) 10 sec, 2x

	- Sitting on Swiss ball and opposite arm and leg raises-**Static** (10x, 2rep) - On Swiss ball bouncing up and down (10x, 2rep) - Sitting on Swiss ball and opposite arm and leg raises-**Dynami**c (combined with bouncing on the ball) (10x, 2rep) - On Swiss ball, Pelvic tilting slowly side to side 10x, 2rep - On Swiss ball, Pelvic tilting slowly forward and backward 10x, 2rep - Sitting on Swiss ball and take three steps forward and backward (one toes, then heels), 2 rep **Double -Figure 8-Cones (4):** To make the exercise more challenging, make the distance between the 4 cones shorter. - Normal walk forward and back along the cones (straight line) - Normal walking in figure 8 pattern around 4 cones (R/L) - Walking in double figure 8 on toes around 4 cones (R/L) - Walking in double figure 8 on heels around 4 cones (R/L) - Walking in double figure 8 heel to toe pattern around 4 cones (R/L) **Airex Balance Pad:** - Standing on the unstable mat, far from the wall with arms crossed over chest and normal squats 8 sec 2x, - Standing on the unstable mat, far from the wall with arms crossed over chest and cross legged squats 8 sec 2x - Standing on the unstable mat, far from the wall with arms crossed over chest and lifting opposite leg up x2 each leg (8 seconds).
12	**Swiss ball:** Toes, Heels and extended leg - Sitting on Swiss ball on toes/heels with arms straight out to sides at shoulder level, turn head to one side, then the other (look over right shoulder, then left) 10 sec, 2x - Sitting on Swiss ball and opposite arm and leg raises-**Static** (10x, 2rep) - On Swiss ball bouncing up and down (10x, 2rep) - Sitting on Swiss ball and opposite arm and leg raises-**Dynami**c (combined with bouncing on the ball) (8x, 2rep) - On Swiss ball, Pelvic tilting slowly side to side 10x, 2rep - On Swiss ball, Pelvic tilting slowly forward and backward 10x, 2rep

- Sitting on Swiss ball and take three steps forward and backward (one toes, then heels), 2 rep

Double -Figure 8-Cones (4):
To make the exercise more challenging, make the distance between the 4 cones shorter.

- Normal walk forward and back along the cones (straight line)
- Normal walking in double figure 8 pattern around 4 cones (R/L)
- Walking in double figure 8 on toes around 4 cones (R/L)
- Walking in double figure 8 on heels around 4 cones (R/L)
- Walking in double figure 8 heel to toe pattern around 4 cones (R/L)

Airex Balance Pad:

- Standing on the unstable mat, far from the wall with arms crossed over chest and normal squats 10 sec 2x,
- Standing on the unstable mat, far from the wall with arms crossed over chest and cross legged squats 10 sec 2x
- Standing on the unstable mat, far from the wall with arms crossed over chest and lifting opposite leg up x2 each leg (10 seconds).

Appendix D

(Published Systematic Review, Conference Abstracts, Awards, and Grants)

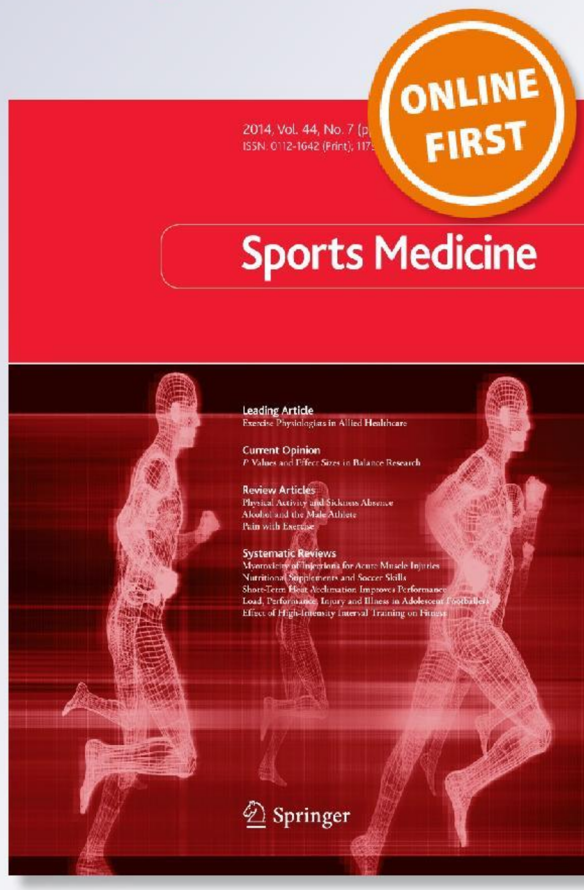
The Effect of Exercise Training on Lower Trunk Muscle Morphology

Behnaz Shahtahmassebi, Jeffrey J. Hebert, Norman J. Stomski, Mark Hecimovich & Timothy J. Fairchild

Sports Medicine

ISSN 0112-1642

Sports Med
DOI 10.1007/s40279-014-0213-7



Springer

Sports Med
DOI 10.1007/s40279-014-0213-7

SYSTEMATIC REVIEW

The Effect of Exercise Training on Lower Trunk Muscle Morphology

Behnaz Shahtahmassebi · Jeffrey J. Hebert · Norman J. Stomski · Mark Hecimovich · Timothy J. Fairchild

Abstract

Background Skeletal muscle plays an important role in maintaining the stability of the lumbar region. However, there is conflicting evidence regarding the effects of exercise on trunk muscle morphology.

Objective To systematically review the literature on the effects of exercise training on lower trunk muscle morphology to determine the comparative effectiveness of different exercise interventions.

Data Source and Study Selection A systematic search strategy was conducted in the following databases: PubMed, SportDiscus, CINAHL, the Cochrane Library and PEDro. We included full, peer-reviewed, prospective longitudinal studies, including randomized controlled trials and single-group designs, such as pre- to post-intervention and crossover studies, reporting on the effect of exercise training on trunk muscle morphology.

Study Appraisal and Synthesis Study quality was assessed with the Cochrane risk-of-bias tool. We classified each exercise intervention into four categories, based on the primary exercise approach: motor control, machine-based resistance, non-machine-based resistance or cardiovascular. Treatment effects were estimated using within-group standardized mean differences (SMDs).

Results The systematic search identified 1,911 studies; of which 29 met our selection criteria: motor control ($n = 12$), machine-based resistance ($n = 10$), non-machine-based resistance ($n = 5$) and cardiovascular ($n = 2$). Fourteen studies (48 %) reported an increase in trunk muscle size following exercise training. Among positive trials, the largest effects were reported by studies testing combined motor control and non-machine-based resistance exercise (SMD [95 % CI] = 0.66 [0.06 to 1.27] to 3.39 [2.80 to 3.98]) and machine-based resistance exercise programmes (SMD [95 % CI] = 0.52 [0.01 to 1.03] to 1.79 [0.87 to 2.72]). Most studies investigating the effects of non-machine-based resistance exercise reported no change in trunk muscle morphology, with one study reporting a medium effect on trunk muscle size (SMD [95 % CI] = 0.60 [0.03 to 1.16]). Cardiovascular exercise interventions demonstrated no effect on trunk muscle morphology (SMD [95 % CI] = −0.16 [−1.14 to 0.81] to 0.09 [−0.83 to 1.01]).

Limitations We excluded studies published in languages other than English, and therefore it is possible that the results of relevant studies are not represented in this review. There was large clinical heterogeneity between the included studies, which prevented data synthesis. Among the studies included in this review, common sources of potential bias were random sequence generation, allocation concealment and blinding. Finally, the details of the exercise parameters were poorly reported in most studies.

Conclusion Approximately half of the included studies reported an increase in lower trunk muscle size following participation in an exercise programme. Among positive trials, studies involving motor control exercises combined with non-machine-based resistance exercise, as well as

Electronic supplementary material The online version of this article (doi:10.1007/s40279-014-0213-7) contains supplementary material, which is available to authorized users.

B. Shahtahmassebi · J. J. Hebert (✉) · M. Hecimovich · T. J. Fairchild
School of Psychology and Exercise Science, Murdoch University, SS2.015, 90 South Street, Murdoch, Perth, WA 6150, Australia
e-mail: J.Hebert@murdoch.edu.au

N. J. Stomski
School of Health Professions, Murdoch University, Perth, WA, Australia

Published online: 12 July 2014

machine-based resistance exercises, demonstrated medium to large effects on trunk muscle size. Most studies examining the effect of non-machine-based resistance exercise and all studies investigating cardiovascular exercise reported no effect on trunk muscle morphology. However, these results should be interpreted with caution because of the substantial risk of bias and suboptimal reporting of exercise details in the included studies. Additional research, using methods ensuring a low risk of bias, are required to further elucidate the effects of exercise on trunk muscle morphology.

1 Introduction

The lumbar spine is subjected to a variety of complex forces during daily tasks [1] and when engaging in physical activity [2–4]. Stability of the lumbar spine plays an important role in reducing the risk of injury [5, 6]. Lumbar spine stability is dependent on three interrelated components: the passive osteoligamentous structures; the skeletal musculature; and the motor control system, which coordinates the complex muscle activity required to mitigate expected and unexpected perturbations [5]. With respect to the lower trunk musculature (i.e. the abdominal muscles and those attaching to the lumbar spine), both global and local muscles are involved in the stabilization of the lumbar spine [7–9]. The coordination of muscle recruitment is critical to this stabilization and prevention of lumbar spine buckling [10, 11], suggesting a significant role for the motor control system [5, 12].

There is a positive relationship between the size and function (e.g. muscular strength, endurance and power) of skeletal muscle [13–17]. Similarly, reductions in trunk muscle mass are associated with low back pain [18–20] and decreased functional capacity [21–23], while exercise-related increases in skeletal muscle mass are associated with better clinical outcome in patients with lumbar spine disorders [14, 18, 24, 25].

A number of studies adopting exercise-based interventions have previously demonstrated increases in trunk muscle size [14, 16, 26], while others have reported no changes [27–29]. Moreover, there is sparse information comparing the effects of different exercise interventions on trunk muscle morphology. Therefore, the aim of this study was to systematically review the literature on the effects of exercise training on lower trunk muscle morphology, in order to determine the comparative effectiveness of different exercise strategies. We hypothesized that (1) exercise training would alter trunk muscle morphology; and (2) more intense forms of exercise, such as machine-based resistance training, would demonstrate the largest effect on trunk muscle morphology.

2 Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [30].

2.1 Criteria for Considering Studies for this Review

2.1.1 Types of Studies and Participants

We included full, peer-reviewed, prospective longitudinal studies, including randomized controlled trials (RCTs) and single-group designs, such as pre- to post-intervention and crossover studies. We excluded animal studies, editorials, letters, case reports, conference proceedings and studies published in languages other than English. Because of detraining effects, we also excluded studies that measured changes in trunk muscle morphology more than 1 week after exercise cessation. Our review protocol placed no restrictions on study participants, including age, sex, clinical status and level of physical fitness.

2.1.2 Types of Interventions

The intervention of interest was participation in an exercise programme. The exercise interventions consisted of any mode of exercise directed by a healthcare provider or exercise professional. We excluded studies reporting the effects of participation in sporting or general physical activities.

2.1.3 Types of Outcome Measures

The outcome of interest was change in lower trunk muscle morphology following an exercise intervention. Specifically, we included studies reporting changes in the size (e.g. cross-sectional area, thickness or volume) or structure (e.g. fatty degeneration, density or fibre type) of individual muscles or changes in body composition related to muscle (e.g. regional or whole-body muscle mass) following an exercise intervention. We considered the lower trunk muscles to include the abdominal musculature, as well as muscles attaching to the lumbar spine. Search terms were used to define appropriate bodily regions (lumbosacral, trunk, spine, lumbar, low back, abdominal and core) and muscles (transversus abdominis, external oblique, internal oblique, rectus abdominis, iliopsoas, multifidus, erector spinae and quadratus lumborum) of interest. There were no restrictions on the type of muscle morphology measure.

2.2 Search Methods Used for Identification of Studies

2.2.1 Electronic Searches

A search strategy was developed in consultation with a reference librarian and conducted in the following databases from inception to 30 April 2012: PubMed, SportDiscus, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Cochrane Central Register of Controlled Trials (CENTRAL) and Physiotherapy Evidence Database (PEDro). We developed the search syntax for PubMed using Medical Subject Headings and free text terms (see Appendix S1 in the Electronic Supplementary Material). This syntax was then adapted as required for use in the remaining databases. Additionally, we screened the reference lists of included studies.

2.3 Data Collection and Analysis

2.3.1 Selection of Studies

Two review authors (B.S. and A.S.) independently screened the titles and abstracts of studies to identify potentially relevant studies. Next, the full texts of potentially relevant articles were retrieved and assessed for inclusion. Disagreements between review authors were resolved by third-party adjudication (by J.J.H.). The review authors were not blinded to study authors, institutions or journals.

2.3.2 Data Extraction and Management

Data were extracted by one review author (B.S.) using a customised form. The extracted information included details of the study design, participants (number of participants, age, sex, clinical status and training level), exercise intervention (exercise protocol, protocol time and frequency), control or comparator condition (protocol, time and frequency) and outcome measures (details of morphology assessment, measurement techniques and device). Any unclear information was resolved through discussion with a second review author (J.J.H.). In addition, we contacted several study authors to seek clarification and obtain additional information. There is no standard or widely adopted classification of trunk muscle exercises. Previously reported classifications [31, 32] did not adequately describe the types of exercises reported by the studies included in this review. Consequently, we classified each study into four categories based on the type of exercise that was implemented. When more than one type of exercise was included in the exercise programme, we classified the study according to the primary exercise intervention. Exercise categories were defined as:

- Motor control exercise: exercise described as 'motor control', 'specific stabilization' or 'core stability' exercise, using interventions targeting specific trunk muscles with a goal of improving control and coordination of the spine and pelvis [33].
- Machine-based resistance exercise: exercise aiming to improve muscular strength and/or endurance by use of machines, such as the MedX lumbar extension [14], David back [34] and Nautilus [35, 36] devices.
- Non-machine-based resistance exercise: exercise aiming to improve muscular strength and/or endurance with static or dynamic body weight resistance, and including the use of simple equipment such as dumbbells, resistance bands and Swiss balls [37].
- Cardiovascular exercise: aerobic exercise (e.g. walking, jogging or cycling) aiming to increase the heart rate and respiration and to improve cardiovascular fitness by involving large muscle groups [38].

2.3.3 Assessment of Risks of Bias in the Included Studies

The risks of bias in all included studies were independently assessed by two reviewer authors (B.S. and N.S.), using the Cochrane risk-of-bias tool [39]. Seven domains were assessed, including sequence generation, allocation concealment, blinding (participants/personnel), blinding (outcome assessor), incomplete outcome data, selective reporting and other sources of bias. Each domain was assigned a score of '+' if the criteria for a low risk of bias were met, '−' if the criteria for a high risk of bias were met and '?' if the data were insufficient to permit judgment. Disagreements between reviewers were discussed and resolved with a third review author (J.J.H.).

2.3.4 Measures of Treatment Effects and Data Analysis

The data were analysed in Review Manager v5.1 software. The effects of exercise on trunk muscle morphology were estimated using standardized mean differences (SMDs) calculated from Hedges' *g* statistics and 95 % confidence intervals (CIs). An SMD score of 0.20 represents a small effect, 0.50 indicates a medium effect and 0.80 indicates large effect [40]. Since muscle morphology is unlikely to be influenced by nonspecific treatment effects, our estimates of treatment effect represent the within-group change in muscle morphology following exercise participation. When possible, we calculated separate treatment effect estimates for each muscle and condition separately.

3 Results

3.1 Results of the Search

The search outcome and study selection process are displayed in Fig. 1. The systematic search identified 1,910 citations: 597 from SportDiscus, 595 from PubMed, 495 from CINAHL, 143 from CENTRAL and 80 from PEDro. Of these citations, 382 were duplicates, thus yielding 1,529 unique studies. One additional study was identified during the peer review of this manuscript (*n* = 1). The manual search of references lists did not identify any additional studies.

The title and abstract screen identified 122 potentially relevant studies, which were retained for full-text review. Ultimately, 29 studies met our selection criteria and were included for analysis [14, 16, 18, 24–29, 35, 41–58]. Of the 93 studies excluded after the full-text screen, the reasons for exclusion were (a) outcome measures other than muscle morphology (*n* = 44); (b) no exercise training intervention (*n* = 35); (c) study was an abstract or review paper (*n* = 10); (d) greater than 1-week duration between exercise cessation and follow-up assessment (*n* = 3); and (e) language other than English (*n* = 1). A list of excluded articles is available from the corresponding author.

3.2 Description of the Included Studies

Twenty-nine studies, comprising 1,244 participants, were classified into motor control (12 studies, *n* = 733), machine-based resistance exercise (10 studies, *n* = 280), non-machine-based resistance exercise (5 studies, *n* = 128) and cardiovascular exercise (2 studies, *n* = 103) conditions. The study characteristics and outcomes are presented in Tables 1 and 2.

Large clinical heterogeneity was observed among the included studies. Major sources of heterogeneity were (1) sample populations (age, sex and health status); (2) exercise mode (motor control, machine-based resistance, non-machine-based resistance or cardiovascular); (3) exercise prescription (frequency, intensity and duration); (4) outcome muscle; (5) type of muscle morphology assessment (e.g. thickness, density or cross-sectional area [CSA]); and (6) method used for muscle measurement (e.g. ultrasound, magnetic resonance imaging [MRI] or computed tomography [CT]). As a result, the planned analyses

Fig. 1 Study flow diagram

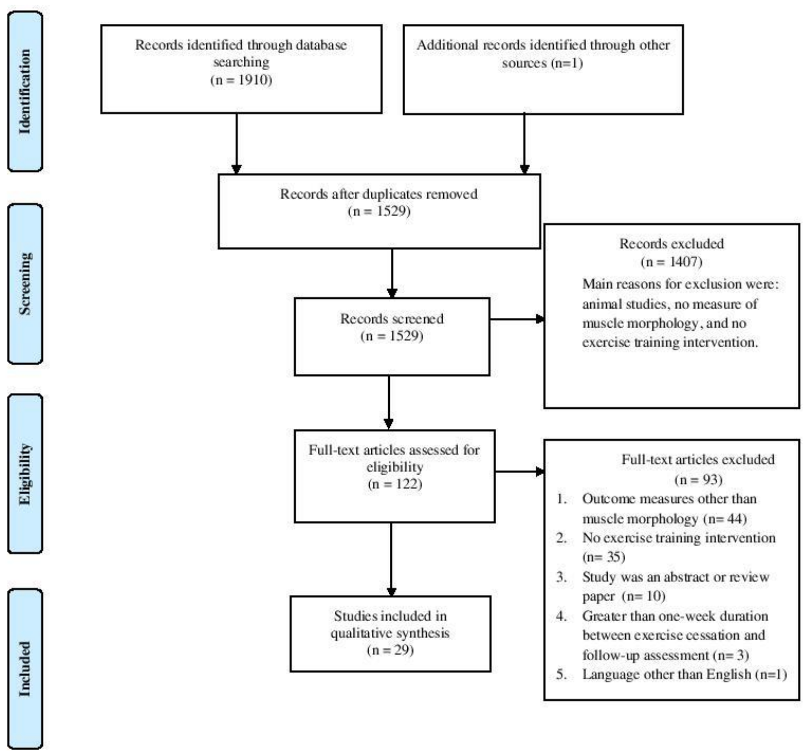


Table 1 Characteristics and outcomes of included studies, based on exercise training categories

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Motor control exercise							
Danneels et al. [46]	MCE1: 19; 43 (13); NR	LBP; NR	MCE1: BSE	10 wk, 3 d/wk	LM; CSA: wk 0, 10; CT	LM CSA-upper L3-MCE1	0.01 (−0.61 to 0.65)
						LM CSA-upper L3-MCE2	0.01 (−0.60 to 0.63)
						LM CSA-upper L3-MCE3	0.21 (−0.40 to 0.83)
	MCE2: 20; 44 (12); NR		MCE2: MCE1 + IDLSE			LM CSA-upper L4-MCE1	−0.01 (−0.64 to 0.62)
						LM CSA-upper L4-MCE2	0.07 (−0.54 to 0.69)
						LM CSA-upper L4-MCE3	0.23 (−0.38 to 0.85)
	MCE3: 20; 43 (12); NR		MCE3: MCE1 + IDSLSE			LM CSA-lower L4-MCE1	−0.01 (−0.65 to 0.61)
						LM CSA-lower L4-MCE2	0.11 (−0.50 to 0.73)
						LM CSA-lower L4-MCE3	0.31 (−0.30 to 0.93)
Akbari et al. [24]	MCE: 25; 39.6 (3.5); NR	LBP; NR	MCE: LLMA + DRE	8 wk, 2 d/wk, 30 min	TrA, LM; thickness: wk 0, 8; US	TrA thickness-MCE	0.82 (0.27 to 1.37)
						TrA thickness-NMRE	0.60 (0.03 to 1.16)
	NMRE: 24; 40 (3.6); NR		NMRE: RE			LM thickness-MCE	0.43 (−0.11 to 0.99)
						LM thickness-NMRE	0.27 (−0.28 to 0.84)
Hides et al. [49]	MCE: 7; 21.9 (2.5); M	LBP; EA	MCE: MAE + WT + CTM	13 wk, 18.5 h/wk	LM; CSA: wk 0, 13; US	LM CSA-LS-L2-MCE	0.11 (−0.75 to 0.99)
						LM CSA-LS-L2-C	0.11 (−0.58 to 0.80)
						LM CSA-LS-L3-MCE	0.14 (−0.73 to 1.01)
						LM CSA-LS-L3-C	0.16 (−0.52 to 0.86)
						LM CSA-LS-L4-MCE	0.30 (−0.57 to 1.17)
						LM CSA-LS-L4-C	0.15 (−0.53 to 0.84)
						LM CSA-LS-L5-MCE	0.92 (0.04 to 1.79)
						LM CSA-LS-L5-C	0.22 (−0.46 to 0.92)
	C: 14; 21.4 (2); M	Healthy; EA	C: WT + CTM			LM CSA-SS-L2-MCE	0.16 (−0.70 to 1.04)
						LM CSA-SS-L2-C	0.24 (−0.44 to 0.93)
						LM CSA-SS-L3-MCE	0.18 (−0.68 to 1.06)
						LM CSA-SS-L3-C	0.17 (−0.51 to 0.86)
						LM CSA-SS-L4-MCE	0.35 (−0.52 to 1.23)
						LM CSA-SS-L4-C	0.17 (−0.52 to 0.86)
						LM CSA-SS-L5-MCE	1.13 (0.26 to 2.01)
						LM CSA-SS-L5-C	0.23 (−0.45 to 0.92)
Sokunbi et al. [27]	MCE1: 23; 39.6 (8.5); F: 10, M: 13	LBP; NR	MCE1: ×1 wkly MAE + NMRE	6 wk, 45 min	LM; CSA: wk 0, 6; US	LM CSA-MCE1	0.06 (−0.51 to 0.65)
	MCE2: 19; 38.1 (8.06); F: 15, M: 4		MCE2: ×2 wkly MAE + NMRE			LM CSA-MCE2	0.20 (−0.45 to 0.87)
	MCE 3: 20; 43.25 (9.5); F: 11, M: 9		MCE: ×3 wkly MAE + NMRE			LM CSA-MCE3	0.30 (−0.32 to 0.93)
	C: 22; 43.25 (9.5); F: 14, M: 8		NT			LM CSA-C	0.19 (−0.45 to 0.85)
Jansen et al. [50]	21; 24.8 (7.4); F: 1, M: 20	CGP; EA	ADIM + NMRE	10 wk, 2 d/wk	TrA, OI, OE; CSA: wk 0, 10; US	TrA thickness	0.66 (0.06 to 1.27)
						OI thickness	0.31 (−0.28 to 0.92)
						OE thickness	0.24 (−0.35 to 0.85)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Hides et al. [42]	MCE: 7; 21.2 (2); M	LBP; EA	MCE: MAE + WT + CTM	13 wk, 18.5 h/wk	TrA, OI; thickness: wk 0, 13; US	TrA thickness-MCE	−0.05 (−1.09 to 0.99)
						TrA thickness-C	−0.07 (−0.76 to 0.62)
	C: 14; 21.2 (2); M	Healthy; EA	C: WT + CTM			OI thickness-MCE	0.16 (−0.88 to 1.21)
						OI thickness-C	0.03 (−0.65 to 0.73)
Klizienė et al. [16]	MCE: 22; 64.8 (5.4); F	NR; MOD/SED	MCE: MAE + NMRE	32 wk, 2 d/wk, 45 min	LM; CSA: wk 0, 16, 32; US	LM CSA-L-wk 0 to 16	0.44 (−0.14 to 1.03)
						LM CSA-R-wk 0 to 16	1.53 (0.93 to 2.12)
						LM CSA-L-wk 0 to 32	2.47 (1.88 to 3.06)
						LM CSA-R-wk 0 to 32	3.39 (2.80 to 3.98)
Lee et al. [54]	20; 24.4 (2.9); F: 4, M: 16	CIS; NR	ADIM with BFPU	2 wk, 7 d/wk, 20 min	TrA, OI, OE; thickness: wk 0, 2; US	TrA thickness	0.00 (−0.61 to 0.61)
						OI thickness	0.00 (−0.61 to 0.61)
						OE thickness	0.00 (−0.61 to 0.61)
Teyhen et al. [45]	MCE: 160; 21.9 (4.2); NR	Healthy; military	MCE: MAE + ASER	12 wk, 4 d/wk, 60 min	OE, IO, TrA, RA, LM, LAM, TAM; thickness + (RA, CSA): wk 0, 12; US	TrA thickness-MCE	−0.10 (−0.32 to 0.11)
						TrA thickness-NMRE	0.09 (−0.15 to 0.34)
						OI thickness-MCE	0.00 (−0.21 to 0.21)
						OI thickness-NMRE	−0.03 (−0.28 to 0.21)
						OE thickness-MCE	−0.16 (−0.38 to 0.05)
						OE thickness-NMRE	−0.24 (−0.50 to 0.00)
						RA thickness-MCE	0.00 (−0.21 to 0.21)
						RA thickness-NMRE	0.07 (−0.18 to 0.32)
	NMRE: 120; 21.9 (4.2); NR		NMRE: ST			RA CSA-MCE	0.01 (−0.20 to 0.23)
						RA CSA-NMRE	0.06 (−0.19 to 0.31)
						LM thickness-MCE	0.00 (−0.21 to 0.21)
						LM thickness-NMRE	0.06 (−0.19 to 0.31)
						TAM thickness-MCE	−0.05 (−0.27 to 0.16)
						TAM thickness-NMRE	−0.05 (−0.31 to 0.19)
						LAM thickness-MCE	−0.09 (−0.31 to 0.12)
						LAM thickness-NMRE	−0.12 (−0.37 to 0.12)
Hides et al. [47]	MCE1: 17; 22.8 (3.5); M	LBP + healthy; EA	MCE1: 15 wk MAE + 7 wk PIL	22 wk, 2 d/wk, 30 min	LM, QL, PM; CSA: wk 7, 15, 22; MRI	LM CSA-L2-wk 0 to 15-MCE1	0.50 (−0.17 to 1.17)
						LM CSA-L2-wk 0 to 15-MCE2	1.00 (0.28 to 1.71)
						LM CSA-L2-wk 0 to 15-C	−0.14 (−0.88 to 0.59)
						LM CSA-L2-wk 0 to 22-MCE1	0.87 (0.20 to 1.54)
						LM CSA-L2-wk 0 to 22-MCE2	−0.14 (−0.85 to 0.57)
						LM CSA-L2-wk 0 to 22-C	1.28 (0.54 to 2.02)
						LM CSA-L3-wk 0 to 15-MCE1	0.39 (−0.28 to 1.06)
						LM CSA-L3-wk 0 to 15-MCE2	0.90 (0.19 to 1.62)
						LM CSA-L3-wk 0 to 15-C	−0.07 (−0.82 to 0.66)
						LM CSA-L3-wk 0 to 22-MCE1	0.68 (0.01 to 1.35)
	MCE2: 15; 22.8 (3.5); M		MCE2: 8 wk MAE + 14 wk PIL			LM CSA-L3-wk 0 to 22-MCE2	0.90 (0.19 to 1.62)
						LM CSA-L3-wk 0 to 22-C	0.87 (0.13 to 1.61)
						LM CSA-L4-wk 0 to 15-MCE1	0.50 (−0.17 to 1.17)
	C: 14; 22.8 (3.5); M		C: 15 wk PIL + 7 wk MAE			LM CSA-L4-wk 0 to 15-MCE2	0.68 (−0.03 to 1.39)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
						LM CSA-L4-wk 0 to 15-C	−0.71 (−1.45 to 0.02)
						LM CSA-L4-wk 0 to 22-MCE1	1.00 (0.32 to 1.67)
						LM CSA-L4-wk 0 to 22-MCE2	0.81 (0.10 to 1.53)
						LM CSA-L4-wk 0 to 22-C	0.63 (−0.10 to 1.37)
						LM CSA-L5-wk 0 to 15-MCE1	0.58 (−0.08 to 1.26)
						LM CSA-L5-wk 0 to 15-MCE2	0.53 (−0.18 to 1.24)
						LM CSA-L5-wk 0 to 15-C	−0.62 (−1.36 to 0.12)
						LM CSA-L5-wk 0 to 22-MCE1	0.25 (−0.42 to 0.92)
						LM CSA-L5-wk 0 to 22-MCE2	0.06 (−0.64 to 0.78)
						LM CSA-L5-wk 0 to 22-C	−0.28 (−1.02 to 0.45)
						OL CSA[d]	0.38 (−0.02 to 0.79)
						PM CSA[d]	0.29 (−0.11 to 0.70)
Machine-based resistance exercise							
Parkkola et al. [35]	12; 23 (2); F: 11, M: 1	NR; SED	NMSM	18 wk, 2 to 3 d/wk, 45 min	(LM and ES), PM; CSA: wk 0, 11, 18; MRI	(LM + ES) CSA-wk 0 to 11	0.53 (−0.26 to 1.33)
						(LM + ES) CSA-wk 0 to 18	0.58 (−0.21 to 1.38)
						PM-wk 0 to 11	0.88 (0.08 to 1.68)
						PM-wk 0 to 18	0.88 (0.08 to 1.68)
Rissanen et al. [56]	30; 39.9 (4); F: 16, M: 14	LBP; NR	HRM + NMREH	9 wk (home), 3 d/wk, 60 min; 3 wk (hospital), 5 d/wk, 120 min	LM; MFS (types I, II): wk 0, 12; MB	LM type I	0.100 (−0.40 to 0.60)
						LM type II-total	0.52 (0.01 to 1.03)
Choi et al. [14]	MRE: 35; 51.05 (9.58); F: 15, M: 20	LD; NR	MRE: MedX	12 wk, 2 d/wk	(LM and LSM); CSA: wk 0, 12; CT	(LM and LSM) CSA-MRE	0.91 (0.45 to 1.38)
	C: 40; 42.02 (17.06); F: 22, M: 18		C: HLE			(LM and LSM) CSA-C	0.33 (−0.10 to 0.76)
Critchley et al. [28]	MRE: 16; 30 (8); F: 12, M: 4	Healthy; NR	MRE: GYM + FW	8 wk, 2 d/wk, 45 min	OI, TrA; thickness: wk 0, 8; US	TrA thickness-MRE	−0.09 (−0.78 to 0.59)
						TrA thickness-NMRE	0.33 (−0.31 to 0.99)
	NMRE: 18; 31 (5); F: 14, M: 4		NMRE: PIL			OI thickness-MRE	−0.05 (−0.74 to 0.63)
						OI thickness-NMRE	0.03 (−0.61 to 0.68)
Jongwoo et al. [51]	MRE1: 7; 26.57 (1.81); M	NR; NR	MRE1: MedX	8 wk, 3 d/wk, 50 min	LM, PV; CSA: wk 0, 8; CT	LM CSA-MRE1	0.48 (−0.56 to 1.53)
						LM CSA-MRE2	0.80 (−0.24 to 1.85)
	MRE2: 7; 26.40 (1.13); M		MRE2: MedX + MCE			PV CSA-MRE1	0.73 (−0.31 to 1.78)
						PV CSA-MRE2	1.60 (0.55 to 2.64)
Dorado et al. [48]	9; 35.7 (5.4); F	Healthy; SED	PIL using BBRD	36 wk, 2 d/wk, 55 min	OT (OE and OI and TrA) + RA; volume: wk 0, 36/MRI	OT CSA-DS	0.74 (−0.18 to 1.66)
						OT CSA-NDS	0.20 (−0.72 to 1.12)
						RA CSA-DS	1.78 (0.85 to 2.70)
						RA CSA-NDS	1.79 (0.87 to 2.72)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Willemink et al. [57]	16; 46.2 (9.7); M	LBP; NR	LBRD	12 wk, 1 d/wk, 30 min + 12 wk[e]	LM; TCSA, FCSA, AF: wk 0, 12, 24; MRI	LM TCSA-L3 to L4-wk 0 to 12	0.05 (−0.64 to 0.74)
						LM TCSA-L3 to L4-wk 0 to 24	−0.16 (−0.86 to 0.52)
						LM FCSA-L3 to L4-wk 0 to 12	0.09 (−0.59 to 0.78)
						LM FCSA-L3 to L4-wk 0 to 24	−0.11 (−0.80 to 0.57)
						LM AFI-L3 to L4-wk 0 to 12	−0.11 (−0.80 to 0.58)
						LM AFI-L3 to L4-wk 0 to 24	−0.12 (−0.81 to 0.57)
						LM TCSA-L4 to L5-wk 0 to 12	0.07 (−0.62 to 0.76)
						LM TCSA-L4 to L5-wk 0 to 24	−0.01 (−0.71 to 0.67)
						LM FCSA-L4 to L5-wk 0 to 12	0.10 (−0.58 to 0.79)
						LM FCSA-L4 to L5-wk 0 to 24	0.00 (−0.68 to 0.70)
						LM AFI-L4 to L5-wk 0 to 12	−0.01 (−0.70 to 0.68)
						LM AFI-L4 to L5-wk 0 to 24	−0.04 (−0.73 to 0.64)
						LM TCSA-L5 to S1-wk 0 to 12	0.03 (−0.65 to 0.73)
						LM TCSA-L5 to S1-wk 0 to 24	−0.02 (−0.71 to 0.67)
						LM FCSA-L5 to S1-wk 0 to 12	0.13 (−0.55 to 0.82)
						LM FCSA-L5 to S1-wk 0 to 24	0.06 (−0.63 to 0.75)
						LM AFI-L5 to S1-wk 0 to 12	−0.13 (−0.82 to 0.56)
						LM AFI-L5 to S1-wk 0 to 24	−0.10 (−0.79 to 0.59)
Non-machine-based resistance exercise							
Chilibeck et al. [13]	NMRE: 19; 20.2 (0.8); F	Healthy; NR	NMRE: RE (BP, LP)	20 wk, 2 d/wk	TLM; MM: wk 0, 10, 20; DEXA	TLM-wk 0 to 10-NMRE	0.04 (−0.59 to 0.67)
						TLM-wk 0 to 20-NMRE	0.32 (−0.31 to 0.96)
	C: 10; 20.2 (0.4); F		C: NR	NR	TM; MM: wk 0, 20; DEXA	NR	NR
Storheim et al. [41]	NMRE: 11; 44.9 (10.3); F: 5, M: 6	LBP; NR	NMRE: NSFT	15 wk, 3 d/wk, 60 min	PV; CSA + density: wk 0, 15; CT	PV CSA-L3 to L4-NMRE	0.10 (−0.72 to 0.94)
						PV CSA-L3 to L4-C	−0.03 (−0.80 to 0.73)
						PV CSA-L4 to L5-NMRE	0.11 (−0.71 to 0.95)
						PV CSA-L4 to L5-C	−0.17 (−0.94 to 0.59)
						PV density-L3 to L4-NMRE	0.39 (−0.44 to 1.22)
	C: 13; 40.9 (11.8); F: 7, M: 6		C: UC by GP	15 wk		PV density-L3 to L4-C	−0.10 (−0.87 to 0.66)
						PV density-L4 to L5-NMRE	0.28 (−0.55 to 1.12)
						PV density-L4 to L5-C	−0.10 (−0.87 to 0.66)
Woohyung et al. [25]	NMRE: 17; 32.7 (5.9); NR	LBP; NR	NMRE: BET	12 wk, 3 d/wk, 45 min	PM, QL, ES, LM; CSA: wk 0, 12; CT	PM CSA-NMRE	0.16 (−0.51 to 0.83)
						PM CSA-C	0.01(−0.67 to 0.71)
						QL CSA-NMRE	0.17 (−0.49 to 0.84)
						QL CSA-C	0.03 (−0.65 to 0.73)
	C 16; 33.1 (5.7); NR		C: MHT, UST, TENS			ES CSA-NMRE	0.21 (−0.46 to 0.88)
						ES CSA-C	0.00 (−0.68 to 0.69)
						LM CSA-NMRE	0.19 (−0.47 to 0.86)
						LM CSA-C	0.02 (−0.66 to 0.71)

Table 1 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes	SMD (95 % CI)
Hoshikawa et al. [58]	NMRE: 16; 12 to 13[f]; M	Healthy; EA	NMRE: ST + STP	24 wk, 4 d/wk + STP as per C	RA, LAM, PM, QL, ES; CSA: wk 0, 24; MRI	RA CSA-NMRE	0.66 (−0.03 to 1.35)
						RA CSA-C	0.81 (0.01 to 1.61)
						LAM -CSA-NMRE	0.49 (−0.19 to 1.19)
						LAM CSA-C	0.54 (−0.25 to 1.34)
	C: 12; 12 to 13[f]; M		C: STP	24 wk, 6 d/wk		PM CSA-NMRE	0.41 (−0.27 to 1.10)
						PM CSA-C	0.74 (−0.05 to 1.54)
						QL CSA-NMRE	0.23 (−0.45 to 0.93)
						QL CSA-NMRE	0.44 (−0.35 to 1.24)
						ES CSA-NMRE	0.48 (−0.20 to 1.17)
						ES CSA-C	0.47 (−0.32 to 1.27)
Cardiovascular exercise							
Kuk et al. [29]	86; 57.8 (6.4); F	O/OP; NR	CVE: CE or TRD (50 % of VO_2max)	24 wk, 3 to 4 d/wk	ABM; MM + lipid: wk 0, 24; CT	L4 to L5-lipid	0.03 (−0.26 to 0.33)
						T12 to L1-lipid	−0.06 (−0.36 to 0.23)
						L4 to L5-MM	−0.04 (−0.34 to 0.25)
						T12 to L1-MM	−0.02 (−0.32 to 0.27)
Sakamaki et al. [43]	CVE1: 9; 21.4 (2.1); M	Healthy; NR	CVE1: BFR walk	3 wk, 6 d/wk, 30 min	(PV, CSA) + (IP, volume): wk 0, 3; MRI	IP volume-CVE1	0.09 (−0.83 to 1.01)
						IP volume-CVE2	0.03 (−0.94 to 1.01)
	CVE2: 8; 21.1 (1.9); M		CVE2: WBFR walk			CSA-L4 to L5-CVE1	−0.08 (−1.00 to 0.84)
						CSA-L4 to L5-CVE2	−0.16 (−1.14 to 0.81)

×*1 wkly* once weekly, ×*2 wkly* twice weekly, ×*3 wkly* three times weekly, *ABM* abdominal muscles, *ADIM* abdominal draw-in manoeuvre, *AFI* area of fatty infiltration, *ASER* army standard exercise regimen, *BBRD* balanced body reformer device, *BET* ball exercise therapy, *BFPU* biofeedback pressure unit, *BFR* blood flow restriction, *BP* bench press, *BSE* back stabilization exercise, *C* comparator or control group, *CE* cycle ergometer, *CGP* patient(s) with chronic groin pain, *CI* confidence interval, *CIS* individual(s) with core instability, *CSA* cross-sectional area, *CT* computed tomography, *CTM* cricket training and matches, *CVE* cardiovascular exercise, *d* day(s), *DEXA* dual-energy x-ray absorptiometry, *DS* dominant side, *DRE* dynamic resistance exercise, *EA* elite athlete(s), *ES* erector spinae, *F* female, *FCSA* functional cross-sectional area, *FW* free weights, *GP* general practitioner(s), *GYM* gym machines, *h* hour(s), *HLE* home-based lumbar exercise, *HRM* hydraulic resistance machine, *IDLSE* intensive dynamic lumbar-strengthening exercise, *IDSLSE* intensive dynamic–static lumbar-strengthening exercise, *IP* iliopsoas, *L* left side, *L1* lumbar spinal level 1, *L2* lumbar spinal level 2, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *LAM* lateral abdominal muscles, *LBP* patient(s) with low back pain, *LBRD* Lower Back Revival device, *LD* patient(s) post-lumbar discectomy, *LLMA* low load muscle activation, *LM* lumbar multifidus, *LP* leg press, *LS* large side, *LSM* longissimus, *M* male, *MAE* muscle activation exercise, *MB* muscle biopsy, *MCE* motor control exercise, *MCE1* MCE subject group 1, *MCE2* MCE subject group 2, *MCE3* MCE subject group 3, *MedX* MedX lumbar extension machine, *MFS* muscle fibre size, *MHT* moist heat therapy, *min* minute(s), *MM* muscle mass, *MOD* moderately active, *MRE* machine-based resistance exercise, *MRI* magnetic resonance imaging, *NDS* nondominant side, *NMRE* non-machine-based resistance exercise, *NMSM* Nautilus multi-station machine, *NR* not reported, *NSFT* Norwegian strength and fitness training, *NT* no treatment, *OE* external oblique, *OI* internal oblique, *O/OP* overweight/obese postmenopausal, *OT* obliques and transversus abdominis, *PIL* Pilates, *PM* psoas major, *PV* paravertebral muscles, *QL* quadratus lumborum, *R* right side, *RA* rectus abdominis, *RE* resistance exercise, *S1* sacral spinal level 1, *SED* sedentary, *SMD* standardized mean difference, *SS* small side, *ST* strength training, *STP* soccer training programme, *T12* thoracic spinal level 12, *TAM* total abdominal muscles, *TCSA* total cross-sectional area, *TENS* transcutaneous electrical nerve stimulation, *TLM* trunk lean mass, *TrA* transversus abdominis, *TRD* treadmill, *UC* usual care, *US* ultrasound, *UST* ultrasound therapy, *VO_2max* maximal oxygen consumption, *WBFR* without blood flow restriction, *wk* week(s), *wk 0* baseline, *WT* weight training, *y* year(s)

[a] Exercise groups are stated where applicable

[b] All data are presented as mean (standard deviation), unless otherwise indicated

[c] Current physical fitness training level, based on the study authors' description of the general physical activity level

[d] Combined data from MCE1, MCE2 and C

[e] Training was continued at a frequency that was tailored to the patients' convenience

[f] Age range

of statistical heterogeneity and random-effects meta-analysis were not conducted.

3.3 Risks of Bias in the Included Studies

The results of the risk-of-bias assessments for each study are presented in Fig. 2 and are summarized as percentages across all studies in Fig. 3. The most common sources of bias involved random sequence generation, allocation concealment and blinding of study participants. While no studies reported the blinding of participants or personnel, the nature of exercise interventions typically precludes this. The blinding of outcome assessors was reported in 15 trials (52 %) [18, 24, 26–29, 41–47, 49, 52]. Thirteen studies (44 %) [14, 24, 27–29, 41, 43–47, 51, 58] randomly assigned participants to intervention groups; however only six trials (20 %) [27–29, 43, 45, 47] sufficiently detailed the method used to generate the sequence of random numbers. Five studies (17 %) [18, 28, 29, 41, 45] adequately reported the method used to conceal group allocation. Eleven studies (37 %) [13, 18, 28, 35, 45, 47, 50, 54, 55, 57, 58] stated that they used methods to address incomplete outcome data, such as using intention-to-treat analysis. Only one study (3 %) [45] referred to a published study protocol that clearly defined the primary and secondary study outcomes.

3.4 Effects of Interventions

We were able to calculate standardized within-group treatment effects from data reported in 23 of the 29 studies [13, 14, 18, 24, 25, 27–29, 35, 41–49, 51, 54, 56–58]. Forest plots summarizing the within-group treatment effects from baseline to the final follow-up point of each study are presented in Figs. 4, 5, 6 and 7. In addition, we computed standardized within-group treatment effects at all time points, including comparator group outcomes (Table 1).

Of the 22 included studies, 10 (45 %) [14, 16, 24, 35, 47–51, 56] reported positive changes in trunk muscle morphology following participation in an exercise training programme. Among trials demonstrating significant treatment effects on trunk muscle morphology, the largest effects were reported by studies [16, 24, 47, 49, 50] that used combined motor control and non-machine-based resistance exercise programmes (SMD [95 % CI] = 0.66 [0.06 to 1.27] to 3.39 [2.80 to 3.98]) and studies [14, 35, 48, 51, 56] that investigated machine-based resistance exercise protocols (SMD [95 % CI] = 0.52 [0.01 to 1.03] to 1.79 [0.87 to 2.72]). Most studies investigating the effects of non-machine-based resistance exercise interventions reported no change in trunk muscle size morphology, while one study [24] reported a significant increase in trunk muscle size (SMD [95 % CI] = 0.60 [0.03 to 1.16]). Cardiovascular exercise interventions [29, 43] demonstrated no effect (SMD [95 % CI] = −0.16 [−1.14 to 0.81] to 0.09 [−0.83 to 1.01]). Because of data limitations, we were unable to calculate SMD statistics for six studies (21 %) [18, 26, 44, 52, 53, 55], and those study outcomes are presented in Table 2.

4 Discussion

4.1 Summary of the Main Results

This was the first systematic review to examine the effect of exercise training on trunk muscle morphology. Of the 29 included studies, 14 (48 %) [14, 16, 18, 24, 26, 35, 44, 46–51, 56] reported positive changes in trunk muscle morphology following participation in an exercise training programme. Among positive trials for which we were able to estimate treatment effects, programmes including motor control exercises combined with non-machine-based resistance exercises [16, 24, 47, 49, 50] and programmes including machine-based exercise interventions [14, 35, 48, 51, 56] reported medium to large effects on trunk muscle size.

Most studies investigating the effects of non-machine-based resistance exercise interventions [13, 28, 41, 45] reported no change in trunk muscle morphology, while three studies reported significant increases in trunk muscle size [24–26]. Cardiovascular exercise interventions [29, 43] had no effect on trunk muscle morphology. These results should be interpreted cautiously because of limitations in the included studies, such as investigation of small samples, suboptimal reporting of exercise details and substantial risks of bias.

4.1.1 Effect of Motor Control Exercise on Trunk Muscle Morphology

Six studies [16, 24, 46, 47, 49, 50] reported positive changes in trunk muscle size following participation in a combined motor control and non-machine-based resistance exercise programme. Klizienė et al. [16] examined changes in lumbar multifidus CSA among 22 elderly women participating in a 32-week motor control and resistance exercise programme. While the authors reported large increases in lumbar multifidus CSA, this study demonstrated several potential sources of methodological bias, including selection, performance and detection bias. Additionally, there was a lack of detailed reporting of the exercise parameters, making it difficult to identify several aspects of the exercise intervention. The large treatment effects may have resulted from the longer duration of

Table 2 Descriptive interpretation of the outcomes of six studies for which standardized mean difference statistics could not be calculated

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes
Motor control exercise						
Hides et al. [18]	MCE: 21; 30.9 (6.5); F: 13, M: 8	LBP; NR	MCE + MT	4 wk, NR	LM; CSA: wk 0, 1 to 4; US	Resolution of LM atrophy and muscle recovery were more rapid and complete in patients who received MCE ($p < 0.001$)
	C: 20; 31 (7.9); F: 10, M: 10		MT			
Danneels et al. [44]	MCE1: 19; 46 (37 to 57)[d]; F: 9, M: 10	LBP; NR	MCE1: BSE	10 wk, 3 d/wk	PV; CSA: wk 0, 10; CT	PV CSA increased in the MCE2 group (L4: $p < 0.02$) and in the MCE3 group (L3: $p < 0.003$; L4: $p < 0.01$). There was no difference in PV CSA in the MCE group. More intense resistance exercise may be necessary to restore the size of the PV in LBP patients with atrophied back muscles
	MCE2: 20; 47 (35 to 52)[d]; F: 11, M: 9		MCE2: MCE1 + IDSE			
	MCE3: 20; 40 (37 to 49)[d]; F: 12, M: 8		MCE3: MCE1 + IDSLSE			
Machine-based resistance exercise						
Mooney et al. [55]	MRE: 8; 45 to 64[e]; F: 4, M: 4	LBP; NR	MRE: MedX	8 wk, 2 d/wk	PV; MM: wk 0, 8; MRI	Four patients with severe fatty infiltration in the lumbar extensor muscles had a decrease in the degree of infiltration but no change in lean muscle mass. There were no changes in fat infiltration or muscle mass among the other patients
	C: 8; 45 to 64[e]; F: 4, M: 4	Healthy; NR				
Kaser et al. [52]	MRE: 25; 43.5 (10.5); F: 13, M: 12	LBP; NR	MRE: DBD	12 wk, 2 d/wk, 30 to 60 min	(PV, CSA) + (ES, MFS): wk 0, 12	There were no significant changes in PV CSA in any of the three groups. Pathological changes in fibre types I, II, IIX, IIC pre- to post-therapy were not significantly different in the three groups (MRE, NMRE, CVE)
	NMRE: 16; 45.2 (11.2); F: 10, M: 6		NMRE: ST + physio			
	CVE: 18; 43.4 (11.7); F: 7, M: 11		CVE: LIA			
Kramer et al. [53]	15; 18 to 57[e]; F: 6, M: 9	DO for TVF; NR	DBD	12 wk, 2 d/wk	(IC and LSM), LM; CSA: wk 0, 12; MRI	For the LSM and IC muscles, the median change in CSA was 1.39 cm^2 (8.3 %; range 0.22 cm^2 [0.9 %] to 5.22 cm^2 [30.5 %]) and for the LM muscle, the median change in CSA was −0.27 cm^2 (−17.5 %; range −0.03 cm^2 [−1.5 %] to −0.84 cm^2 [−45.4 %])

Table 2 continued

Study	No. of subjects[a]; age (y)[b]; sex	Clinical status; training level[c]	Exercise protocol	Protocol time (wk), frequency	Muscle(s); measurement; device	Outcomes
Non-machine-based resistance exercise						
Lescher et al. [26]	14; 45 to 56[e]; M	LBP; SED	RE	12 wk,7 d/wk, 10 min	(ES and QL); CSA: wk 0, 12; MRI	There was a significant change in ES and QL CSA following 3 mo NMRE ($p < 0.01$)

BSE back stabilization exercise, *C* comparator or control group, *CSA* cross-sectional area, *CT* computed tomography, *CVE* cardiovascular exercise, *d* day(s), *DBD* David back device, *DO* patients post-dorsal osteosynthesis, *ES* erector spinae, *F* female, *IC* iliocostalis, *IDLSE* intensive dynamic lumbar-strengthening exercise, *IDSLSE* intensive dynamic–static lumbar-strengthening exercise, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *LBP* patient(s) with low back pain, *LIA* low-impact aerobics, *LM* lumbar multifidus, *LSM* longissimus, *M* male, *MCE* motor control exercise, *MCE1* MCE subject group 1, *MCE2* MCE subject group 2, *MCE3* MCE subject group 3, MedX MedX lumbar extension machine, *MFS* muscle fibre size, *min* minute(s), *MM* muscle mass, *mo* month(s), *MRE* machine-based resistance exercise, *MRI* magnetic resonance imaging, *MT* medical treatment, *NMRE* non-machine-based resistance exercise, *NR* not reported, *OE* external oblique, *OI* internal oblique, *physio* physiotherapy, *PIL* Pilates, *PV* paravertebral muscles, *QL* quadratus lumborum, *RE* resistance exercise, *SED* sedentary, *ST* strength training, *TVF* thoracolumbar vertebral fracture, *US* ultrasound, *wk* week(s), *wk 0* baseline, *y* year(s)

[a] Exercise groups are stated where applicable

[b] All data are presented as mean (standard deviation), unless otherwise indicated

[c] Current physical fitness training level, based on the study authors' description of the general physical activity level

[d] Median (interquartile range)

[e] Range

training (32 weeks); this is particularly evident when considering the effect sizes at 16 weeks, which were comparable to those in other studies of similar exercise duration.

An RCT with a low risk of bias [47] investigated the effects of three multimodal training programmes (which included motor control exercises) on lumbar multifidus, quadratus lumborum and psoas muscle CSA. The study participants comprised 46 elite male Australian Football League athletes. Each of the three training programmes was defined by the duration and sequencing of two exercise periods implemented during the 22-week playing season: motor control exercises plus routine team training (the motor control period) or Pilates exercises plus routine team training (the Pilates period). Group 1 (prolonged motor control training) completed a 15-week motor control exercise period, followed by a 7-week Pilates period. Group 2 (short-term motor control training) completed a 7-week Pilates period, followed by an 8-week motor control period and then another 7-week Pilates period. Group 3 (control) participants completed a 15-week Pilates period and then a 7-week motor control period. Muscle CSA was assessed by MRI at baseline, week 15 and week 22. Participants in group 1 (prolonged training) demonstrated no change in lumbar multifidus CSA by week 15 but moderate to large increases in lumbar multifidus CSA at the L2 to L4 lumbar spinal levels by week 22. Participants in group 2 (short-term training) demonstrated large increases in lumbar multifidus CSA at the L2 to L3 lumbar spinal levels by week 15 and at L2 to L4 by week 22. Finally, group 3 (control) participants experienced no change in lumbar multifidus CSA by week 15 but large increases in lumbar multifidus CSA at L2 to L3 by week 22 (following the 7-week motor control intervention). There were no changes in lumbar multifidus CSA at the remaining spinal levels, nor were there differences in muscle size among the other muscles that were measured (the quadratus lumborum and psoas major). It is noteworthy that as professional athletes, the study participants maintained an intensive exercise training schedule prior to and throughout the duration of the study. Therefore, these study results may not generalize beyond similar athletic populations.

Two studies with high risks of bias [24, 46] reported that lumbar multifidus thickness and CSA increased in patients with low back pain following participation in a combined motor control and non-machine-based resistance exercise programme. However, our treatment effect estimates demonstrated no significant changes in lumbar multifidus thickness or CSA. Akbari et al. [24] investigated the effect of an 8-week motor control and resistance exercise programme on transversus abdominis and lumbar multifidus muscle thickness among 25 patients with chronic low back pain. They reported increases in transversus abdominis and

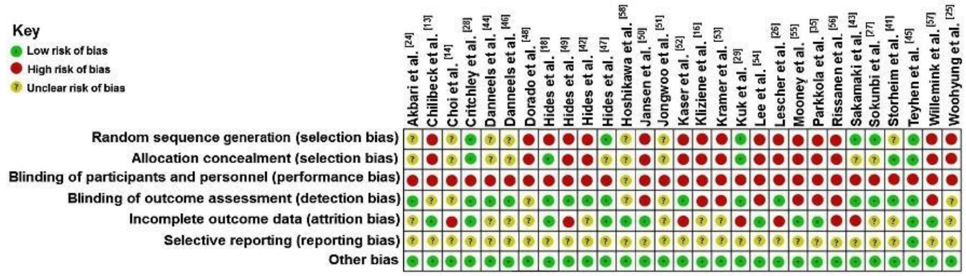


Fig. 2 Risk-of-bias summary: review authors' judgments for each risk-of-bias item from each included study

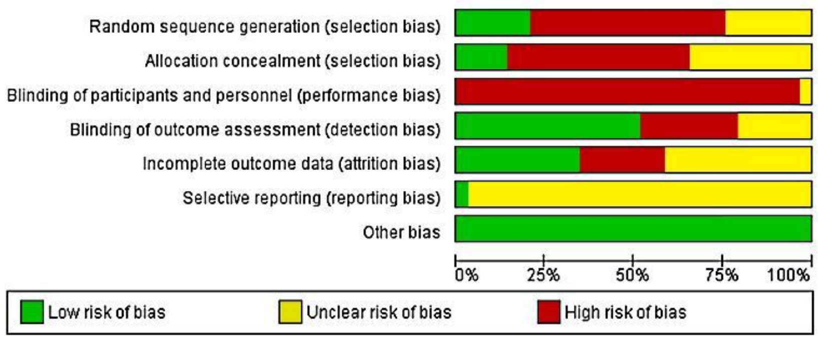


Fig. 3 Plot of the distribution of the review authors' judgments across studies for each risk-of-bias item

lumbar multifidus muscle thickness. Another study [46] examined the impact of a 10-week motor control exercise programme on lumbar multifidus CSA in 59 patients with chronic low back pain. Participants were randomly assigned to receive motor control exercises, motor control and dynamic resistance exercises, or motor control and dynamic–static resistance exercises. Lumbar multifidus CSA was measured at the upper end-plate of L3, lower end-plate of L4 and upper end-plate of L4. The authors reported increases in lumbar multifidus muscle CSA at the upper end-plate of L3, upper end-plate of L4 and lower end-plate of L4 among participants performing the motor control and dynamic–static resistance exercises, with no change in muscle morphology occurring in the other groups.

One study with a high risk of bias [49] examined changes in lumbar multifidus CSA at the L2 to L5 lumbar spinal levels in 21 young elite cricketers with and without low back pain. Participants with low back pain performed 8 weeks of motor control and non-machine-based resistance exercises, followed by 4 weeks of cricket matches (on 4 days per week). Participants without low back pain completed 8 weeks of non-machine-based resistance exercises and 4 weeks of cricket matches (on 4 days per week). The athletes in both groups demonstrated no change in lumbar multifidus CSA at the L2 to L4 lumbar spinal levels. However, for athletes with low back pain, there were large increases in lumbar multifidus CSA at L5 on the asymptomatic and symptomatic sides. Similarly, Jansen et al. [50] reported the effect of exercises targeting the lateral abdominal muscles among 21 young football players with chronic groin pain. There were moderate increases in transversus abdominis thickness and no change in internal or external oblique muscle thickness following 14 weeks of motor control and resistance exercises. However, the results of this study must be interpreted cautiously because of the high risk of bias and small sample size.

Two studies with high risks of bias [27, 42] reported no differences in abdominal and lumbar multifidus muscle size following motor control and non-machine-based resistance exercise training. Finally, one higher-quality study [45] and one lower-quality study [54] evaluating the effects of short-term motor control exercise programmes reported no changes in lumbar and abdominal muscle CSA.

4.1.2 *Effect of Machine-Based Resistance Exercise on Trunk Muscle Morphology*

Two studies with high risks of bias [14, 48] demonstrated significant increases in lumbar multifidus and lateral abdominal muscle size following participation in a

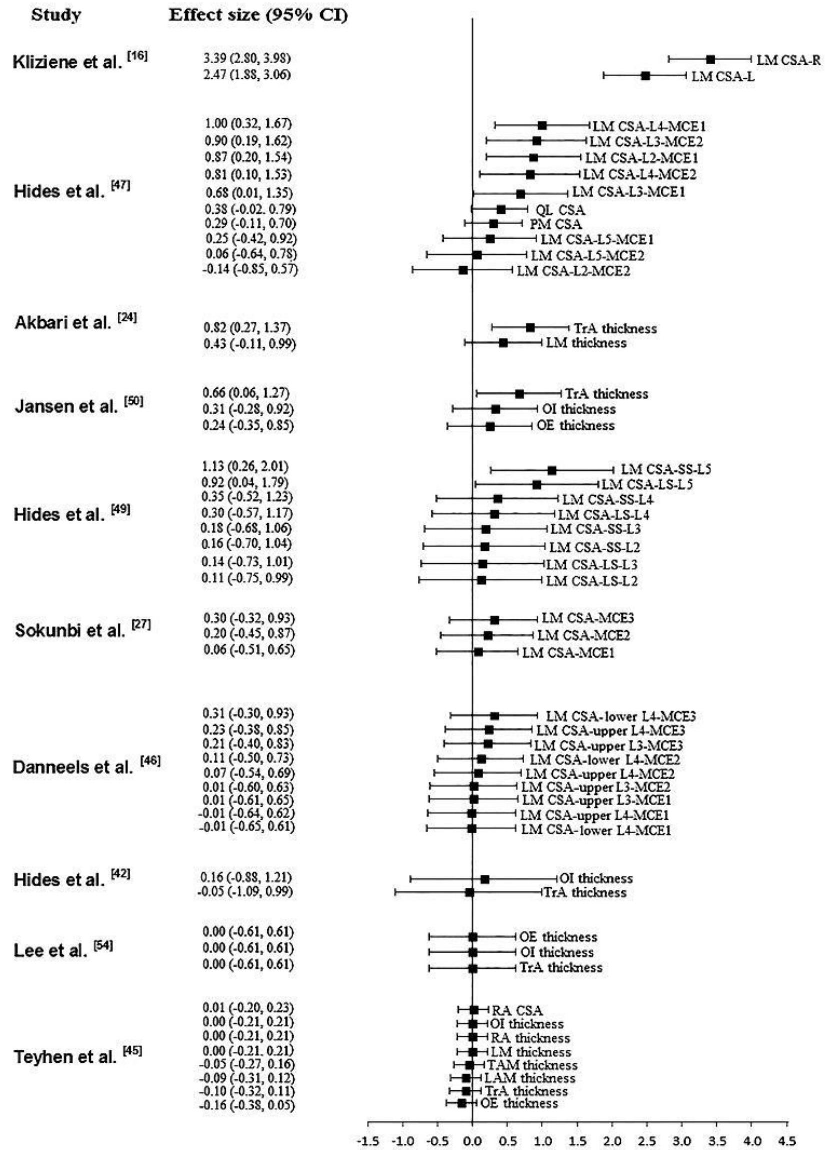


Fig. 4 Forest plot summarizing the effect [effect size, standardized mean difference and 95 % confidence interval (CI)] of motor control exercise training interventions on trunk muscle morphology (baseline versus post-training). *CSA* cross-sectional area, *L* left side, *L2* lumbar spinal level 2, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *LAM* lateral abdominal muscles, *LM* lumbar multifidus, *LS* large side, *MCE1* motor control exercise group 1, *MCE2* motor control exercise group 2, *MCE3* motor control exercise group 3, *OE* external oblique, *OI* internal oblique, *PM* psoas major, *QL* quadratus lumborum, *R* right, *RA* rectus abdominis, *SS* small side, *TAM* total abdominal muscles, *TrA* transversus abdominis

machine-based resistance exercise. Dorado et al. [48] examined changes in rectus abdominis and lateral abdominal muscle volume in nine sedentary female participants participating in a 36-week Pilates exercise programme using the 'balance body reformer' device. There were large increases in rectus abdominis volume on the dominant and nondominant sides, while lateral abdominal muscle volume remained unchanged. Participants ($n = 35$) in another study [14] completed 12 weeks of training on a MedX lumbar extension machine, 6 weeks after lumbar disc surgery. Following the 12-week exercise intervention, there was a large increase in paraspinal muscle CSA.

One study with a high risk of bias [51] examined the impact of an 8-week exercise intervention using a MedX lumbar extension machine, with or without motor control exercises, on paraspinal and lumbar multifidus muscle CSA, among 14 young male adults. Participants performing the machine-based resistance and motor control exercises demonstrated increases in paraspinal and lumbar multifidus muscle CSA.

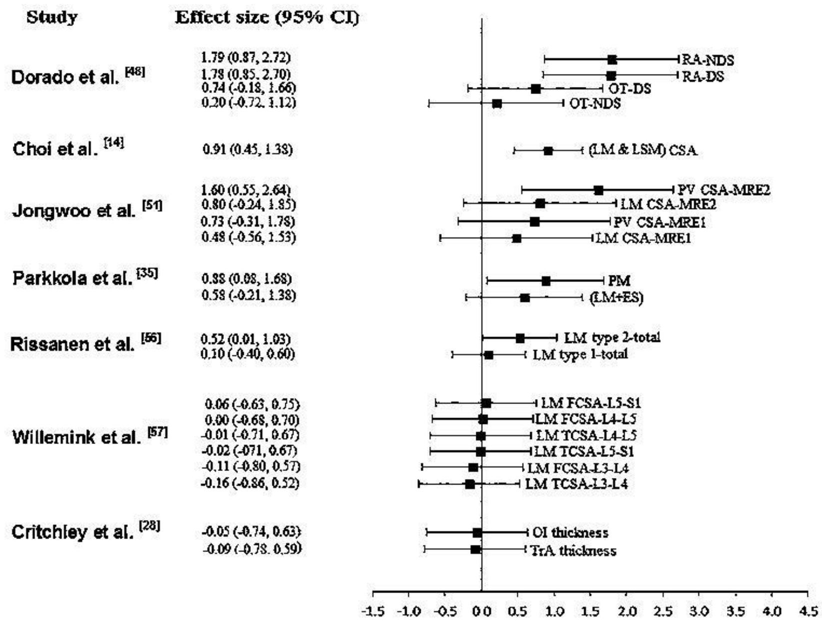


Fig. 5 Forest plot summarizing the effect [effect size, standardized mean difference and 95 % confidence interval (CI)] of machine-based resistance exercise training interventions on trunk muscle morphology (baseline versus post-training). *CSA* cross-sectional area, *DS* dominant side, *ES* erector spinae, *FCSA* functional cross-sectional area, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *LM* lumbar multifidus, *LSM* longissimus, *MRE1* machine-based resistance exercise group 1, *MRE2* machine-based resistance exercise group 2, *NDS* nondominant side, *OI* internal oblique, *OT* obliques and transversus abdominis, *PM* psoas major, *PV* paravertebral muscles, *RA* rectus abdominis, *S1* sacral spinal level 1, *TCSA* total cross-sectional area, *TrA* transversus abdominis

One study with a high risk of bias, reported by Parkkola et al. [35], examined changes in psoas major and paraspinal muscle CSA following an 18-week machine-based resistance exercise programme using a Nautilus multi-station device. Among the 12 sedentary participants, there were large increases in psoas muscle CSA but no changes in paraspinal muscle CSA. Another study with a high risk of bias [56] investigated the effect of a 12-week machine-based and non-machine-based resistance exercise training programme on lumbar multifidus type I and II muscle fibre size. Lumbar multifidus muscle biopsies were obtained from 30 patients with chronic low back pain before and after a 12-week exercise programme. There were moderate increases in type II muscle fibre size and no changes in the size of type I muscle fibres. Finally, one higher-quality study [28] and one lower-quality study [57] reported no effects on lateral abdominal and lumbar muscle size following 12 weeks of machine-based resistance exercise training interventions.

4.1.3 *Effect of Non-machine-Based Resistance Exercise on Trunk Muscle Morphology*

One study with a high risk of bias [24] examined changes in transversus abdominis and lumbar multifidus muscle thickness among 25 patients with chronic low back pain participating in an 8-week progressive non-machine-based resistance exercise intervention. The authors reported increases in transversus abdominis and lumbar multifidus muscle thickness. However, the findings on lumbar multifidus thickness must be interpreted cautiously because our treatment effect estimates demonstrated no significant changes in lumbar multifidus thickness.

Another study with a high risk of bias [25] investigated the effect of a 12-week Swiss ball exercise programme on psoas major, quadratus lumborum, erector spinae and lumbar multifidus muscle CSA among 17 patients with chronic low back pain. The authors reported increases in psoas major, quadratus lumborum, erector spinae and lumbar multifidus muscle CSA. However, the results from this study must be interpreted cautiously because our treatment effect estimates demonstrated no significant changes in psoas major, quadratus lumborum, erector spinae and lumbar multifidus muscle CSA.

The remaining five studies investigating the effect of non-machine-based resistance exercise [13, 28, 41, 45, 58] demonstrated no significant changes in trunk muscle morphology. The methodological quality of these studies varied from high to low.

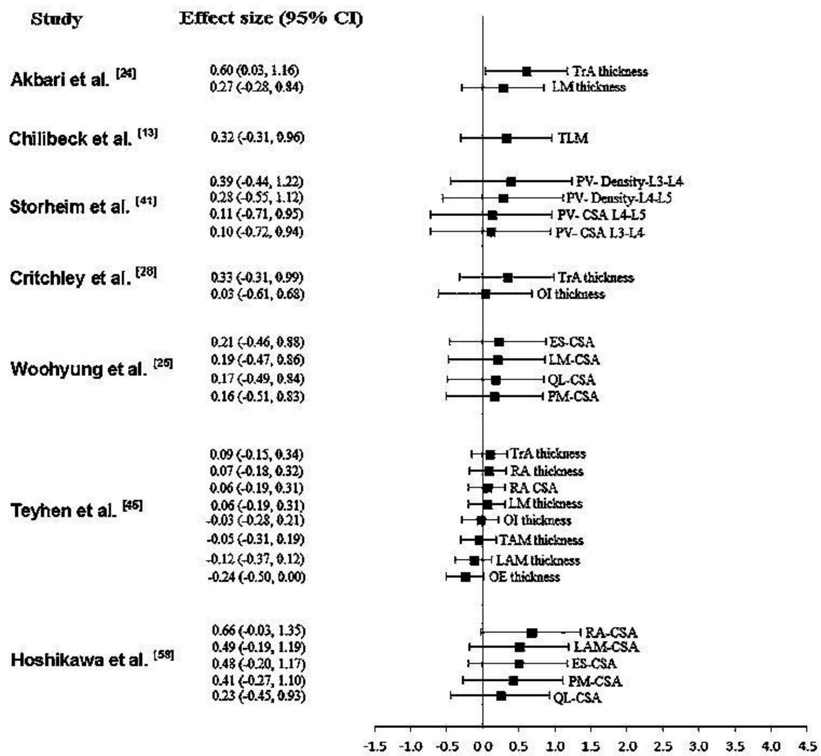


Fig. 6 Forest plot summarizing the effect [effect size, standardized mean difference and 95 % confidence interval (CI)] of non-machine-based resistance exercise training interventions on trunk muscle morphology (baseline versus post-training). *CSA* cross-sectional area, *ES* erector spinae, *L3* lumbar spinal level 3, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *LAM* lateral abdominal muscles, *LM* lumbar multifidus, *OE* external oblique, *OI* internal oblique, *PM* psoas major, *PV* paravertebral muscles, *QL* quadratus lumborum, *RA* rectus abdominis, *TAM* total abdominal muscles, *TLM* trunk lean mass, *TrA* transversus abdominis

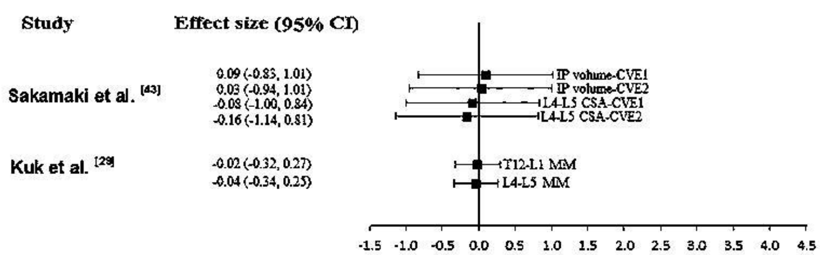


Fig. 7 Forest plot summarizing the effect [effect size, standardized mean difference and 95 % confidence interval (CI)] of cardiovascular exercise training interventions on trunk muscle morphology (baseline versus post-training). *CSA* cross-sectional area, *CVE1* cardiovascular exercise group 1, *CVE2* cardiovascular exercise group 2, *IP* iliopsoas, *L1* lumbar spinal level 1, *L4* lumbar spinal level 4, *L5* lumbar spinal level 5, *MM* muscle mass, *T12* thoracic spinal level 12

4.1.4 Effect of Cardiovascular Exercise on Trunk Muscle Morphology

One higher-quality study [29] and one lower-quality study [43] examined the effects of cardiovascular exercise training interventions on trunk muscle morphology. Neither exercise programme resulted in morphological changes in the iliopsoas, abdominal and lumbar paraspinal muscles. Kuk et al. [29] investigated the effect of 24 weeks of cardiovascular exercise on abdominal muscle mass among 86 overweight or obese postmenopausal women. Participants exercised three to four times per week on a cycle ergometer or a treadmill at 50 % of maximal oxygen consumption (VO_2max), expending 4, 8 or 12 kcal/kg per week. In the second study, Sakamaki et al. [43] examined changes in iliopsoas volume and lumbar paraspinal muscle volume in 17 young males following a 3-week treadmill walking programme.

4.1.5 *Descriptive Interpretation of the Results of Six Studies*

We were unable to estimate treatment effects from the data reported in six studies [18, 26, 44, 52, 53, 55]. One higher-quality study by Hides et al. [18] investigated the effect of medical treatment, with and without motor control exercises, on lumbar multifidus CSA among 41 patients with acute, unilateral low back pain. At baseline, the patients exhibited asymmetry in lumbar multifidus CSA, purportedly resulting from unilateral atrophy (mean asymmetry = 24 %). Following 4 weeks of treatment, there was a significant difference between the groups in mean asymmetry, favouring the exercise group (motor control exercise and medical treatment = 0.7 %, medical treatment only = 17 %).

Three studies with high risks of bias [26, 44, 53] reported positive changes in trunk muscle morphology following participation in different types of exercise training interventions. Lescher et al. [26] reported that an intensive period of non-machine-based resistance exercise participation (daily for 12 weeks) increased paraspinal muscle CSA among 14 sedentary, middle-aged patients with low back pain. Ten weeks of motor control exercises combined with non-machine-based resistance exercises were shown to increase lumbar paraspinal muscle CSA among patients with chronic back pain and back muscle atrophy [44]. In this study, 59 participants were randomized to receive motor control exercises, motor control and dynamic resistance exercises, or motor control and dynamic–static resistance exercises. Lumbar paraspinal muscle CSA was measured at the upper end-plate of L3 and at the upper and lower end-plates of L4. The authors reported increases in paraspinal muscle CSA at the upper end-plate of L4 among participants in the motor control and dynamic resistance exercise group. Additionally, there were increases in paraspinal muscle CSA at the upper end-plate of L3 and at the lower end-plate of L4 among participants completing the motor control and dynamic–static resistance exercise programme, but no differences in the motor control exercise group. Participants in another study [53] completed 12 weeks of training on 'David back exercise devices' 24 weeks after lumbar spine spinal surgery. The authors reported only descriptive statistics demonstrating an increase in paraspinal muscle CSA and no change in lumbar multifidus CSA.

Finally, two studies with high risks of bias [52, 55] examined the effects of machine-based resistance exercise training on trunk muscle morphology. Neither exercise programme resulted in morphological changes in the lumbar paraspinal muscle. Kaser et al. [52] investigated the effect of 12 weeks of machine-based resistance exercises, non-machine-based resistance exercises and aerobic exercises on lumbar paraspinal muscle CSA and erector spinae muscle fibre size (types I, IIA, IIX and IIC) among 34 patients with chronic low back pain. In the second study [55], 16 participants with and without low back pain completed an 8-week machine-based resistance exercise programme using a MedX lumbar extension machine.

4.2 Quality of the Evidence

As evidenced by the lack of precision in the calculated treatment effects, many studies were likely underpowered and therefore prone to type II error. Most studies demonstrated a range of methodological limitations, such as (1) inadequate reporting of randomization sequence generation; (2) concealment of treatment allocation; and (3) incomplete reporting of outcome data. Other methodological weaknesses included a lack of blinding of participants or personnel measuring treatment outcomes, and issues of selective reporting. Given the nature of exercise interventions, it is usually not possible to blind participants and clinicians to an individual's treatment group allocation. However, the blinding of research personnel responsible for the measurement of treatment outcomes is a potentially important method of reducing bias. Indeed, a recent systematic review investigating the clinical importance of paraspinal muscle morphology reported a trend toward larger effect sizes when outcome assessors were not blinded [59].

4.3 Study Limitations and Potential Biases in the Review Process

A potentially important measurement issue among some of the included studies involves the quantification of muscle changes derived from suboptimal imaging techniques. Many studies appeared to have reported changes in muscle size from partial muscle measures (e.g. CSA or thickness) as opposed to comprehensive measures of muscle volume. Moreover, many of these studies appeared to generalize changes observed in part of the muscle to the muscle in its entirety. Such generalization requires the assumption that exercise-induced change in skeletal muscle size is a homogenous process that occurs equally throughout the muscle. However, evidence from peripheral skeletal muscle suggests that hypertrophy is a heterogeneous process, with some parts of a muscle experiencing greater hypertrophy than other parts [60]. While this phenomenon has not been investigated in the lower trunk musculature, negative changes in muscle size (i.e. atrophy) appear to occur asymmetrically within paraspinal muscles [61], suggesting that this concern is equally valid in that region. Therefore, the use of incomplete measures of muscle size represented another potential source of bias among many of the studies in this review.

The primary strengths of this review were our search strategy, which implemented a comprehensive examination of five relevant databases, and a study selection process undertaken by two independent reviewers using predefined criteria. However, we excluded studies published in languages other than English, and therefore it is possible that the results of relevant studies are not represented in this review. The quality of many of the included studies was suboptimal because of the risks of selection, performance, detection and attrition biases. We were unable to combine study results for meta-analyses, because of clinical heterogeneity related to differences in the sample populations, exercise modes, exercise prescriptions, outcome muscles and methods of muscle measurement. Finally, it was difficult to classify many exercise programmes, because of poor or incomplete reporting. Specifically, the exercise protocols often lacked details related to exercise prescription, setting, type of equipment used, a system to monitor adverse events and reasons for withdrawal, and measures of motivation, adherence and compliance.

4.4 Implications for Practice

Exercise-induced hypertrophy of skeletal muscle is a complex biological response. Several conceptual models have been developed to explain the cellular, biomechanical and molecular mechanisms involved in skeletal muscle remodelling arising from muscle loading [62]. Consequently, recommendations for exercise parameters ideally suited to inducing skeletal muscle hypertrophy have been developed. These recommendations include factors such as exercise duration of at least 6 to 8 weeks [63], high intensity of mechanical loading (i.e. 80 to 95 % of repetition maximum) [64] and high-load/low-repetition training [65]. In addition, it is assumed that training history is an important determinant of exercise-induced hypertrophy, with untrained individuals experiencing greater change [66]. However, the muscles of the lower trunk are likely to require special consideration, as high-intensity exercises may be unsafe because of low back injury [67].

Our systematic review identified that the largest effects of exercise on trunk muscle morphology have been reported by studies implementing training programmes consisting of (1) motor control exercises combined with non-machine-based resistance exercises; or (2) machine-based resistance exercises. However, the exercise prescription details were often poorly reported, and the studies were prone to several types of methodological bias. The identification of optimal exercise approaches aimed at enhancing trunk muscle morphology requires evidence from additional high-quality randomized trials.

4.5 Implications for Research

Most studies investigating the effects of exercise on trunk muscle morphology have suffered from methodological limitations. Future research should adhere to recommended methodological and reporting standards related to randomization; treatment allocation concealment; blinding of outcome assessors, participants and research personnel (if applicable; history and reasons for drop-outs; and performance of an intention-to-treat analysis. In addition, future studies should be sufficiently powered to identify effects sizes of interest.

A critical element of understanding, appraising and replicating studies investigating the effect of exercise interventions is comprehensive and detailed reporting of the exercise prescription. Traditionally, the reporting of exercise details has been suboptimal [68], and the studies included in this review are no exception. Slade and Keating [68] have developed reporting standards for trials involving exercise interventions, and adherence to these recommendations will improve the quality of future exercise trials.

5 Conclusion

This is the first systematic review to examine the effect of exercise training on lower trunk muscle morphology. Our search strategy identified 29 relevant studies. Approximately half of the included studies (n = 14, 50 %) reported an improvement in trunk muscle morphology following participation in an exercise training programme. Exercise training programmes comprising motor control exercises combined with non-machine-based resistance exercises, as well as machine-based resistance exercise programmes, demonstrated the largest treatment effects. Cardiovascular exercise programmes had no effect on trunk muscle morphology. However, these results should be interpreted with caution because of the potential for methodological bias and suboptimal reporting of exercise details among the included studies. Further, additional high-quality research is needed to identify the optimal exercise interventions to improve lower trunk muscle morphology.

Acknowledgments The authors would like to thank Ms Margaret Solosy for assistance with developing the search strategy, Dr Golnaz Shahtahmassebi for statistical advice and Mr Andrew Schechter (A.S.) for assisting with study selection. The contributions of the authors are as follows: B.S.—study conception and design, data acquisition, analysis and interpretation, drafting and final approval of the manuscript; J.J.H.—study conception and design, data interpretation, critical revision and approval of the final manuscript; N.J.S.—data acquisition, critical revision and final approval of the manuscript; M.H.—study conception, critical revision and final approval of the manuscript; T.J.F.—study conception and design, data interpretation, critical revision and final approval of the manuscript.

Conflicts of interest The authors have no conflicts of interest that are directly relevant to the content of this review. No sources of funding were used in the preparation of this review.

References

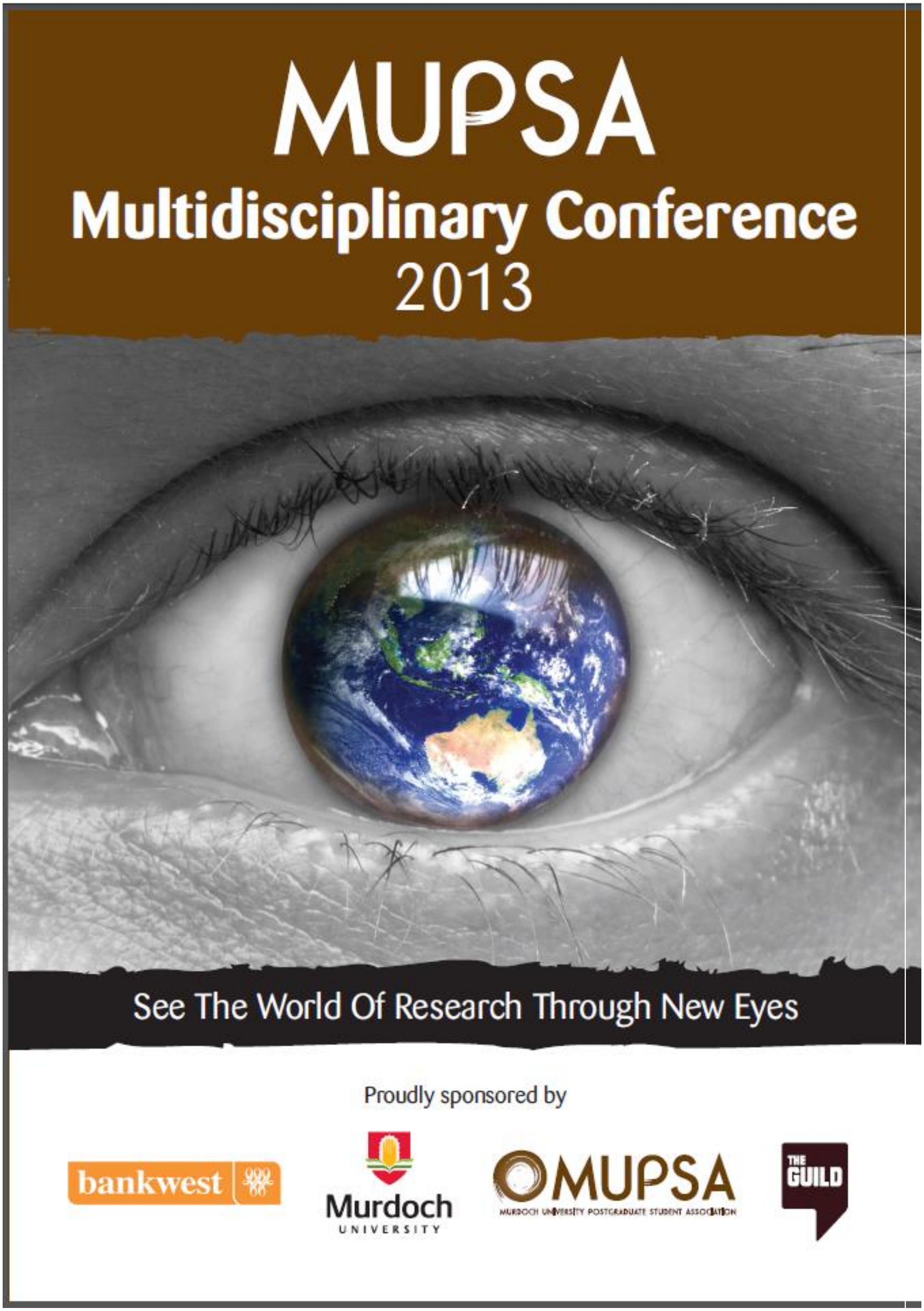
1. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. Clin Biomech. 1996;11(1):1–15.
2. d'Hemecourt PA, Luke A. Sport-specific biomechanics of spinal injuries in aesthetic athletes (dancers, gymnasts, and figure skaters). Clin Sports Med. 2012;31(3):397–408. doi:10.1016/j.csm.2012.03.010.
3. Donatelli R, Dimond D, Holland M. Sport-specific biomechanics of spinal injuries in the athlete (throwing athletes, rotational sports, and contact-collision sports). Clin Sports Med. 2012;31(3):381–96. doi:10.1016/j.csm.2012.03.003.
4. Alexander MJ. Biomechanical aspects of lumbar spine injuries in athletes: a review. Can J Appl Sport Sci. 1985;10(1):1–20.
5. Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. J Spinal Disord. 1992;5(4):383–9 (discussion 397).
6. Panjabi MM. Clinical spinal instability and low back pain. J Electromyogr Kinesiol. 2003;13(4):371–9.
7. Cholewicki J, Panjabi MM, Khachatryan A. Stabilizing function of trunk flexor-extensor muscles around a neutral spine posture. Spine (Phila Pa 1976). 1997;22(19):2207–12.
8. Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. Acta Orthop Scand Suppl. 1989;230:1–54.
9. Stevens VK, Vleeming A, Bouche KG, et al. Electromyographic activity of trunk and hip muscles during stabilization exercises in four-point kneeling in healthy volunteers. Eur Spine J. 2007;16(5):711–8. doi:10.1007/s00586-006-0181-1.
10. McGill SM. Low back stability: from formal description to issues for performance and rehabilitation. Exerc Sport Sci Rev. 2001;29(1):26–31.
11. Crisco JJ III, Panjabi MM. Euler stability of the human ligamentous lumbar spine. Part I: theory. Clin Biomech. 1992;7(1):19–26.
12. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine (Phila Pa 1976). 1996;21(22):2640–50.
13. Chilibeck PD, Calder AW, Sale DG, et al. A comparison of strength and muscle mass increases during resistance training in young women. Eur J Appl Physiol Occup Physiol. 1998;77(1–2):170–5.
14. Choi G, Raiturker PP, Kim MJ, et al. The effect of early isolated lumbar extension exercise program for patients with herniated disc undergoing lumbar discectomy. Neurosurgery. 2005;57(4):764–72.
15. Evans WJ. Reversing sarcopenia: how weight training can build strength and vitality. Geriatrics. 1996;51(5):46–7, 51–3; quiz 54.
16. Klizienė I, Sipavičienė S, Imbrasienė D, et al. Effect of core stability exercise on cross sectional area of lumbar multifidus muscle and physical capacity. Educ Phys Train Sport. 2011;83:9–15.
17. Singh DK, Bailey M, Lee RY. Ageing modifies the fibre angle and biomechanical function of the lumbar extensor muscles. Clin Biomech. 2011;26(6):543–7. doi:10.1016/j.clinbiomech.2011.02.002.
18. Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. Spine (Phila Pa 1976). 1996;21(23):2763-9.
19. Parkkola R, Rytokoski U, Kormano M. Magnetic resonance imaging of the discs and trunk muscles in patients with chronic low back pain and healthy control subjects. Spine (Phila Pa 1976). 1993;18(7):830–6.
20. Beneck GJ, Kulig K. Multifidus atrophy is localized and bilateral in active persons with chronic unilateral low back pain. Arch Phys Med Rehabil. 2012;93(2):300–6.
21. Hicks GE, Simonsick EM, Harris TB, et al. Trunk muscle composition as a predictor of reduced functional capacity in the health, aging and body composition study: the moderating role of back pain. Gerontol A Biol Sci Med Sci. 2005;60(11):1420–4.
22. Hicks GE, Simonsick EM, Harris TB, et al. Cross-sectional associations between trunk muscle composition, back pain, and physical function in the health, aging and body composition study. Gerontol A Biol Sci Med Sci. 2005;60(7):882–7.
23. Sihvonen T, Herno A, Paljarvi L, et al. Local denervation atrophy of paraspinal muscles in postoperative failed back syndrome. Spine (Phila Pa 1976). 1993;18(5):575–81.
24. Akbari A, Khorashadizadeh S, Abdi G. The effect of motor control exercise versus general exercise on lumbar local stabilizing muscles thickness: randomized controlled trial of patients with chronic low back pain. J Back Musculoskelet Rehabil. 2008;21(2):105–12.
25. Woohyung L, Yoonmi L, Wontae G. The effect of lumbar strengthening exercise on pain and the cross-sectional area change of lumbar muscles. J Phys Ther Sci. 2011;23(2):209–12.
26. Lescher S, Bender B, Eifler R, et al. Isometric non-machine-based prevention training program: effects on the cross-sectional area of the paravertebral muscles on magnetic resonance imaging. Clin Neuroradiol. 2011;21(4):217–22. doi:10.1007/s00062-011-0104-3.
27. Sokunbi O, Watt P, Moore A. A randomised controlled trial (RCT) on the effects of frequency of application of spinal stabilisation exercises on multifidus cross sectional area (MFCSA) in participants with chronic low back pain. Physiother Singap. 2008;11(2):9–16.
28. Critchley DJ, Pierson Z, Battersby G. Effect of Pilates mat exercises and conventional exercise programmes on transversus abdominis and obliquus internus abdominis activity: pilot randomised trial. Man Ther. 2011;16(2):183–9. doi:10.1016/j.math.2010.10.007.
29. Kuk JL, Church TS, Blair SN, et al. Associations between changes in abdominal and thigh muscle quantity and quality. Med Sci Sports Exerc. 2008;40(7):1277–81.
30. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol. 2009;62(10):e1–34. doi:10.1016/j.jclinepi.2009.06.006.
31. Mayer J, Mooney V, Dagenais S. Evidence-informed management of chronic low back pain with lumbar extensor strengthening exercises. Spine J. 2008;8(1):96–113. doi:10.1016/j.spinee.2007.09.008.
32. Martuscello JM, Nuzzo JL, Ashley CD, et al. Systematic review of core muscle activity during physical fitness exercises. J Strength Cond Res. 2013;27(6):1684–98. doi:10.1519/JSC.0b013e318291b8da.
33. Macedo LG, Maher CG, Latimer J, et al. Motor control exercise for persistent, nonspecific low back pain: a systematic review. Phys Ther. 2009;89(1):9–25. doi:10.2522/ptj.20080103.
34. Kankaanpaa M, Taimela S, Airaksinen O, et al. The efficacy of active rehabilitation in chronic low back pain. Effect on pain intensity, self-experienced disability, and lumbar fatigability. Spine (Phila Pa 1976). 1999;24(10):1034–42.
35. Parkkola R, Kujala U, Rytokoski U. Response of the trunk muscles to training assessed by magnetic resonance imaging and

muscle strength. Eur J Appl Physiol Occup Physiol. 1992;65(5): 383–7.
36. Darden E. The Nautilus book. Chicago: Contemporary Books; 1990.
37. Thompson WR, Gordon NF, Pescatello LS, et al. ACSM's guidelines for exercise testing and prescription. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2010.
38. Agarwal SK. Cardiovascular benefits of exercise. Int J Gen Med. 2012;5:541–5. doi:10.2147/IJGM.S30113.
39. Higgins JP, Altman DG, Gotzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ. 2011;343:d5928. doi:10.1136/bmj.d5928.
40. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale: L. Erlbaum Associates; 1988.
41. Storheim K, Holm I, Gunderson R, et al. The effect of comprehensive group training on cross-sectional area, density, and strength of paraspinal muscles in patients sick-listed for subacute low back pain. J Spinal Disord Tech. 2003 Jun;16(3):271-9.
42. Hides JA, Stanton WR, Wilson SJ, et al. Retraining motor control of abdominal muscles among elite cricketers with low back pain. Scand J Med Sci Sports. 2010;20(6):834–42.
43. Sakamaki M, Bemben MG, Abe T. Legs and trunk muscle hypertrophy following walk training with restricted leg muscle blood flow. J Sports Sci Med. 2011;10(2):338–40.
44. Danneels LA, Cools AM, Vanderstraeten GG et al. The effects of three different training modalities on the cross-sectional area of the paravertebral muscles. Scand J Med Sci Sports. 2001;11(6): 335–41.
45. Teyhen DS, Childs JD, Dugan JL, et al. Effect of two different exercise regimens on trunk muscle morphometry and endurance in soldiers in training. Phys Ther. 2013;93(9):1211–24.
46. Danneels L, Vanderstraeten G, Cambier D, et al. Effects of three different training modalities on the cross sectional area of the lumbar multifidus muscle in patients with chronic low back pain. Br J Sports Med. 2001;35(3):186–91. doi:10.1136/bjsm.35.3.186.
47. Hides JA, Stanton WR, Mendis MD, et al. Effect of motor control training on muscle size and football games missed from injury. Med Sci Sport Exerc. 2012;44(6):1141–9. doi:10.1249/Mss.0b013e318244a321.
48. Dorado C, Calbet JA, Lopez-Gordillo A, et al. Marked effects of Pilates on the abdominal muscles: a longitudinal magnetic resonance imaging study. Med Sci Sport Exerc. 2012;44(8):1589–94. doi:10.1249/MSS.0b013e31824fb6ae.
49. Hides J, Stanton W, McMahon S, et al. Effects of stabilization training on multifidus muscle cross-sectional area among young elite cricketers with low back pain. J Orthop Sports Phys Ther. 2008;38(3):101–8.
50. Jansen JA, Mens JM, Backx FJ, et al. Changes in abdominal muscle thickness measured by ultrasound are not associated with recovery in athletes with longstanding groin pain associated with resisted hip adduction. J Orthop Sports Phys Ther. 2009;39(10): 724–32. doi:10.2519/jospt.2009.3068 2354 [pii].
51. Jongwoo KIM, Wontae G, Byeongjun H. The effects of resistivity and stability-combined exercise for lumbar muscles on strength, cross-sectional area and balance ability: exercises for prevention of lower back pain. J Phys Ther Sci. 2011;23(2):247–50.
52. Kaser L, Mannion AF, Rhyner A, et al. Active therapy for chronic low back pain: part 2. Effects on paraspinal muscle cross-sectional area, fiber type size, and distribution. Spine (Phila Pa 1976). 2001;26(8):909–19.
53. Kramer M, Dehner C, Katzmaier P, et al. Device-assisted muscle strengthening in the rehabilitation of patients after surgically stabilized vertebral fractures. Arch Phys Med Rehabil. 2005;86(3):558–64. doi:10.1016/j.apmr.2004.09.008.
54. Lee N-G, Jung J-H, You JH, et al. Novel augmented ADIM training using ultrasound imaging and electromyography in adults with core instability. J Back Musculoskelet Rehabil. 2011;24(4): 233–40.
55. Mooney V, Gulick J, Perlman M, et al. Relationships between myoelectric activity, strength, and MRI of lumbar extensor muscles in back pain patients and normal subjects. J Spinal Disord. 1997;10(4):348–56.
56. Rissanen A, Kalimo H, Alaranta H. Effect of intensive training on the isokinetic strength and structure of lumbar muscles in patients with chronic low back pain. Spine (Phila Pa 1976). 1995;20(3):333–40.
57. Willemink MJ, van Es HW, Helmhout PH, et al. The effects of dynamic isolated lumbar extensor training on lumbar multifidus functional cross-sectional area and functional status of patients with chronic non-specific low back pain. Spine (Phila Pa 1976). 2012;37(26):E1651–8.
58. Hoshikawa Y, Iida T, Muramatsu M, et al. Effects of stabilization training on trunk muscularity and physical performances in youth soccer players. J Strength Cond Res. 2013;27(11):3142–9. doi:10.1519/JSC.0b013e31828bed36.
59. Fortin M, Macedo LG. Multifidus and paraspinal muscle group cross-sectional areas of patients with low back pain and control patients: a systematic review with a focus on blinding. Phys Ther. 2013;. doi:10.2522/ptj.20120457.
60. Narici MV, Hoppeler H, Kayser B, et al. Human quadriceps cross-sectional area, torque and neural activation during 6 months strength training. Acta Physiol Scand. 1996;157(2): 175–86. doi:10.1046/j.1365-201X.1996.483230000.x.
61. Hebert JJ, Kjaer P, Fritz JM, et al. The relationship of lumbar multifidus muscle morphology to previous, current, and future low back pain: a nine-year population-based prospective cohort study. Spine (Phila Pa 1976). 2014. doi:10.1097/BRS.0000000000000424.
62. Timson BF. Evaluation of animal models for the study of exercise-induced muscle enlargement. J Appl Physiol. 1990;69(6): 1935–45.
63. Staron RS, Karapondo DL, Kraemer WJ, et al. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. J Appl Physiol. 1994;76(3):1247–55.
64. Fry AC. The role of resistance exercise intensity on muscle fibre adaptations. Sports Med. 2004;34(10):663–79.
65. Campos GE, Luecke TJ, Wendeln HK, et al. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. Eur J Appl Physiol. 2002;88(1–2):50–60. doi:10.1007/s00421-002-0681-6.
66. Cardinale M, Newton R, Nosaka K. Strength and conditioning biological principles and practical applications. Chichester: Wiley; 2011.
67. McGill SM. Low back exercises: evidence for improving exercise regimens. Phys Ther. 1998;78(7):754–65.
68. Slade SC, Keating JL. Exercise prescription: a case for standardised reporting. Br J Sports Med. 2012;46(16):1110–3. doi:10.1136/bjsports-2011-090290.

Electronic Supplementary Material Appendix S1. Search syntax PubMed

Limits/exclusions	NOT ("addresses"[Publication Type] OR "autobiography"[Publication Type] OR "bibliography"[Publication Type] OR "biography"[Publication Type] OR "case reports"[Publication Type] OR "congresses"[Publication Type] OR "consensus development conference"[Publication Type] OR "consensus development conference, nih"[Publication Type] OR "dictionary"[Publication Type] OR "directory"[Publication Type] OR "editorial"[Publication Type] OR "interview"[Publication Type] OR "lectures"[Publication Type] OR "legal cases"[Publication Type] OR "legislation"[Publication Type] OR "letter"[Publication Type] OR "news"[Publication Type] OR "newspaper article"[Publication Type] OR "patient education handout"[Publication Type] OR "video audio media"[Publication Type] OR "webcasts"[Publication Type]) Limits: Humans, English
Exercise	"exercise/injuries"[MeSH Terms] OR "exercise/instrumentation"[MeSH Terms] OR "exercise/methods"[MeSH Terms] OR "exercise/physiology"[MeSH Terms] OR "exercise/standards"[MeSH Terms] OR "exercise/therapeutic use"[MeSH Terms] OR "exercise movement techniques"[MeSH Terms] OR "exercise movement techniques/therapeutic use"[MeSH Terms] OR "exercise movement techniques/therapy"[MeSH Terms])) OR "core stabilization"[Title/Abstract] OR "core stabilisation"[Title/Abstract] OR "core stability"[Title/Abstract] OR "core stabiliser"[Title/Abstract] OR "core stabilizer"[Title/Abstract] OR "core stability"[Title/Abstract] OR "trunk stability"[Title/Abstract] OR "trunk stabilisation"[Title/Abstract] OR "core stabilization"[Title/Abstract] OR "trunk stabilization"[Title/Abstract] OR "lumbar stability"[Title/Abstract] OR "lumbar stabilisation"[Title/Abstract] OR "lumbar stabilization" [Title/Abstract] OR "motor control"[Title/Abstract] OR strengthening[Title/Abstract] OR endurance[Title/Abstract] OR "athletic training"[Title/Abstract] OR "functional training"[Title/Abstract] OR "functional exercise"[Title/Abstract] OR sport*[Title/Abstract] OR "resistance training"[Title/Abstract] OR power[Title/Abstract] OR concentric[Title/Abstract] OR eccentric[Title/Abstract] OR isokinetic[Title/Abstract] OR isotonic[Title/Abstract] OR isometric[Title/Abstract] OR plyometric[Title/Abstract] OR "strength training"[Title/Abstract] OR "resistive exercise"[Title/Abstract] OR resist*[Title/Abstract] OR weight lift*[Title/Abstract] OR strengthening[Title/Abstract] OR weight train[Title/Abstract]
Morphology	size[Title/Abstract] OR morphology[Title/Abstract] OR architecture[Title/Abstract] OR hypertrophy[Title/Abstract] OR "cross sectional"[Title/Abstract] OR hyperplasia[Title/Abstract] OR circumference[Title/Abstract] OR volume[Title/Abstract] OR diameter[Title/Abstract] OR thickness[Title/Abstract] OR "pennation"[Title/Abstract] OR "muscle fiber"[Title/Abstract] OR "muscle fibre"[Title/Abstract] OR "fiber length"[Title/Abstract] OR "fibre length"[Title/Abstract] OR fascicle[Title/Abstract] OR pennate[Title/Abstract] OR morphometry[Title/Abstract] OR "fiber angle"[Title/Abstract] OR "fibre angle"[Title/Abstract] OR "pennation angle"[Title/Abstract] OR hypertrop*[Title/Abstract]
Muscle	muscle*[Title/Abstract] OR muscul*[Title/Abstract] OR musculature[Title/Abstract] OR muscles OR muscle[Title/Abstract] OR "neuromuscular"[Title/Abstract]

Region	"transverse abdominis"[Title/Abstract] OR "transversus abdominis"[Title/Abstract] OR "external oblique"[Title/Abstract] OR "internal oblique"[Title/Abstract] OR "obliquus internus"[Title/Abstract] OR "obliquus externus"[Title/Abstract] OR "rectus abdominis"[Title/Abstract] OR "iliacus" [Title/Abstract] OR "iliopsoas"[Title/Abstract] OR "pectoralis major" [Title/Abstract]
	"multifidus"[Title/Abstract] OR "psoas" OR "erector spinae"[Title/Abstract] OR "paraspinal"[Title/Abstract] OR "quadratus lumborum"[Title/Abstract] OR "Iliocostalis lumborum"[Title/Abstract] OR "Iliocostalis thoracis"
	"lumbosacral region/analysis"[MeSH Terms] OR "lumbosacral region/anatomy and histology"[MeSH Terms] OR "lumbosacral region/therapeutic use"[MeSH Terms] OR "lumbosacral region/therapy"[MeSH Terms] OR trunk[Title/Abstract] OR spine[Title/Abstract] OR lumbar[Title/Abstract] OR lumbo*[Title/Abstract] OR abdomen*[Title/Abstract] OR core[Title/Abstract] OR Low back [Title/Abstract] OR lower back [Title/Abstract]


MUPSA
Multidisciplinary Conference
2013
See The World Of Research Through New Eyes
Proudly sponsored by
bankwest
Murdoch
UNIVERSITY
MUPSA
MURDOCH UNIVERSITY POSTGRADUATE STUDENT ASSOCIATION
THE GUILD

Systematic review of the effect of exercise training on the human trunk muscle morphology

Behnaz Shahtahmassebi, Jeffrey Hebert, Mark Hecimovich, Norman Stomski and Timothy Fairchild

School of Psychology and Exercise Science

b.shahtahmassebi@murdoch.edu.au

Background and aims: Skeletal muscle plays an important role in maintaining the stability of the lumbar region and reducing injury risk. Exercise training may increase strength and cross sectional area of trunk muscles, however the most effective exercise intervention for training the complex trunk musculature is currently not known. Therefore, we systematically reviewed the literature to 1) identify the effects of exercise training on trunk muscle morphology and 2) identify the exercise strategy with the largest effect.

Method: A systematic search strategy was conducted in the following databases from inception to April 30, 2012: PubMed, SPORTDiscus, CINAHL, The Cochrane Library and PEDro. We assessed bias using the Cochrane risk of bias tool and estimated treatment effects with standardised mean differences (SMD) using Review Manager v5.1 (software).

Results: The systematic search identified 1910 studies; SportDiscus (n = 597), PubMed (n = 595), CINAHL (n = 495), The Cochrane Library (n = 143) and PEDro (n = 80). Ultimately, 28 studies were included for qualitative synthesis. The most common source of bias involved random sequence generation, allocation concealment and blinding. We found the largest effect for motor control exercise (SMD - 0.02; 95% CI - 0.24, 0.19 to SMD 2.93; 95% CI 2.34, 3.52), and no effect for cardiovascular exercise (SMD - 0.03; 95% CI - 0.33, 0.26 to SMD - 0.02; 95% CI -0.97, 0.92).

Discussion: Few exercise interventions altered trunk muscle morphology while 80% demonstrated no change. Motor control exercise had the largest effect, whereas, cardiovascular exercise had no effect. However, these results should be interpreted with caution owing to the potential for bias and suboptimal reporting of exercise details in the included studies.

Conclusion: Given that most studies to date have potentially important methodological limitations and lack explicit exercise descriptions, additional high quality research is needed to identify the effects of exercise training on trunk muscle morphology.

21 October 2013

THE GUILD

MURDOCH UNIVERSITY
GUILD OF STUDENTS

Murdoch University
South St, Murodch WA 6150
T (08) 9360 2158
F (08) 9360 7463
E reception@the-guild.com.au

www.the-guild.com.au

To Whom It May Concern,

This to certify that the following Doctorate by Research candidate, enrolled at Murdoch University Australia, was awarded the prize of Best Presentation in Stream 2 of the MUPSA Multidisciplinary Conference, which took place on 3 October 2013:

Behnaz Shahtahmassebi
Student number: 31161981

I congratulate Miss Shahtahmassebi on her engaging and informative presentation, and thank her for her support of MUPSA's annual academic conference.

Yours sincerely,

Vincent Bligh
MUPSA President
Mobile 0410 557 581
Email V.Bligh@the-guild.com.au
Murdoch University Postgraduate Student Association
Murdoch University
90 South St, Murdoch WA 6150

MUPSA **Multidisciplinary Conference**
3 October 2013
See The World Of Research Through New Eyes

www.mupsaconference.com.au

Murdoch OMUPSA

by students, for students

Lower trunk muscle morphology predicts functional abilities in healthy older adults: a cross sectional study

Behnaz Shahtahmassebi[1], Timothy Fairchild[2], Jeffrey J. Hebert[3], Mark Hecimovich[4]
PhD candidate, Murdoch University; 2. PhD, Murdoch University; 3. PhD, Murdoch University; 4. PhD, University of Northern Iowa

Introduction: The degenerative loss in skeletal muscle size associated with aging is often accompanied by a decrease in balance and functional mobility which may result in reduced quality of life, increased risk of falling and increased mortality rates (1). Much of our knowledge regarding the inverse relationship between poor functional outcomes and the aging process is restricted to the peripheral musculature. More recently, particular attention has started focusing on the muscles of the trunk due to their important role in performing activities of daily living (2), their association with balance and mobility in older adults (3) and falls. To date, the association between trunk muscle morphology and functional abilities has not been comprehensively explored. Therefore, the primary purpose of this study was to evaluate the association between trunk muscle morphology and functional abilities.
Methodology: Sixty-four community-dwelling older adults (60 years and older) were recruited to participate in this cross sectional study. Participants underwent real-time ultrasound imaging assessment for the measurement of lower trunk muscle morphology (muscle thickness and cross sectional area CSA)). The lower trunk muscles included the anterior abdominal muscles (rectus abdominis (RA)), lateral abdominal muscles internal (the internal oblique and external obliques and transversus abdominis (LAM)) and posterior lower trunk muscles (lumbar multifidius lumbar spinal level L4/L5 and L5/S1 (LM L4/L5 and LM L5/S1). Functional outcomes were assessed using Berg Balance Test (BBT), Multi-Directional Reach Test (MDRT), Timed up and go (TUG), The 30 seconds Chair Stand Test (30sec-CST), Sit and Rise Test (SRT), Four Square Step Test (FSST), Six-minute Walk Test (6MWT) . Univariate and multivariate linear regression statistical models were used to examine the association and relationship between lower trunk muscle morphology and functional outcomes.
Results: Univariate analyses revealed significant positive correlations between 6MWT, BBT, MDRT forward, 30sec-CST, SRT and RA-CSA. Moreover, MDRT backward was positively correlated with RA-CSA and LAM and with the composite trunk muscles. TUGT and FSST were also found to be positively correlated with LM L4/L5 and LM L5/S1. After adjustment for demographic variables (age, sex, BMI), the relationship between trunk muscle morphology and functional measures showed that the effects of RA-CSA was significantly and positively associated with distance covered in the 6 MWT ($P < 0.001$). The effect of LAM was positively and significantly associated with results from the BBT ($P < 0.001$). There were no associations between MDRT forward, right and left sides with lower trunk muscle morphology however, a positive and significant association was found between MDRT backward and RA-CSA ($P < 0.001$). RA-CSA and LM L4/L5 were significant independent predictors of the results from 30 sec-CST ($P < 0.001$). TUG and FSST showed a positive and significant relationship with LM L4/L5 ($P < 0.001$). Finally, a significant positive association between RA-CSA and SRT was found ($P < 0.001$).
Discussion: Findings revealed positive associations between lower trunk muscle morphology and balance/functional motility. After adjusting for demographic variables, lower trunk muscle morphology was an independent predictor of static, dynamic and functional performance in older adults. Declining lower trunk muscle morphology, particularly in the anterior abdominal muscles (RA-CSA), was a common finding in this older cohort and was associated with reduced functional capacities. Thus improving trunk muscle morphology may lead to reduced balance impairments and improved functional capacities in older individuals.

Key words: Lower trunk muscle, Morphology, Functional abilities, Older adults

[2]*Centre for Research and Expertise in Social Gerontology (CREGÉS), Integrated Health and Social Services University Network for West-Central Montreal, Montréal, Canada;* johanne.filiatrault@umontreal.ca, manon.parisien.cvd@ssss.gouv.qc.ca

[3]*School of Rehabilitation, Université de Montréal, Montréal, Canada;* nathalie.bier@umontreal.ca

[4]*Research Centre of the Institut universitaire de gériatrie de Montréal (CRIUGM), Montréal, Canada*

[5]*Université de Montréal Public Health Research Institute (IRSPUM), Montréal, Canada*

Introduction: In recent years, an interest toward pole walking (PW) has been observed. It appears to be an activity that can produce many health benefits, including among older adults. To our knowledge, no study has assessed a PW program specifically designed for older people and offered by community organizations until now. Consequently, a biweekly program of 12 weeks of PW was developed, and enhanced by complementary exercises and strategies promoting an active lifestyle. This study aimed to examine the short-term effects of this new program on physical capacities among community-dwelling older adults. ***Methods:*** This quasi-experimental study involved six community organizations that were responsible for recruiting 63 people aged 60 years and older. Community organizations and participants were either assigned to the experimental group (participating in the program, two 60-min sessions/week) or to the control group (three-month waiting list). Participants were assessed before and after the PW program through several tests measuring walking speed, upper and lower limb muscle strength and flexibility, balance, mobility, grip strength, and cardiovascular endurance. Comparisons between groups over time were evaluated using a two-way ANOVA with repeated measures adjusted for age, living alone, and height. ***Results:*** Seventy-eight percent of participants came to the post-test (n = 49; mean age: 70 years; 86% women). Groups were different at baseline for living alone, height, balance, and lower limb muscle strength. The multilevel analysis indicated significantly greater improvement in upper and lower limb strength in the experimental groups compared to control groups ($p < .05$). In fact, participants from the experimental groups were, on average, able to do 10.6% more repetitions in the 30-s arm curl test after the program, whereas control participants had a decrease of 4.5%. Regarding lower limb strength, a mean increase of 8.9% was found in the number of repetitions in the 30-s chair stand test for the experimental groups compared to the control groups who had a 3.1% decrease. ***Conclusion:*** The PW program seems to have contributed to a significant improvement in the participants' upper and lower limb strength. Preliminary data from this study are promising.

The Effect of a 12-Week Supervised Multimodal Exercise Training Program on Lower Trunk Muscle Morphology and Functional Ability in Healthy Older Adults: A Randomized Controlled Trial

Shahtahmassebi, Behnaz[1]; Hecimovich, Mark[2]; Hebert, Jeffrey[1]; Fairchild, Timothy[1]

[1]*Murdoch University, Perth, Australia;* B.Shahtahmassebi@murdoch.edu.au, J.Hebert@murdoch.edu.au, T.Fairchild@murdoch.edu.au

[2]*University of Northern Iowa, Iowa, United States;* mark.hecimovich@uni.edu

Introduction: Aging-related decrements in trunk muscle morphology and function are associated with decreased balance and increased falls risk (Granacher, Gollhofer, Hortobagyi, Kressig, & Muehlbauer, 2013; Granacher, Lacroix, Muehlbauer, Roettger, & Gollhofer, 2013). Previously, balance and/or resistance training of the peripheral musculature have demonstrated good efficacy for prevention of falls in older adults (Lee & Park, 2013). However, the efficacy of training the lower trunk musculature remains largely unexplored. Therefore, the purpose of this study was to assess changes in trunk muscle morphology and functional ability following a 12-week supervised multimodal exercise training program amongst healthy older individuals. ***Methods:*** We conducted a single-blinded parallel group randomised clinical trial to investigate the effectiveness of a 12-week exercise program on trunk muscle size and functional ability in healthy older individuals. Sixty-four individuals (mean [SD] age: 69.8 [7.5] years; 59.4% female) were randomised to receive a multimodal exercise program comprising walking and balance exercises with or without strength/motor control training of the trunk muscles. Lower trunk muscle size was measured using ultrasound imaging. Functional ability was assessed using the six-minute walk test, the Berg Balance test, the 30 Second Chair Stand, and the Timed Up and Go. All participants completed baseline, six-week, and 12-week assessments. Consistent with the intention-to-treat principle, all data was analysed using a linear mixed model, and the main effects of exercise group and the exercise group by time interactions explored. ***Results:*** Participants performing the trunk exercises experienced greater increases (mean difference [95% CI]) in trunk muscle hypertrophy (1.6 [1.0, 2.2]) at the end of the 12-week training program. In addition, participants performing the trunk exercises showed significantly greater improvements in their 30 Second Chair Stand (5.9 [3.3, 8.4] repetitions) and Timed Up and Go (–0.74 [–1.40, –0.03] s) performance when compared to the exercise group which did not incorporate the trunk muscle exercises. ***Conclusion:*** These findings support the inclusion of strength/motor control training of the trunk muscles as part of a multimodal exercise program in older individuals. ***References:*** Granacher, U., Gollhofer, A., Hortobagyi, T., Kressig, R.W., & Muehlbauer, T. (2013). The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: A systematic review. *Sports Medicine, 43*(7), 627–641. Granacher, U., Lacroix, A., Muehlbauer, T., Roettger, K., & Gollhofer, A. (2013). Effects of core instability strength training on trunk muscle strength, spinal mobility, dynamic balance and functional mobility in older adults. *Gerontology, 59*(2), 105–113. Lee, I.H., & Park, S.Y. (2013). Balance improvement by strength training for the elderly. *J Phys Ther Sci, 25*(12), 1591–1593.

The Role of Genetic Factors in Modifying the Relationship Between Physical Activity and Measures of Alzheimer's Disease Risk

Brown, Belinda[1]; Rainey-Smith, Stephanie[1]; Laws, Simon[1]; Villemagne, Victor[2]; Bourgeat, Pierrick[3]; Peiffer, Jeremiah[4]; Porter, Tenielle[1]; Taddei, Kevin[1]; Macaulay, Lance[3]; Rowe, Christopher[2] ; Ames, David[5]; Masters, Colin[5]; Martins, Ralph[1]

[1]*Edith Cowan University, Perth, Western Australia;* belinda.brown@ecu.edu.au, s.rainey-smith@ecu.edu.au, s.laws@ecu.edu.au, t.porter@ecu.edu.au, k.taddei@ecu.edu.au, r.martins@ecu.edu.au

[2]*Austin Health, Melbourne, Victoria;* victorlv@unimelb.edu.au, Christopher.rowe@austin.org.au

[3]*CSIRO, Brisbane, Queensland;* Pierrick.Bourgeat@csiro.au, lance.macaulay@csiro.au

[4]*Murdoch University, Perth, Western Australia;* j.peiffer@murdoch.edu.au

[5]*University of Melbourne, Melbourne, Victoria;* dames@unimelb.edu.au, c.masters@unimelb.edu.au

Introduction: Previous research suggests regular physical activity is associated with better cognitive function, less brain beta-amyloid (Aβ; a toxic protein implicated in Alzheimer's disease), and larger hippocampal volume. However, it is apparent that some people receive more benefit from physical

MURDOCH UNIVERSITY
GUILD OF STUDENTS

Murdoch University
South St, Murodch WA 6150
T (08) 9360 2158
F (08) 9360 7463
E reception@the-guild.com.au

www.the-guild.com.au

Behnaz Shahtahmassebi
Flat 122, Room 1, Murdoch Student Village
PO Box 1055
CANNING VALE DC
WA 6970

5 September 2014

Dear Ms. Shahtahmassebi,

MUPSA Small Research Support Grant

I write with great pleasure to inform you that MUPSA Committee has approved your application for the above Grant, to the value of AUD474.

We wish you all the best with incorporating the pedometers into your research.

We request an original report of 200 words on how the MUPSA Small Research Grant assisted your research. Please see the MUPSA Blog for examples of previous recipients' reports. Please submit your report and copies of all receipts of Grant expenditure to the MUPSA Secretary, via mupsasecretary@the-guild.com.au, within 60 days of receiving the funding.

Thank you for your support of MUPSA.

I extend my warmest wishes for the completion of your thesis.

Yours sincerely,

Sarah Clement
President
Murdoch University Postgraduate Student Association
Murdoch University Guild of Students
90 South St, Murdoch WA 6150
Phone (08) 9360 7316
Email S.Clement@the-guild.com.au

http://mupsa.the-guild.com.au
https://www.facebook.com/Murdoch.MUPSA
https://twitter.com/MUPSAMurdoch

MUPSA

by students, for students

Murdoch
UNIVERSITY

RESEARCH AND DEVELOPMENT OFFICE
Graduate Research

www.murdoch.edu.au

South Street, Murdoch
Western Australia 6150
Telephone: 08 9360 6003
N.Enright@murdoch.edu.au

Ref: 31161981

1 September 2015

To whom it may concern,

Please be advised that Ms Behnaz Shahtahmassebi competed in the 2015 Three Minute Thesis (3MT®) Competition at Murdoch. The competition cultivates students' academic, presentation, and research communication skills and supports their capacity to effectively explain their research in three minutes, in a language appropriate to a non-specialist audience.

Ms Shahtahmassebi presented her talk, entitled *'Falls prevention exercise programme for older adults',* to a judging panel of four senior academic staff members, and was selected as the winner of the 2015 competition. As the winner, she receives a $2,500 research travel grant and entry to the Trans-Tasman 3MT Final on Friday October 2 2015 at The University of Queensland.

In addition to this, she was also selected as the 'People's Choice' winner, which comes with a further travel grant to the value of $500.

On behalf of Graduate Research, we congratulate Ms Shahtahmassebi on her achievements and wish her all the best in representing Murdoch University at the Trans-Tasman final.

Regards,

Professor Neal Enright
Dean of Graduate Studies
Murdoch University


TRANS-TASMAN

3MT® THREE MINUTE THESIS

FOUNDED BY THE UNIVERSITY OF QUEENSLAND

FINALIST 2015

Behnaz Shahtahmassebi

A.G. [signature]

Professor Alastair McEwan
Dean, UQ Graduate School

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Appendix E

(CONSORT 2010 checklist of information to include when reporting a randomised trial)

CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	106
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	107
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	108
	2b	Specific objectives or hypotheses	108
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	109
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	NA
Participants	4a	Eligibility criteria for participants	109
	4b	Settings and locations where the data were collected	109
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	110-111
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	110 111-113
	6b	Any changes to trial outcomes after the trial commenced, with reasons	NA
Sample size	7a	How sample size was determined	114
	7b	When applicable, explanation of any interim analyses and stopping guidelines	NA
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	109
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	109
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until	109

		interventions were assigned	
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	109
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those assessing outcomes) and how	110
	11b	If relevant, description of the similarity of interventions	NA
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	114
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	NA
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	130
	13b	For each group, losses and exclusions after randomisation, together with reasons	130
Recruitment	14a	Dates defining the periods of recruitment and follow-up	114
	14b	Why the trial ended or was stopped	NA
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	131
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	132-138
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	132-138
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	NA
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	NA
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	123
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	123
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	123

Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	116-124
Other information			
Registration	23	Registration number and name of trial registry	109
Protocol	24	Where the full trial protocol can be accessed, if available	NA
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	NA

*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up to date references relevant to this checklist, see www.consort-statement.org.