Maximal-Intentional Velocity Resistance Training Interventions for Older Adults: design and implementation.

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for the degree of Doctor of Philosophy

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Candidate declaration

I hereby declare that:

1. I have been enrolled for another award of the University, or other academic or professional organisation, whilst undertaking my research degree. I was an enrolled student for the following award:

   Name of award: Postgraduate Certificate in Sport and Exercise Nutrition

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2. None of the material contained in the thesis has been used in any other submission for an academic award.
3. I am aware of and understand the University's policy on plagiarism and certify that this thesis is my own work. The use of all published or other sources of material consulted have been properly and fully acknowledged.
4. The work undertaken towards the thesis has been conducted in accordance with the SHU Principles of Integrity in Research and the SHU Research Ethics Policy.
5. The word count of the thesis is 40,556.

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Thesis Abstract

Older age is associated with significant declines in muscle mass and function which affect the ability to perform activities of daily living (ADLs), independence, quality of life (QoL), risk of mortality, and healthcare costs, implicating these changes in muscle as a major health issue for individuals and society (Lanza et al., 2003; Maden-Wilkinson et al., 2015; Beaudart et al., 2017; Kim et al., 2018). It has been strongly suggested that maximal-intentional velocity resistance training (MIV-RT), otherwise known as power training, explosive, high-speed or high-velocity resistance training (RT) (de Vos et al., 2005, Richardson et al., 2019, Sayers and Gibson, 2010, Pearson et al., 2022) is an optimal method for improvements in functional ability, improves muscle mass and function and thus, should be prioritised for older adults (OAs) (Cadore et al., 2018; Orssatto et al., 2019).

However, despite existing evidence to support MIV-RT as an effective method to improve muscle mass and function in OAs (Blazevich et al., 2020a; Rodriguez-Lopez et al., 2022; Morrison et al., 2023), methodological issues in research studies preclude the ability to draw definitive conclusions about the efficacy and safety of MIV-RT. This includes heterogeneity in study designs, inconsistencies in terminology and programme design and the use of suboptimal methods to understand the risks associated with this training type.

Therefore, this thesis has taken a critical lens to understand and advance MIV-RT interventions for OAs. By examining and clarifying the terminology and methods used to describe and measure the ability to produce force rapidly, chapter 3 aims to improve understanding and consistency in the application of terminology and outcome measurements, facilitating effective communication of research findings, and the development of effective RT interventions. A systematic review of MIV-RT interventions for OAs (Chapter 4) highlights gaps in intervention design and reporting practices, hindering the literature and our understanding of MIV-RT for OAs. Chapter 5 explores in detail the implementation of MIV-RT in real-world settings, comparing practitioner insights with research evidence, and highlighting disparities between research and applied practice, including the utilisation of different equipment and exercises. Moreover, practitioners' reasons for not prescribing MIV-RT for OAs are identified, including a perceived lack of safety or risk of injury and fear from OAs, providing recommendations for future research studies tailored to the needs of all stakeholders. Indeed, this thesis highlights that the safety of MIV-RT for OAs remains uncertain (Chapter 2) and that identification of practical and sensitive measurement tools is necessary to better assess the safety of MIV-RT for OAs. Therefore, Chapter 6 investigates the validity and reliability of novel measurement tools to measure postural stability, a potential indicator of the safety of MIV-RT, demonstrating that pressure insoles may provide a valid and reliable tool.

Overall, this thesis advances our understanding of MIV-RT for OAs and offers specific and practical recommendations for future MIV-RT interventions. By addressing critical underpinning factors and providing evidence-based insights, this work aims to promote the design of interventions that target the desired and most relevant physiological adaptations, reduce barriers to real-world implementation and effectively communicate findings through accurate and thorough reporting.

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iv. List of Abbreviations

%1RM	Percentage of One Repetition Maximum
1RM	One Repetition Maximum
30s-STS	30 second Sit-To-Stand
5STS	Five times Sit-To-Stand
6MWT	6-Minute Walk Test
8ftUG	8 ft Up-and-Go Test
ADLs	Activities of Daily Living
CERT	Consensus on Exercise Reporting Template
cm	centimetre
CMJ	Counter-movement Jump
COP	Centre of Pressure
$deg \cdot s^{-1}$	degrees per Second
FP	Force Plate (Kistler force plates)
Hz	Hertz (sampling rate)
IMU	Inertial Measurement Unit
INS	Pressure Insoles (Tekscan F-scan tethered system)
kg	kilogram
m/s	meters per Second
MIV-RT	Maximal Intent Resistance Training
N	Newtons
OAs	Older Adults
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QoL	Quality of Life
RCT	Randomised Control Trial
RFD	Rate of Force Development
RM	Repetition Maximum
RPE	Ratings of Perceived Exertion
RS	Inertial Measurement Unit (RunScribe™ footpods)
RT	Resistance Training
SI	Systéme International d'Unite's
SPPB	Short Physical Performance Battery
T	Total Time in Seconds
TBF	Toigo and Boutellier (2006) framework for exercise mechanobiological description
TRT	Traditional Resistance Training
TUG	Timed Up and Go
W	watts

v. List of Terminologies Adopted in This Thesis

Activities of daily living	Physical tasks required for independent life that are measured in a standardised setting, otherwise known as physical performance or functional outcomes e.g. rising from a chair.
Body mass	The quantity of matter that a person's body has, measured in kilograms.
Body weight	The gravitational force between a person’s body and the earth, measured in newtons.
Body weight (exercise)	An exercise that uses your own body weight as resistance, not needing any external weights or equipment to perform e.g. push-up, sit-up.
Centre of pressure	The point where the combined forces from all forces applied to a contact area (e.g. foot) on a surface (e.g. the ground) are concentrated.
Displacement	The change in position or the distance moved in a straight line.
Intervention	A planned activity that is designed to change the behaviour or outcome of an individual.
Impulse	The product of the magnitude of force and the duration for which it is applied, calculated from the area under a force-time curve and is expressed in newton-seconds ($N.s^{-1}$).
Lower body	Muscle groups located inferior to the waist i.e. legs.
Maximal-Intent Resistance Training	Resistance training performed with maximal intention velocity.
Maximal strength	Maximal force production.
Muscle function	The ability to produce force in a particular way.
Older adults	People aged 65 years or over, unless stated otherwise.
Peak power	An instantaneous value representing the point of maximum power output and therefore the highest rate of work done.

Power	The rate of performing work, expressed in the SI-derived unit Watts (W).
Practitioners	A person who applies the principles of a particular discipline in a practical way.
Rapid force production	The ability to produce force quickly.
Rate of force development	The measure of how quickly an applied force increases during a period of time, calculated from the slope of a force-time curve, expressed in newtons per second ($N.s^{-1}$).
Resistance Training	Exercise involving the application of force against an opposing force (i.e., resistance) in an attempt to overcome that resistance
Upper body	Muscle groups located superior to the waist i.e. torso or arms.
Velocity	The change in displacement over time of an object's motion, measured in metres per second (m/s).
Work	The total force with respect to the distance moved and is expressed in the unit Joules (J).

Chapter: 1 Introduction and Thesis Structure

1.1 Thesis Introduction

Globally, the number and proportion of older adults (OAs) is increasing (United Nations, 2019). Older age is associated with significant declines in muscle mass and function which affect the ability to perform activities of daily living (ADLs), independence, quality of life (QoL), risk of mortality, and healthcare costs, implicating these changes in muscle as a major health issue for individuals and society (Lanza *et al.*, 2003; Maden-Wilkinson *et al.*, 2015; Beaudart *et al.*, 2017; Kim *et al.*, 2018). Therefore, the development of interventions to reverse or attenuate declines in muscle mass and function is imperative to aid healthy ageing, improve QoL, and reduce social and economic burdens.

Resistance training (RT) is an established and effective method to improve muscle mass and function in all people, including healthy OAs and those with chronic diseases or mobility limitations (Kraemer *et al.*, 2017; Fragala *et al.*, 2019; Katsoulis, Stathokostas and Amara, 2019). The efficacy of RT relies on the structuring or design of the training stimulus (i.e., training programme or intervention) (Fleck and Kraemer, 2014) and therefore, requires consideration. This includes the manipulation of training variables, such as load, volume, or time under tension, the application of fundamental RT principles, and consideration of factors affecting adherence such as risks associated with the training (Kraemer and Ratamess, 2004; Toigo and Boutellier, 2006).

Recently, advocacy for OAs to participate in RT involving maximal intentional velocity has increased considerably (Cadore *et al.*, 2018; Fragala *et al.*, 2019; Izquierdo *et al.*, 2021; Schaun, Bamman and Alberton, 2021). It has been strongly suggested that this RT modality known as maximal-intentional velocity resistance training (MIV-RT), power training, explosive, high-speed or high-velocity (de Vos et al., 2005, Richardson et al., 2019, Sayers and Gibson, 2010, Pearson et al., 2022) is an optimal method for improvements in functional ability, improves muscle mass and function and thus, should be prioritised for OAs (Cadore *et al.*, 2018; Orssatto *et al.*, 2019).

However, despite existing evidence to support MIV-RT as an effective method to improve muscle mass and function in OAs (Blazevich *et al.*, 2020; Rodriguez-Lopez *et al.*, 2022; Morrison *et al.*, 2023), methodological issues in research studies prevent the ability to draw definitive conclusions about the efficacy and safety of MIV-RT. This includes heterogeneity in study designs, inconsistencies in terminology and programme design and the use of suboptimal methods to understand the risks associated with this training type. For example, recent meta-analyses have highlighted, based on The Grading of Recommendations, Assessment, Development and Evaluation (GRADE) appraisal, that at present, the quality of evidence is low (Lopez *et al.*, 2022; Morrison *et al.*, 2023).

Therefore, a critical investigation of the implementation of MIV-RT for OAs is required to enhance future RT interventions to identify the most effective methods to address age-related loss of muscle mass and function, ultimately improving the lives of OAs.

1.2 Thesis Structure

Below is a summary of the topic of each of the chapters presented in this thesis; the relationships between these chapters are illustrated in Figure 1.1.

Chapter 1 Introduces the thesis and provides an overview of the thesis and its structure. **Chapter 2** provides a narrative review of literature to identify problems, possible solutions and gaps in knowledge related to an ageing population and age-related changes in muscle. This chapter concludes with the thesis aims and objectives. **Chapter 3** is a narrative commentary on the terminology used in literature to describe and measure the ability to produce force rapidly. **Chapter 4** is a systematic review of literature exploring the extent of mechanical specificity in MIV-RT studies and the quality of intervention reporting. **Chapter 5** presents a survey exploring the implementation of MIV-RT among applied practitioners. **Chapter 6** presents a validity and reliability study of novel methods to measure postural stability. **Chapter 7** provides a general discussion of the thesis alongside limitations of the work and recommendations for future research.

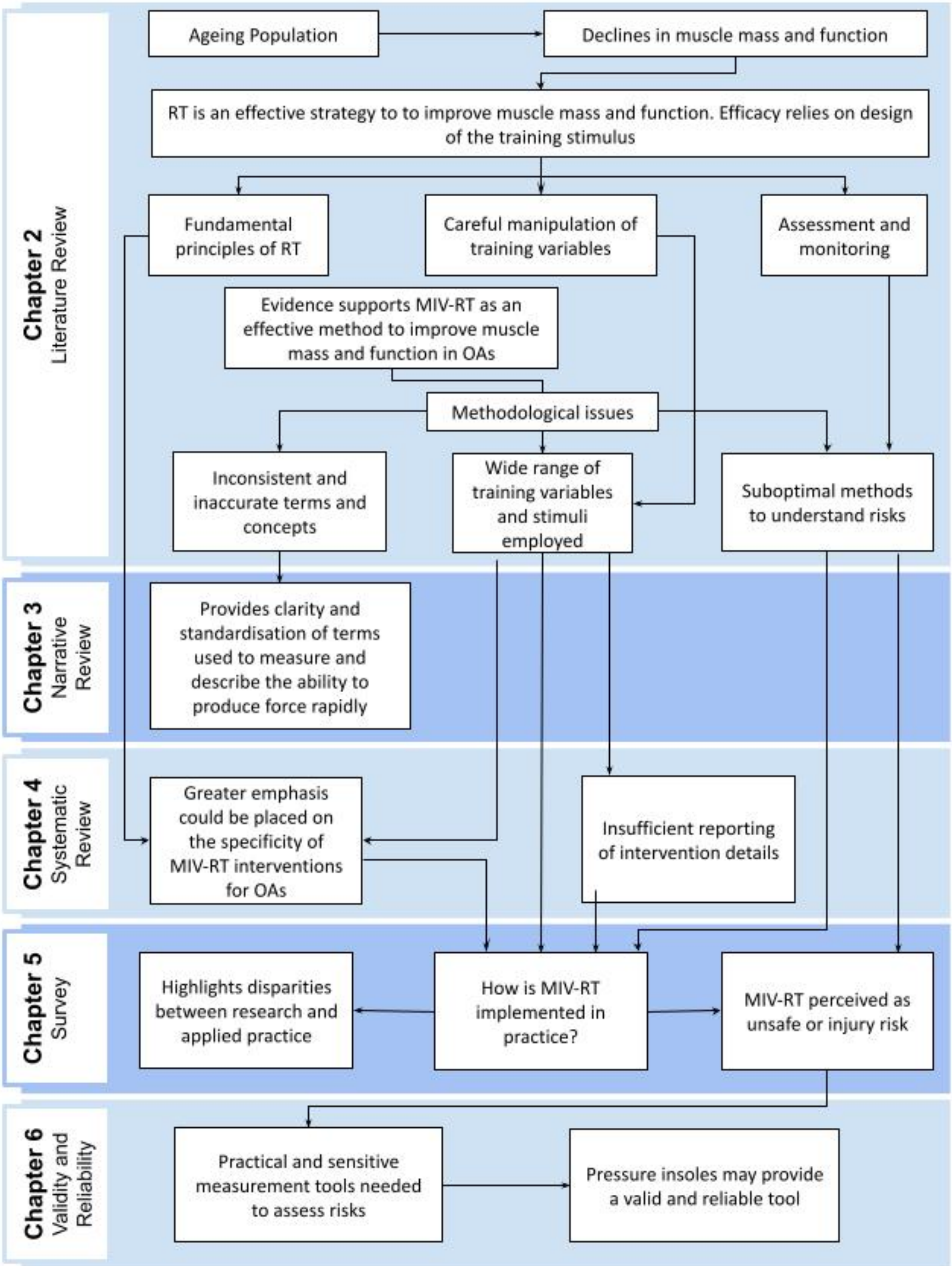


Figure 1.1 - Schematic demonstrating the golden thread of the thesis and relationships between studies.

1.3 Impact of the COVID-19 pandemic

An original objective of this PhD was to carry out several experimental studies to evaluate the safety and effectiveness of MIV-RT for OAs. This would have included an investigation into the acute effects of MIV-RT on postural stability alongside fatigue, pain and falls risk and a subsequent large-scale RCT. However, the combination of the uncertainty of the COVID-19 pandemic and associated lockdowns, social distancing advice and additional precautions accompanying the recruitment of an at-risk population made this unattainable.

In March 2020, at the approximate mid-point of my PhD studies, the closure of universities and subsequent national lockdowns halted my data collection. In the year that followed, there was continued uncertainty around whether face to face data collection could take place amid fluctuating infection rates and government restrictions. Therefore, in order to progress the programme of research a significant change in the direction of the PhD was made to replace the planned studies with research that could be conducted remotely including a systematic review and an online survey.

This was a difficult decision given the time and effort that had been invested into the original programme of research, which included protocol development, pilot testing and ethics applications. In addition, being unable to undertake an RCT, which is generally considered the gold-standard for effectiveness research was disappointing. The absence of an RCT in this thesis may be viewed by some as a limitation; however, I strongly believe that the requirement to think laterally has led to work that is of greater quality and impact than a RCT would have achieved. It provided an opportunity to conduct novel research and challenge conventional thinking in this field. By focusing on critical underpinning factors that inform the design of interventions and practice, often overlooked in research, this thesis lays the groundwork for future studies and advancements in this field.

Furthermore, I am grateful for the opportunity to develop and conduct studies using a variety of research methods. This experience has enhanced my skills and adaptability as a researcher and given me a deep appreciation for mixed-methods and pragmatic approaches to research. Ultimately, this experience has made me a more rounded and adaptable researcher, with a body of work that I am proud of.

Chapter: 2 Literature Review

2.1 Ageing Population

Globally the number and proportion of OAs is increasing. In 2019 there were 703 million people aged 65 years or over, however, by 2050 this number is projected to more than double to 1.5 billion, with OAs constituting 16% of the population or 1 in 6 people (United Nations, 2019).

In the United Kingdom alone, projections suggest that by 2066, there will be 20.4 million people aged over 65 years, a rise of 72.9% from 2016. At this point, OAs will comprise over a quarter of the UK population (Office for National Statistics, 2019). The quickest increase is expected to occur in those aged 85 years and over with the number of people in this age group expected to triple between 2016 and 2066. This predicted rise surpasses that of any other age group and has the potential to alter the structure of the population, as represented in Figure 2.1.

Figure 2.1 - Projected population structures for 1966, 2016 and 2066, adapted from Office for National Statistics (2019), removed due to copyright restrictions.

These population changes are thought to be driven by increased life expectancy and reduced birth rates (United Nations, 2019). Collectively these factors lead to a greater number of OAs and a slower increase in the number of young people in a population. Crucially, by 2045-2050, a person aged 65 years old is expected to live on average for 19 more years

(United Nations, 2019) making life as an OA a significant proportion of overall life. This has implications for health and social care planning as well as a significant economic burden and therefore interventions which can help individuals maintain their independence for as long as possible potentially have large societal benefits.

2.2 Age-related Changes in Muscle Mass, Function and Activities of Daily Living.

2.2.1 Changes in Muscle Mass

Cross-sectional studies comparing the muscle volume of older and younger individuals have consistently shown significant reductions in muscle mass of 20-30% between the two groups (Janssen *et al.*, 2000; Maden-Wilkinson *et al.*, 2014; Fuchs *et al.*, 2023; Naruse, Trappe and Trappe, 2023). Additionally, investigations have identified that lower body muscles are more affected than upper body muscles, with the thigh muscles more affected than other muscles in the lower body and among the thigh muscles, the quadriceps are the most affected (Janssen *et al.*, 2000; Maden-Wilkinson *et al.*, 2014; Fuchs *et al.*, 2023).

Data from cross-sectional studies such as these suggest that between the ages of ~25 and ~75 years, reductions in muscle mass for all muscle groups occur at 0.13%-0.66% per year (Naruse, Trappe and Trappe, 2023) or up to 0.7% per year for the quadriceps (Fuchs *et al.*, 2023). In addition, evidence suggests that this decline is not linear but accelerates later in life (Janssen *et al.*, 2000; Lauretani *et al.*, 2003; Kim *et al.*, 2018). For example, a study that examined the muscle mass of people aged 18-88 years observed some reductions in the 3rd decade of life, however, substantial losses in muscle mass began to occur in the fifth decade

(Janssen *et al.*, 2000). In addition, several longitudinal studies have shown losses that exceed those predicted from cross-sectional studies. For example, (Goodpaster *et al.*, 2006) observed losses in lean leg mass of ~1% per year over a 3-year period in OAs aged 70-79. Elsewhere, Frontera *et al.* (2000) measured the quadriceps muscle cross-sectional area in 65-year-old men over a 12-year period and reported a loss of 16.1%, suggesting an annual loss of 1.3%.

It is suggested that type 2 muscle fibres are more susceptible than type 1 fibres to age-related atrophy and loss (McPhee *et al.*, 2018; Cruz-Jentoft and Sayer, 2019; Coletti *et al.*, 2022). Cross-sectional studies to measure muscle fibre type distribution in older and young OAs have shown greater distribution of type 1 fibres in OAs alongside reductions in muscle mass (Naruse, Trappe and Trappe, 2023). For instance, Nilwik *et al.*, (2013) who observed 14% less quadriceps cross-sectional area in older men compared to young men also found that the size and proportion of type 2 muscle fibres were significantly smaller in the older men (-29% and 26% respectively).

2.2.2 Changes in Muscle Function

2.2.2.1 Maximal Force Production

Losses in maximal force production (i.e., maximal strength) exceed those of muscle mass. The Health, Aging and Body Composition Study measured changes in muscle mass and strength in 1678 OAs over five years and found annual declines in knee extensor strength exceeded declines in leg muscle mass by 2-5 times (Delmonico *et al.*, 2009). Also, a study conducted over 10 years on 120 OAs aged 48-78 years found that some OAs who maintained or even gained muscle mass still experienced significant losses in maximal strength (Hughes *et al.*, 2001). A combination of cross-sectional and longitudinal studies suggest maximal strength may decline at a rate of more than 10% per decade (Frontera *et al.*, 2000, 2008; Hughes *et al.*, 2001; Goodpaster *et al.*, 2006; Francis *et al.*, 2017). For instance, Delmonico *et al.* (2009) found men lost 16.1% of maximal knee extensor torque over 5 years whilst Francis *et al.* (2017) reported reductions of 12.2% for women in their 6th decade compared to those in their 5$^{th.}$

In accordance with the declines in muscle mass, the lower body exhibits more severe declines in strength compared to the upper body, and losses are accelerated as age advances (Hughes *et al.*, 2001; Kim *et al.*, 2018; Suetta *et al.*, 2019; Haynes *et al.*, 2020). For instance, Hughes *et al.* (2001) found that over ~10 years the rate of decline in knee extensor and flexor strength was 14 and 16% respectively which exceeded declines of elbow extensors (11%) and flexors (7.5%). Kim *et al.*, (2018) found that maximum strength losses were moderate between the ages of 65 and 70 for men and 75 for women but subsequently, the decline progressively accelerated. Similarly, a large scoping review of 57 studies concluded that maximum isometric and dynamic leg strength declined abruptly in the sixth and fifth decades of life, respectively (Haynes *et al.*, 2020).

2.2.2.2 Outcomes Related to Rapid Force Production

Loss in muscle function related to rapid force production exceeds that of both muscle mass and maximum strength and accelerates at an even greater rate (Skelton *et al.*, 1994; Izquierdo *et al.*, 1999; Lanza *et al.*, 2003; Lauretani *et al.*, 2003; Macaluso and De Vito, 2003; Suetta *et al.*, 2019). In a cross-sectional study involving 1030 people aged 20 to 85+ years Lauretani *et al.* (2003) found that individuals aged 20-29 had 54% greater power output (W) during a single leg extension movement than those aged 65-74 and 75% more than those aged 85+. In comparison, maximal isometric knee extension strength and calf cross-sectional area were 50 and 20% greater, respectively.

Using a Nottingham Leg Extension Power Rig, Suetta *et al.* (2019) found a difference of 41% in maximal leg extension power output (W) between the age groups of 20-29 and 70-79 years. Thompson *et al.* (2014) reported a 26.7% lower maximal rate of velocity development ($deg \cdot s^{-1}$) in the knee extensors in older men (72 years) compared to younger men (25 years) and Izquierdo *et al.* (1999) found that maximal rate of force development (RFD) was 64% lower in men aged ~71 compared to those aged ~21 years. In addition, Reid *et al.* (2014) found that healthy OAs that preserved both muscle mass and maximum strength over 3 years experienced a loss of peak power output of 8.5% or ~2.8% per year, suggesting that significant reductions in power output appear to happen even if both muscle mass and maximal strength are preserved.

In longitudinal studies, annual losses in power output of 2.9 – 5.5% have been reported in both healthy and mobility-limited OAs (Skelton *et al.*, 1994; Frontera *et al.*, 2008; Clark *et al.*, 2013; Reid *et al.*, 2014). For example, Clark *et al.* (2013) observed 16 healthy OAs over 3 years and found power output (W) measured during a leg press movement decreased between the ages of ~75 and 78 years by 16.5%, suggesting a decline of 5.5% per year.

2.2.3 Mechanisms / Pathophysiology

The age-related changes in muscle have been described as a physiological phenomenon (Cruz-Jentoft and Sayer, 2019) and numerous studies suggest that these changes result from various complex and interindividual structural and electrophysiological alterations. These include increased infiltration of intramuscular fat (Pinel *et al.*, 2021), reductions in circulating insulin-like growth factor and growth hormone (Sherlock and Toogood, 2007; Ryall, Schertzer and Lynch, 2008), deficits in calcium handling within the sarcoplasmic reticulum such as calcium leakage (Andersson *et al.*, 2011), and elevated levels of pro-inflammatory cytokines (Nishikawa *et al.*, 2021). Additionally, environmental factors such as reduced physical activity, low protein and energy intake, and chronic diseases are frequently identified as contributing factors to the presence of low muscle mass and function (Cruz-Jentoft and Sayer, 2019).

Furthermore, a progressive loss of motor units (motor neurons and muscle fibres) as well as changes to existing motor units are considered a significant contributor to age-related loss of muscle mass and function (Gerstner *et al.*, 2017; Larsson *et al.*, 2019). The production of force is determined by the recruitment of motor units and the discharge rate of action potentials that innervate each active motor unit (Mota, Gerstner and Giuliani, 2019). Ageing leads to the loss of motor units, resulting in denervated muscle fibres that are susceptible to atrophy and potential total loss if not reinnervated by other motor units (Rudolf *et al.*, 2014; Larsson *et al.*, 2019). It is considered that ageing preferentially affects the denervation of type 2 muscle fibres (Coletti *et al.*, 2022) which could explain the observed preferential loss of these fibres mentioned in Chapter 2.2.1. In addition, the recruitment of type 2 motor units is crucial for generating high forces, with the rate of recruitment mediating RFD (Maffiuletti *et al.*, 2016; Del Vecchio *et al.*, 2019). Therefore, it is plausible that a progressive loss of or changes to type 2 motor units may be a significant contributor to the accelerated decline in strength and rapid force production associated with ageing.

2.2.4 Activities of Daily Living

Activities of daily living are routine tasks such as feeding, dressing, continence and mobilisation (Edemekong *et al.*, 2022). The use of the term ADLs in this thesis refers exclusively to mobilisation related activities i.e., physical tasks required for independent life, otherwise known as physical performance or functional outcomes (Cruz-Jentoft and Sayer, 2019). Commonly used assessments include the timed-up-and-go (TUG), five times sit-to-stand (5STS), thirty second sit-to-stand (30s-STS), stair climb and 6-minute walk test (6MWT) (Correa *et al.*, 2012; Beijersbergen *et al.*, 2017; Edholm, Strandberg and Kadi, 2017; Dobbs, Simonson and Conger, 2018; Richardson *et al.*, 2019; Filho *et al.*, 2022) (Table 2.1).

Table 2.1 – Tests of activities of daily living and their description

Test of ADLs		Description
Five Times Sit-to-Stand	**5STS**	The 5STS test requires participants to rise from a chair 5 times as quickly as possible (Whitney *et al.*, 2005).
Thirty Second Sit-to-Stand	**30s-STS**	The 30s-STS test requires participants to complete as many repetitions of rising from a chair as possible in 30 seconds (Jones, Rikli and Beam, 1999).
Timed Up-and-Go / Eight Foot Up-and-Go	**TUG / 8ftUG**	The TUG and 8ftUG requires the participant to stand from a chair, walk a required distance before changing direction, returning and sitting back down (Podsiadlo and Richardson, 1991; Rikli and Jones, 1999). The only difference between the two tests is the distance between the chair and the change of direction; the TUG is 3 metres and the 8ftUG is 8 feet (~2.4 metres).
Stair ascent/descent		Stair negotiation tests require participants to ascend and/or descend a flight of stairs as quickly and safely as possible. The stairs can be of any height as resultant measures are generally calculated relative to the stair height and participants body weight. Commonly used stair heights are 4 and 10 steps (Nightingale, Pourkazemi and Hiller, 2014).
Four Metre Walk		The 4m walk test requires participants to walk at their usual pace in a straight line for 8 metres whereby the first and last 2 metres are used for acceleration and deceleration, and the participants speed across the middle 4 metres is recorded (Peters, Fritz and Krotish, 2013).
Six Minute Walk Test	**6MWT**	This test requires participants to walk continuously for 6 minutes as fast as they can, originally developed as a test to measure aerobic capacity and endurance (American Thoracic Society, 2002).
Short Physical Performance Battery	**SPPB**	This collection of tests evaluates balance, gait, strength, and endurance. The tests include standing with feet in a side-by-side, semi-tandem and full-tandem position; a timed 8 feet walk; and rising from a chair 5 times as quickly as possible (Guralnik *et al.*, 1994).

2.2.4.1 Contributions of Muscle Mass, Maximal Strength and Rapid Force Production to Activities of Daily Living.

ADLs, as with any movement, require the production and application of force specific to that movement (Knudson, 2007; Bartlett, 2014). Therefore, muscle mass, maximal strength and the ability to produce force rapidly all influence the performance of ADLs (Montgomery *et al.*, 2020). However, various evidence suggests that outcomes related to the ability to produce force rapidly may be stronger predictors of performance in many ADLs above than maximal strength or muscle mass (Suzuki, Bean and Fielding, 2001; Larsen *et al.*, 2009; Maden-Wilkinson *et al.*, 2015; Kamo *et al.*, 2019; Smith *et al.*, 2020; Winger *et al.*, 2020; Hester *et al.*, 2021). For instance, Maden-Wilkinson *et al.* (2015) examined the relationships between muscle size, maximal strength and power output with performance in 6MWT and TUG in 66 healthy OAs. They found that muscle mass did not correlate with performance in either test, but power output during a countermovement jump (CMJ) did. Suzuki, Bean and Fielding, (2001) found that in older women with functional limitations, peak power output of the ankle flexors was an independent predictor of 10 repetition STS and stair climb performance. Also, Winger *et al* (2020) found that in in 1242 older men, outcomes related to rapid force production (CMJ peak power (W/kg body weight) and velocity at peak power (m/s)) were more strongly associated with 400 m walk time, 6 m usual gait speed and 5STS than measures of maximal strength and handgrip strength.

Furthermore, Orssatto, Bezerra, Schoenfeld, *et al.*, (2020) examined the relationship between ADLs (TUG, stair ascent and descent) and muscle mass, maximal strength (5RM leg press and curl) and rapid force production related outcomes (CMJ height, mean power and impulse, RFD) in healthy OAs. They found that although both maximal and rapid force production were correlated to ADLs, outcomes related to the ability to produce force rapidly had the greatest correlations. Specifically, TUG showed moderate-large correlations with CMJ height (r = −0.551) and impulse (r = −0.473) but showed a weaker correlation with 5RM leg curl (r = −0.414) and did not correlate with 5RM leg press. In addition, large correlations were observed between stair ascent and descent and CMJ height (r = −0.570 - −0.677) as well as moderate correlations with RFD (0-200ms) (r = −0.444 - −0.451). Whilst stair descent was moderately correlated with 5RM leg curl (r = −0.426) it did not correlate with 5RM leg press and stair ascent did not correlate with either test of dynamic maximal strength. Additionally, muscle mass was not correlated with any of the ADLs.

Collectively, these findings suggest that outcomes related to ability to produce force rapidly may be better predictors of performance in many ADLs above that of maximal strength or muscle mass. When considered alongside the more pronounced declines discussed previously, suggests interventions aimed at counteracting or attenuating age-related declines in muscle should prioritise targeting the ability to produce force rapidly. However, it should be noted that much of this evidence is limited to cross-sectional observations involving OAs without mobility limitations or comorbid conditions. Therefore, it is difficult to make decisive conclusions or generalise these findings to all OAs.

2.2.4.2 Age Related Declines in Activities of Daily Living

Considering the previously discussed age-related declines in muscle mass and function along with their contribution to the performance of ADLs, it is not surprising that the performance of ADLs become more difficult as age advances (Landers *et al.*, 2001). Significant declines in the performance of ADLs among older OAs compared to younger individuals have been consistently demonstrated. For example, (Van Roie *et al.*, 2019) found OAs required 18% greater time taken to ascend 6 steps and during 30s-STS, Suetta *et al.* (2019) recorded ~11 fewer repetitions completed by individuals aged 70-79 compared to those in their 20's, a difference which was further increased in those aged 80+. Elsewhere, performance reductions of 20-30% have been observed in 6MWT and TUG tests (Maden-Wilkinson *et al.*, 2015) and when completing 5STS, the oldest participants took 3 seconds longer than the youngest to complete the test, a difference of 34% (Landi *et al.*, 2017).

2.2.5 Implications of Reduced Muscle Mass, Function and Activities of Daily Living

Declines in muscle mass and function and subsequently, a reduced ability to perform ADLs have significant implications on an individual's health and wellbeing as well as on the wider society. For example, in a 3 year longitudinal study, Trombetti *et al.* (2016) found that declining muscle mass, maximal strength, peak power output and the performance of ADLs independently contributed to increased fear of falling whilst muscle mass and ADLs also determined deterioration in QoL independent of other factors. Elsewhere, lower handgrip strength has been associated with depression symptoms (Gariballa and Alessa, 2018), diabetes (Peterson *et al.*, 2016) and osteoporosis (McGrath *et al.*, 2017) and impaired RFD with increased risk of falls (Kamo *et al.*, 2019).

Considering these findings, it is not surprising that the concurrent decline in muscle mass and function, as observed in sarcopenia (presence of low muscle strength and quantity/quality, Cruz-Jentoft and Sayer, 2019), contributes to an increased rate of falls and fractures, physical disability, chronic metabolic disease and mortality risk, reduced QoL as well as increased healthcare costs (Beaudart *et al.*, 2017; Yeung *et al.*, 2019; Xu *et al.*, 2022), implicating these changes in muscle as a major health issue for individuals and the wider society.

2.2.6 Section Summary

This section has shown that the age-related decline of muscle mass and function are significant, affects the ability to perform ADLs and has serious consequences on health, independence, QoL, risk of mortality and healthcare costs, implicating these changes in muscle as a major health issue for individuals and society. Of particular concern may be declines in the ability to produce force rapidly, which evidence suggests may be more pronounced and has strong associations with ADL performance. Therefore, the development of interventions to reverse or mitigate the age-related declines is imperative to aid healthy ageing, improve QoL and to lessen social and economic burdens.

2.3 Resistance Training

Resistance training (RT), otherwise known as strength or weight training, is exercise involving the application of force against an opposing force (i.e., resistance) in an attempt to overcome that resistance (Fleck and Kraemer, 2014). Extensive research conducted over several centuries has established RT as a highly effective approach for improving muscle mass and function in people of all ages, including healthy OAs and those with chronic diseases or mobility limitations (Kraemer *et al.*, 2017; Fragala *et al.*, 2019; Katsoulis, Stathokostas and Amara, 2019). This section (2.3) will present knowledge and recommendations relating to the design and implementation of RT programmes.

2.3.1 The Goal of Resistance Training

The foundation of designing an effective RT programme (i.e., intervention) is to establish the specific goal of the intervention (i.e., the desired adaptations or outcomes) and to understand the physiological requirements of achieving that outcome (Kraemer and Ratamess, 2004). This crucial step serves as a guide for RT programme design, to maximise the desired outcomes.

For example, considering the detrimental effects of age-related decline in ADLs on the health and well-being of OAs (Chapter 2.2.7), an intervention goal might be to improve performance in rising from a chair or stair climbing or a combination of both. To achieve these improvements, understanding the physiological and biomechanical demands (e.g., specific application of force) associated with an improved performance is essential, allowing the RT intervention to be designed to address those demands.

2.3.2 Resistance Training Variables

The programming of RT involves the strategic manipulation of training variables (Stone, Stone and Sands, 2007b). These variables include but are not limited to the type of muscle action, time under tension (i.e., the time muscle is under active tension), the magnitude of resistance (i.e., load), training volume (number of sets and repetitions), the type, number and sequence of exercises, the rest in between repetitions, sets and training sessions, the intended velocity of movement and the effort applied (Kraemer and Ratamess, 2004; Toigo and Boutellier, 2006; Fisher *et al.*, 2011).

Since the 1960's researchers have aimed to understand the optimal design of RT programmes through investigations of physiological adaptations resulting from different variations and combinations of these variables (Kraemer *et al.*, 2017). Through this research, it is considered that each of these variables plays a role in determining the stimuli of the intervention, which ultimately influences the type and magnitude of muscular adaptations (Toigo and Boutellier, 2006).

For example, the intent to move with maximal velocity (i.e., as fast as possible) is considered a significant influence on neural adaptations and improvements in the ability to produce force rapidly (Cormie, McGuigan and Newton, 2011; Turner *et al.*, 2021; Comfort *et al.*, 2023). Moreover, there is evidence to suggest that the intent to move with maximal velocity is more critical than the actual velocity achieved (Behm and Sale, 1993). In addition, evidence suggests that ballistic movements (where the objective is to accelerate throughout the range of movement, attempting to project the body/object as far as possible) involve greater force (peak and average), RFD, velocity and muscle activation than non-ballistic movements (performing a movement with maximal intentional velocity with a return to zero velocity at the end of the movement) and thus, could provide a more specific and efficacious stimulus for improvements in the ability to produce force rapidly (García-Ramos *et al.*, 2018; Mc Dermott *et al.*, 2022).

RT recommendations are often based on a 'repetition continuum', a concept which proposes that the number of repetitions performed at a given load will result in a specific adaptation (Bird, Tarpenning and Marino, 2005; American College of Sports Medicine, 2009). However, contemporary research challenges this concept suggesting that hypertrophy can be achieved across a range of loads and although evidence continues to support higher loads for improvements in maximal strength (Schoenfeld *et al.*, 2021; Carvalho *et al.*, 2022), this may be influenced by greater similarities between training with higher loads and the typical methods to measure maximal strength which involve reaching maximal loads (1RM) (Fisher *et al.*, 2020).

Additionally, recent evidence suggests that muscle hypertrophy is augmented more by higher training volumes than other variables such as frequency or time under tension (Wilk *et al.*, 2019; Kneffel *et al.*, 2021). Moreover, it has been proposed that training close to failure is a key determinant of hypertrophic adaptations (Fisher, Steele and Smith, 2013) although this may be less important for novice exercisers (Schoenfeld *et al*., 2021).

These examples demonstrate the role of training variables in determining the stimuli of an intervention, which may ultimately influence the type and magnitude of muscular adaptations. Thus, when designing a RT intervention, it is crucial to consider based on best available evidence, each variable, their interaction with each other, and how they could influence the physiological adaptations required for the intervention goal. This process can be guided by the fundamental principles of RT which are discussed in the following section.

2.3.3 Fundamental Principles of Resistance Training

It is generally accepted that the selection and manipulation of RT variables should be guided by the fundamental principles of overload, progression and specificity (Fleck and Kraemer, 2014). These principles, as explained by Fleck and Kraemer (2014) suggest that for adaptation to occur, the neuromuscular system must be challenged to do more than it is accustomed to, a process termed *overload* which must be gradually *progressed* (i.e., progressive overload) as the system adapts to meet the demands. Such progression is achieved through manipulation of training variables, for example, training to failure, increasing load or volume or decreasing rest periods. Finally, the principle of *specificity* implies that the adaptations from an intervention will be specific to the demands that were imposed (Kraemer and Ratamess, 2004), otherwise known as 'specific adaptations to imposed demands' or SAID (Stone, Stone and Sands, 2007b). As such, to achieve the goal of an intervention, the physiological demands imposed should align with the physiological requirements of the desired outcome or intervention goal.

2.3.4 Individualisation, Safety and Adherence

Although not classed as a fundamental principle, individualisation is considered an important component of effective RT programmes (Kraemer and Ratamess, 2004). Individualisation ensures the physiological stimuli are appropriate and safe as well as affecting adherence to a programme, a critical element of effective RT (Helms *et al.*, 2020; Larsen, Kristiansen and Van Den Tillaar, 2021). For example, health or injury concerns may prevent an individual from tolerating an intervention, performing it as intended or without experiencing adverse outcomes. In addition, individual preferences, for example of certain exercises, equipment or settings can impact enjoyment, motivation and adherence so warrant consideration (Box *et al.*, 2019; Blazer *et al.*, 2021). Furthermore, practicalities such as the availability of time, space and equipment may impact the types of RT programming that is feasible and so should not be overlooked in research or practical settings.

2.3.5 Assessment and Monitoring

Assessment and monitoring are integral components of RT programmes and play a crucial role in adhering to the fundamental principles as well as ensuring programmes are safe (Comfort, Jones and McMahon, 2018). Initially, assessment is essential for establishing baseline performance levels and determining appropriate training variables to ensure the principle of overload is effectively applied (Steele *et al.*, 2017, 2022; Mangine *et al.*, 2018). Throughout the intervention, ongoing monitoring allows for the tracking of progress, aligning with the principle of progression (Thompson *et al.*, 2020). Moreover, assessment and monitoring can contribute to motivation and adherence, as individuals are motivated by real-time feedback on their performance (Wilson *et al.*, 2017). Additionally, they serve as vital tools for risk management and injury prevention, enabling the identification of potential issues, such as fatigue, that may heighten the risk of injury or hinder adherence (Scott *et al.*, 2016). By identifying such issues and making any necessary adjustments to the programme, programme deliverers can ensure the safety and well-being of participants. In addition, post-training assessments evaluate the effectiveness of the RT programme, determining if the desired goal has been successfully achieved.

There are various options for assessment and monitoring methods, including objective and subjective measures such as one repetition maximum (1RM) testing or collection of ratings of perceived exertion (RPE) and may involve various outcome variables of interest such as power output, velocity, impulse or RFD (Kraemer and Ratamess, 2004; Comfort, Jones and McMahon, 2018; Buskard *et al.*, 2019; Shattock and Tee, 2022; Thompson *et al.*, 2022). The choice of assessment and monitoring methods should be based on several considerations such as the specific goals of the programme and the validity and reliability of the method, safety, as well as the available resources (Comfort, Jones and McMahon, 2018; Hecksteden *et al.*, 2018). As such, it may be that in different circumstances, such as research and practice, the most appropriate methods might be different.

2.3.6 Section Summary

This section presented existing knowledge and recommendations relating to the design of RT programmes, highlighting important considerations such as the manipulation of training variables, application of fundamental RT principles, and assessment and monitoring methods.

2.4 Maximal-intentional Velocity Resistance Training (MIV-RT)

This thesis adopts the term MIV-RT to describe RT involving maximal intentional velocity of the load. Therefore, MIV-RT can involve activities such as jumping, throwing, bounding, and weightlifting, and may include plyometric, ballistic, or isometric muscle actions. This modality of RT has been studied extensively in untrained individuals and athletes and is often recommended and programmed to improve the ability to produce force rapidly (Paton and Hopkins, 2005; Caserotti *et al.*, 2008; Edholm, Strandberg and Kadi, 2017).

As will be discussed in chapter 3, this type of RT is also referred to as power training, explosive, high-speed and high-velocity RT (de Vos et al., 2005, Richardson et al., 2019, Sayers and Gibson, 2010, Pearson et al., 2022). In this literature review, the terminology used by individual authors to describe MIV-RT will be retained and presented in quotation marks to preserve the original meaning intended by the authors as well as highlight the substantial variation in the terminology used.

2.4.1 Maximal-intentional Velocity Resistance Training for Older Adults

Recently, advocacy for the implementation of MIV-RT for OAs has increased considerably (Cadore *et al.*, 2018; Fragala *et al.*, 2019; Schaun, Bamman and Alberton, 2021). For instance, Cadore *et al.*, (2018, page 82), stated that:

> *"explosive resistance training must be prescribed in healthy and frail elderly individuals, at least in combination with traditional resistance training, because this type of training optimizes functional abilities gains, reduces incidence of falls, improves muscle strength and power output, and stimulates muscle hypertrophy."*

In addition, Orssatto *et al.*, (2019, page 105), suggested that 'fast-velocity' RT should be prioritised for OAs as when compared to 'slow-velocity' RT *"is superior for improving power output, explosive force, and functional capacity"*.

Indeed, evidence in OAs suggests that muscle actions that are performed with maximal intentional velocity involve greater force (peak and average), RFD, velocity and muscle activation than slow, controlled muscle actions (i.e., traditional resistance training, TRT) and thus, could provide a more specific and efficacious stimulus for improvements in the ability to produce force rapidly (Mc Dermott *et al.,* 2022). In addition, international expert consensus guidelines and position statements state that RT programmes for OAs should include ‘power’ training performed as fast as possible during concentric muscle actions (Fragala *et al.*, 2019; Izquierdo *et al.*, 2021).

However, these guidelines and position statements lack in depth analysis of the evidence base, for example, consideration of individual study quality, or the potential effects of training and testing selections on specific outcomes. Therefore, to establish a comprehensive understanding of the current evidence base, the following section critically reviews the literature on the effects of MIV-RT on muscle mass and function in OAs.

2.4.1.1 Effects of Maximal-intentional Velocity Resistance Training on Muscle Mass

Various studies suggest that MIV-RT may be an effective RT modality for improvement in muscle mass (i.e., hypertrophy) in OAs. For example, Orssatto *et al.*, (2020) conducted a meta-analysis of 19 studies and found that ‘power training’ (defined as ‘training with high-velocity movements’ and ‘fast concentric velocity’) improved muscle mass compared to non-exercising controls and showed similar improvements to ‘moderate-velocity’ RT (i.e., TRT). More recently, Rodriguez-Lopez *et al.* (2022) conducted a 12-week intervention involving high (80% 1RM) and low-load (40% 1RM) ‘power-orientated’ leg press training in 45 well-functioning (no evidence of frailty or low physical-function), untrained older women. They found that both loading conditions induced similar and significant increases in quadriceps cross-sectional area (average of +7-9%) that were greater than controls, therefore, supporting MIV-RT as an effective strategy to improve muscle mass in older women. In addition, these findings suggest that improvements in muscle mass may be achieved without the need for ‘high loads’ (e.g., 80% 1RM), lending support to the notion that muscle hypertrophy can be achieved across a wide spectrum of loads (Fisher *et al.*, 2020; Schoenfeld *et al.*, 2021).

However, in mobility-limited OAs (self-reported difficulty in mobility-related tasks e.g., rising from a chair and Short Physical Performance Battery score of ≤ 9), non-significant increases in muscle mass have been observed following light (40% 1RM) or heavy (70% 1RM) 'power training', (Reid *et al.*, 2015). Therefore, it is possible that OAs with mobility limitations experience slower or attenuated adaptations compared to those without limitations. Alternatively, it may be that adherence to MIV-RT interventions is more challenging for OAs with mobility limitations and thus, they experience a reduced physiological stimulus. However, Reid et al. (2015) did not report on the fidelity of the intervention, therefore in this case, adherence is unclear. Furthermore, the contrasting outcomes in the studies of 'well-functioning' (Rodriguez-Lopez *et al.,* 2022) and 'mobility-limited' OAs (Reid et al., 2015) could be explained by differences in the prescribed training variables. For example, although the low-load groups lifted the same %1M, the well-functioning OAs completed substantially more sets and repetitions (6x12 vs 3x10). Therefore, it is plausible that the 'well-functioning' OAs were closer to momentary failure, a key determinant of hypertrophic adaptations (Fisher, Steele and Smith, 2013).

Indeed, heterogeneity in training programmes and outcome measures may be limiting our understanding of the efficacy of MIV-RT and the ability to draw definitive conclusions. For example, in the meta-analysis by Orssatto, Bezerra, Shield, *et al.* (2020), the outcomes of individual studies were notably mixed. In the comparison of 'power training' versus 'moderate-velocity training', two studies favoured 'moderate-velocity RT', two favoured 'power' training and the remaining three showed no difference with a similar situation in the studies comparing 'power training' with controls. The authors highlighted heterogeneity in the sex and health of participants, training variables and muscle mass measurements as possible reasons for the observed variances. Indeed, among the studies included in the analysis, 5 different methods were used to assess muscle mass. In addition, some studies assessed the whole body whilst others assessed upper or lower body only. Combining different assessment methods of muscle mass within a quantitative synthesis of research is problematic as they may provide different levels of accuracy and thus, limit the validity and integrity of the results.

These findings indicate that despite evidence to suggest that MIV-RT may be an effective strategy to improve muscle mass in OAs, more studies involving more homogenous study designs are required to get an accurate understanding of its effectiveness.

2.4.1.2 Effects of Maximal-intent Resistance Training on Maximal Strength

Several meta-analyses and randomised control trials (RCT) have shown that MIV-RT is an effective intervention to improve maximal strength in OAs (Bottaro *et al.*, 2007; Henwood, Riek and Taaffe, 2008; Steib, Schoene and Pfeifer, 2010; Richardson *et al.*, 2019; Rodriguez-Lopez *et al.*, 2022). For example, Rodriguez-Lopez *et al.* (2022) observed significant improvements in leg press 1RM following both high (80% 1RM) and low-load (40% 1RM) 'power-orientated' training. Elsewhere, Bottaro, Machado, Nogueira, Scales and João Veloso, (2007) found that 10 weeks of 'power training' (concentric phase performed AFAP) performed twice per week increased leg press and chest press 1RM by 27 and 28% respectively and Henwood, Riek and Taaffe, (2008) observed a 51 ± 9% increase in maximal strength across 6 exercises following 22 weeks of 'high-velocity training'. In addition, both studies found MIV-RT was equally as effective as TRT in improving maximal strength. This observation was backed up by a meta-analysis from Steib, Schoene and Pfeifer, (2010) which included a total of 29 studies and concluded that 'power training' enhanced maximal strength to a similar degree to TRT.

However, more recent findings challenge these observations (Richardson *et al.*, 2019; Vieira *et al.*, 2022). Richardson *et al.* (2019) found MIV-RT was significantly less effective at increasing maximal strength when compared to TRT. They found that MIV-RT performed twice per week increased leg press 1RM by 9% whereas TRT performed once or twice per week increased it by 25% and 40% respectively. In addition, (Vieira *et al.*, 2022) observed greater increases in maximal strength for both leg and bench press with TRT compared to MIV-RT. These authors suggested that the reasons their results disagreed with previous work could be due to differences in programming. For example, Richardson *et al.* (2019) volume-load matched MIV-RT and TRT whereby the 'high-velocity' groups performed twice as many reps than the TRT groups but at half the load (3 sets of 14 reps at 40% 1RM versus 3 sets of 7 reps at 80% 1RM). In contrast, in studies that observed comparable improvements between MIV-RT and TRT, all training variables, except for the intent to move with maximal velocity (and subsequently, time under tension) were similar between modalities (Bottaro *et al.*, 2007; Henwood, Riek and Taaffe, 2008). This suggests that load may be more critical to improvements in maximal strength than intent or time under tension and highlights the significance of acute training variables in the design and interpretation of interventions. The significance of load for maximal strength improvements is further supported by the aforementioned study from Rodriguez-Lopez *et al.* (2022), which found high-load MIV-RT (80% 1RM) resulted in greater gains in 1RM than low-load MIV-RT (40% 1RM) despite the low-load condition involving greater time under tension per set.

Furthermore, in the studies from Richardson *et al.* (2019) and Vieira *et al.* (2022), maximal strength was measured using methods that aligned more closely with the TRT than the MIV-RT and thus, the results may have been influenced by test specificity. For example, Richardson *et al.* (2019) adopted an estimated 1RM method whereby participants reached momentary failure between 2 and 10 repetitions. Recent evidence suggests that on a leg press, reaching momentary failure in this repetition range requires loads between 80 and 95% 1RM (Nuzzo *et al.*, 2023). Hence, the testing method adopted by Richardson *et al.* (2019) involved repetitions and loads that shared similarities with the TRT (7 reps at 80% 1RM) but not the MIV-RT (14 reps at 40% 1RM). Similarly, in the study from Vieira *et al.* (2022), TRT involved 2 sets of 10-12 repetitions to momentary muscle failure which was almost identical to the maximal strength test which involved a 10-repetition maximum (i.e., 10 repetitions to momentary muscle failure). As previously mentioned, the principle of specificity implies that the adaptations from an intervention will be specific to the demands that were imposed (Kraemer and Ratamess, 2004) and so, could explain why TRT was more effective than MIV-RT at improving maximal strength in these particular studies.

Collectively, these findings suggest that MIV-RT may be an effective method to improve maximal strength, however, higher loads or test specificity may be more influential than maximal intentional velocity for this particular outcome. Thus, underscoring the importance of selecting training variables that align with the intervention goals.

2.4.1.3 Effects of Maximal-intent Resistance Training on Rapid Force Production Outcomes

There is substantial evidence supporting MIV-RT as an effective modality to improve the ability to produce force rapidly (Bottaro *et al.*, 2007; Correa *et al.*, 2012; Ramírez-Campillo *et al.*, 2014; Straight *et al.*, 2016; Guizelini *et al.*, 2018; Moran, Ramirez-Campillo and Granacher, 2018; Blazevich *et al.*, 2020; Rodriguez-Lopez *et al.*, 2022). For instance, a meta-analysis from Blazevich *et al.*, (2020) found that RT performed at ‘high-speed’ and RT performed at ‘slow-speed’ but with maximal intent (thus both constituting MIV-RT) resulted in significant increases in peak RFD. In addition, Correa *et al.* (2012) found that CMJ height (cm) increased by 25% following 6 weeks of ‘rapid strength training’ involving knee extension, knee flexion and lateral box jumps and Bottaro, Machado, Nogueira, Scales and João Veloso, (2007) found that ‘power training’ increased leg press and chest press power output (W) by 31 and 37% respectively.

In several studies, superior improvements in rapid force production have been observed following MIV-RT when compared to TRT (Bottaro *et al.*, 2007; Correa *et al.*, 2012). For example, the 'power training' used by Bottaro, Machado, Nogueira, Scales and João Veloso, (2007) increased leg press and chest press power output (W) by 31 and 37% respectively compared to 8 and 13% following TRT. However, some studies have found no differences between training types or more modest improvements in RFD. For example, a meta-analysis from Guizelini, De Aguiar, *et al.*, (2018) found no differences in improvements in RFD between 'explosive RT' and TRT. In addition, although Ramírez-Campillo, Castillo, De La Fuente, *et al.*, (2014) observed greater improvements in CMJ height (cm) following 'high-speed' RT (+23%) compared to 'slow-speed' RT (+13.3%), the difference was not statistically significant. The inconsistent findings may be attributed to variations in methodologies and outcome variables, for instance measuring power output rather than RFD or jump height, highlighting the importance of independently measuring and discussing outcome variables related to rapid force production.

Despite this, terms related to these outcome variables are often used interchangeably and, in some cases, inaccurately, which may be attributed to the adoption of colloquial and general terms such as 'explosive strength' and 'muscle power' used to describe proficiency in these outcomes. For example, RFD and power have been used interchangeably to describe 'explosive strength' with RFD suggested as a direct alternative to measuring power (Bardstu et al., 2022). Further, Sklivas et al. (2022) discussed links between deficits in 'muscle power' and declines in ADLs with reference to research from Izquierdo et al. (1999). However, in this study, Izquierdo et al. (1999) did not measure power output and measured RFD and jump height, collectively calling them measures of 'explosive strength'. Furthermore, a meta-analysis by Moran, Ramirez-Campillo and Granacher (2018) found that ‘jumping exercise’ resulted in improvements in ‘muscular power’. However, the outcome of ‘muscular power’ in this study involved the combination of 7 different outcome variables with only one of them directly measuring power output (W): CMJ (cm), Wingate peak power output (W kg lean mass-1), 30s-STS test (repetitions), RFD (N·s − 1) and hop impulse (N/s).

Situations like this could lead to inaccurate conclusions being made about the efficacy of this training type on power output when in fact the effects were on other qualities. Similarly, other studies have reported significant improvements in ‘muscle power’ following ‘power training’ and ‘high-speed RT’ when the outcomes measured were CMJ, ball throwing, 10-m walking sprint and RFD (RFD over 0-100ms and peak RFD) (Ramírez-Campillo *et al.*, 2014; Tiggemann *et al.*, 2016). Consequently, when designing and evaluating RT programmes, researchers and practitioners may overlook the most relevant outcome variables or fail to target the desired outcomes.

The inconsistent and incorrect use of terms including ‘power’ in sport and exercise science related research has been discussed extensively (Winter et al., 2016, Cronin and Sleivert, 2005, Knudson, 2009). As described by these authors, and evidenced in this literature review, possessing ‘power’ or being ‘powerful’ is often used to describe ability in ‘short, dynamic or impulsive movements like a maximal effort jump’ (Knudson, 2009, page 1903) which is not consistent with the mechanical definition of power: the rate of performing work (Rodgers and Cavanagh, 1984), expressed in the Systéme International d’Unites (SI) -derived unit, watts (W) (Bureau International des Poids et Mesures, 2019) (Winter et al., 2016). As such, for several decades it has been advised that researchers in sports and exercise science apply terms and measurements according to the laws of physics and SI units to allow for effective and unambiguous cross-disciplinary communication (Winter et al., 2016, Knuttgen and Kraemer, 1987).

Previous attempts to clarify terminology have been predominantly in the context of athletic performance and aimed at strength and conditioning professionals (Winter et al., 2016, Knudson, 2009, Turner et al., 2020). However, it is evident that inconsistent and misapplied terminology relating to rapid force production is also commonplace in research concerning RT for OAs, suggesting the need for clarification in this field of research to provide clear guidance for both researchers and practitioners.

2.4.1.4 Effects of Maximal-intent Resistance Training on Activities of Daily Living

Multiple RCTs have provided evidence that MIV-RT is effective in improving ADLs. For instance, improvements of 8% in stair climb time (12 steps) (Beltran Valls *et al.*, 2014), 17.3% in TUG ((Englund *et al.*, 2017), 44% in 5STS (Bean *et al.*, 2004) and 43% in 30s-STS (Bottaro *et al.*, 2007) have been reported following MIV-RT interventions.

In addition, the effect of MIV-RT on ADLs performance has been the focus of multiple systematic reviews and meta-analyses (Rice and Keogh, 2009; Byrne *et al.*, 2016; Katsoulis, Stathokostas and Amara, 2019; Balachandran *et al.*, 2022; Lopez *et al.*, 2022; Pearson *et al.*, 2022; Morrison *et al.*, 2023). However, the findings of these studies present conflicting results. While some pairwise meta-analyses have indicated that MIV-RT is more effective than TRT in improving ADL performance (Tschopp, Sattelmayer and Hilfiker, 2011; Ramírez-Campillo *et al.*, 2014), others have reported similar effectiveness between the training modalities (Da Rosa Orssatto *et al.*, 2019; Balachandran *et al.*, 2022; Pearson *et al.*, 2022; Morrison *et al.*, 2023).

Recent evidence suggests that the effectiveness or superiority of MIV-RT in improving ADLs depends on the specific outcome that is measured. Lopez *et al.*, (2022) conducted a comprehensive review and network meta-analysis examining the effects of MIV-RT and TRT on ADLs which included analysis of 79 interventions involving 3575 OAs. They found that compared to controls, the effectiveness of each training type depended on the test. For instance, 'high-velocity' RT was more effective for improving fast walking speed, TUG, and 5STS, while TRT was more effective for 30s-STS and the 6MWT suggesting that different ADLs respond to different physiological stimuli. This demonstrates the importance of considering the principle of specificity and tailoring interventions to the desired outcomes as discussed earlier in this thesis (sections 2.3.3 and 2.4.1.2). The concept of specificity has been mentioned, although briefly in this context previously (Rice and Keogh, 2009). For instance, Tschopp, Sattelmayer and Hilfiker (2011) suggested that the selection of ADL outcomes included in their meta-analysis, comparing MIV-RT with TRT might have influenced the results, implying that one training type may have appeared more effective due to greater specificity to the included outcomes. In addition, in their meta-analysis, Morrison *et al.* (2023) acknowledged the potential implications of training specificity in the interpretation of outcomes, stating that this is an overlooked concept. However, despite these observations, the degree of specificity in MIV-RT for OAs has yet to be discussed or explored in detail.

The specificity of a training programme relies on the selection of training variables that meet the physiological and biomechanical demands of the outcome measurement.

However, the growing number of systematic reviews and meta-analyses has highlighted a wide range of training variables and stimuli employed by researchers. For instance, the aforementioned meta-analysis by Morrison *et al.* (2023) included studies with frequencies of 1, 2 and 3 per week, intensities ranging from 40 - 80% 1RM and an array of set and repetition combinations including 2x6, 3x14 and 4x12. This is problematic since the inclusion of studies with different training variables within a meta-analysis makes it difficult to determine which specific variables or combination of variables are responsible for the observed effects, which can hinder the establishment of clear recommendations and best practices in the field (Arruda *et al.*, 2017).

Some meta-analyses have conducted subgroup analyses to explore the influence of different training variables on ADLs. For instance, in their pairwise meta-analysis, Morrison *et al.* (2023) reported that when training programmes with higher training frequencies were analysed separately, several outcomes favoured MIV-RT over TRT. Moreover, high-heterogeneity scores observed in many meta-analyses suggest substantial variability among the included studies in terms of their design (Moran, Ramirez-Campillo and Granacher, 2018; Lopez *et al.*, 2022; Pearson *et al.*, 2022). It is typical for review authors to acknowledge variation in programme design, but limited discussion has been made about the potential effects of different programme designs on specific ADLs. In particular, little attention has been given to the exercises or equipment selected by researchers, with some reviews failing to report exercises at all (Guizelini *et al.*, 2018; Balachandran *et al.*, 2022; Lopez *et al.*, 2022). However, the selection of exercises is influential to the specificity of a RT programme, a fundamental principle of RT (Chapter 2.3.4).

The concept of mechanical specificity suggests that the closer exercises are to the performance outcomes in terms of kinetic and kinematic variables (e.g., direction and rate of force application, muscle actions, joint motion) the greater the likelihood of improvement and transfer of training effects (Thepaut-Mathieu, Van Hoecke and Maton, 1988; Wilson, Murphy and Walshe, 1996; Stone, Stone and Sands, 2007b). Thus, in MIV-RT interventions for OAs, the degree of improvement in ADL outcomes may be influenced by the kinetic and kinematic specificity of the exercises employed, making it important to consider. Therefore, further exploration and discussion of the potential effects of programme design on specific ADLs outcomes are warranted in order to enhance our understanding of the effectiveness of MIV-RT for OAs.

In addition, the results of several meta-analyses were affected by methodological limitations in the included RCTs (Lopez *et al.*, 2022; Morrison *et al.*, 2023). For instance, both Lopez *et al.*, (2022) and Morrison *et al.* (2023) applied The Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach to assess the certainty (i.e., quality) of evidence in their meta-analyses exploring the effects of MIV-RT on ADLs. The GRADE approach considers factors such as study limitations, inconsistency of results, indirectness of evidence, imprecision and publication bias and the certainty of evidence is downgraded based on these domains (Guyatt *et al.*, 2008). In both meta-analyses, the quality of evidence of the effects on MIV-RT on performance of ADLs was downgraded, often multiple times which resulted in all outcomes having a low or very low certainty of evidence, precluding the ability to draw accurate conclusions. This highlights the need for more high-quality RCTs to improve the precision and certainty of evidence and understand the true effectiveness of MIV-RT.

2.4.1.5 Section Summary

Despite evidence to support MIV-RT as an effective method to improve muscle mass and function, heterogeneity in study designs, inconsistent terminology, and consideration of training variables are precluding the ability to draw definitive conclusions about the efficacy of MIV-RT or to establish best practices in the field.

2.5 Safety of Maximal-intentional Velocity Resistance Training Interventions

MIV-RT is considered a safe training modality for both healthy and mobility-limited OAs, largely owing to the absence of reported adverse events in research studies (Vetrovsky *et al.*, 2019; Radaelli *et al.*, 2023). For example, Radaelli *et al.* (2023) recently concluded that 'power training' is safe for OAs based on a low occurrence of injury, citing several randomised controlled trials and meta-analyses. Indeed, although some cases of injury, including exacerbation of osteoarthritis (Fielding *et al.*, 2002) and joint pain (Marsh *et al.*, 2009), have been reported during MIV-RT interventions, the overall number of reported adverse events remains relatively low. For instance, a 12-month MIV-RT intervention involving an individual with osteoporosis and increased risk of falling reported no adverse events and resulted in significant improvements in bone mineral density and balance (Aquino *et al.*, 2020). However, the investigators did implement an 8-week preparatory training phase involving TRT designed to improve baseline strength and ensure proper form was learned. Elsewhere, 49 postmenopausal women (23 classed as osteoporotic and the remainder osteopenic) completed 8 months of twice-weekly, 30-minute, supervised 'high-intensity resistance and impact training' where impact loading involved jumping chin-ups performed with maximal intentional velocity and drop landings (Watson *et al.*, 2018). Only one adverse event was recorded during the 2600 training sessions which was not related to the portion of the RT involving maximal-intentional velocity. Moreover, Balachandran *et al.* (2022), who conducted a review of 20 RCTs found 3.27 adverse events per 1000 person sessions of ‘power training’ which was comparable to TRT at 2.08 events. However, adverse events were not reported in 30% of the included studies, which raises concerns about accurately evaluating safety based on the absence of reported adverse events in research studies. In addition, although reporting guidelines such as the CONSORT statement recommend detailed reporting of all adverse events (defined as harmful events that occur during a trial) (Ioannidis, 2004), it is not mandatory to adhere to these guidelines; thus, the accuracy and consistency of adverse events measurements is uncertain. For instance, it is common for RCTs to lack reporting on how adverse events were measured or collected (e.g., measurement instruments, personnel responsible, timing, passive or active measurement) or the definitions used for adverse events (i.e., what constituted an adverse event) (Niemeijer *et al.*, 2020; James, Von Heideken and Iversen, 2021). Without this information it is uncertain whether the absence of reported adverse events truly reflects the safety of MIV-RT or if certain adverse events are being overlooked or underestimated. For instance, delayed onset muscle soreness (DOMS) is a commonly expected result of unfamiliar exercise (McHugh *et al.*, 1999) and so may not be considered an adverse event to those working in the field of sport and exercise (e.g., researchers or practitioners) but may be viewed differently to those unfamiliar with this phenomenon. Considering DOMS has been shown to occur alongside decreases in postural stability and the performance of ADLs, increased fear of falling and reductions in non-exercise physical activity (e.g., housework) in OAs (Gray *et al.*, 2018; Naderi *et al.*, 2021), the degree of DOMS experienced may provide valuable insights into both physical and psychological risks associated with MIV-RT, informing its safety, tolerability and feasibility.

2.5.1 Acute effects on muscle strength and activities of daily living

A limited number of studies have specifically investigated the potential adverse effects of MIV-RT as a primary outcome in order to gain further insights into its safety. However, the available evidence suggests that MIV-RT may lead to acute impairments in muscle strength and the ability to carry out ADLs, perhaps highlighting safety concerns (Rodriguez-Lopez *et al.*, 2021; Pinto *et al.*, 2022). Rodriguez-Lopez et al., (2021) measured various parameters in OAs including maximal strength, RFD, 5STS performance, and muscle damage biochemistry immediately before and after single sessions of 'power-oriented' leg press at two different loads (volume-load matched heavy-load: 80 % 1RM and light-load: 40 % 1RM). They found moderate declines in maximal strength following both sessions (ES= 0.65) but considerable declines in RFD, including decreases in peak RFD of 27% (low load) and 29% (high load). Muscle strength and, in particular, rapid force production, is essential to carry out ADLs (Chapter 2.2.5), therefore, rapid declines could have a significant impact on the everyday lives of OAs. Indeed, Rodriguez-Lopez et al. (2021) found that the time needed to complete 5STS increased following both sessions (high-load: +0.3 s [0.1 to 0.6], $p = 0.014$, ES= 0.73; and low-load: +0.5 s [0.2 to 0.8], $p< 0.001$, ES = 0.98). However, despite the statistical significance, this was less than the minimal detectable change previously reported for this test (2.5 s) (Goldberg et al., 2012); hence, these differences may be explained by measurement error.

Additionally, Rodriguez-Lopez et al., (2021) observed elevated creatine kinase concentration 24 h after the sessions ($p = 0.001$, ES = 1.85), which suggests an inflammatory response and muscle damage (Markus *et al.*, 2021). However, as the authors did not reassess maximal strength or RFD at this time point, the time it took for these measures to return to pre-training levels is unknown. Yet, such information is required to understand the severity and duration of any impairments, thus helping to better understand the risks associated with MIV-RT and to inform the development of safe and effective programmes, for instance optimal recovery periods between sessions.

Pinto *et al.* (2022) found that a session of 'high-velocity' deadlifts (3 x 10 reps) negatively affected 6MWT at 24 h post-exercise, suggesting that acute impairments in ADLs may occur. However, in the same participants, performance in both the 5STS and TUG improved in the 48h following MIV-RT, indicating a potential learning effect in these tests, which may render them unsuitable for detecting acute changes in muscle function.

Additionally, OAs may adopt less stable movement patterns in order to maintain speed during ADLs (Helbostad *et al.*, 2007; Esbjörnsson and Naili, 2020) meaning time-based tests of ADLs may be unsuitable for detecting functional deficits following MIV-RT. For instance, Helbostad *et al.* (2007) found that fatiguing exercise did not affect gait speed but resulted in altered gait patterns, such as greater mediolateral trunk accelerations and step width, suggesting a more unstable gait. In addition, Esbjörnsson and Naili (2020) found that during 5STS, individuals with total hip arthroplasty displayed significantly more lateral shift of their centre of mass than healthy controls, despite similar completion times. Therefore, despite the ease of administration and minimal equipment requirements, time-based tests such as 5STS and TUG may not be sufficiently sensitive to identify functional deficits or potential harms following MIV-RT. Consequently, identification of practical and sensitive measurement tools is necessary to better assess the safety of MIV-RT for OAs.

2.5.2 Postural stability as a measure of safety

Postural stability (a component of balance) is considered the ability to maintain the body's centre of mass within the base of support, in order to remain upright and balanced (Manor *et al.*, 2010; Takacs *et al.*, 2013). In various studies, the precise measurement of postural stability, acquired as the centre of pressure (COP) and its trajectory (i.e., postural sway) has been predictive of fall risk in OAs (Maki, Holliday and Topper, 1994; Piirtola and Era, 2006; Johansson *et al.*, 2017; Watt, Clark and Williams, 2018; Quijoux *et al.*, 2020). In both static and dynamic tasks, maintaining postural stability requires the complex coordination of various systems including neuromuscular activity, as muscular forces are required to stabilise centre of mass (Fujiwara *et al.*, 2006; Jeon *et al.*, 2021). Hence, activities that fatigue the neuromuscular system could have a deleterious effect on postural stability and subsequently, risk of falling. Therefore, the measurement of postural stability before and after an activity, is a potentially useful tool for assessing the safety of that activity. Exercise-induced fatigue has been associated with decreased neuromuscular function and postural stability in OAs (Baudry *et al.*, 2007; Morrison *et al.*, 2016; Naderi *et al.*, 2021), which could be in part, the result of decreased muscle excitability (Enoka and Duchateau, 2008). For instance, Naderi et al. (2021) found that a single bout of calf muscle RT designed to induce muscle damage (3 exercises, 4 sets of 10 reps with 75% 1RM) increased COP sway area by 35.7% during standing balance in untrained OAs. In addition, they discovered that the degree of COP sway peaked 48 hours after the exercise bout and remained elevated compared to baseline at 72 hours, suggesting OAs may suffer from impairments in postural stability for several days after RT. This is supported by evidence showing that when compared with young adults, OAs had a slower rate of recovery in postural stability following fatiguing RT (Lin *et al.*, 2009). Thus, the measurement of postural stability in the 72 hours after exercise could provide important information about risk of falls and recovery durations required for OAs, however, this has yet to be explored following a range of RT protocols.

The potential value in investigating postural stability following a range of RT protocols is highlighted by evidence suggesting that alterations in postural stability may be specific to the exercise performed. For instance, Egerton, Brauer and Cresswell (2009) found that moderate-intensity exercise (self-paced exercise representative of everyday activities e.g., walking, mini squats and lunges, carrying bags, stepping over obstacles) did not alter dynamic postural stability in young or OAs, contrasting with significant alterations observed following exercise designed to induce fatigue or momentary muscular failure (Moore, Korff and Kinzey, 2005; Baudry *et al.*, 2007; Naderi *et al.*, 2021). In addition, Lin et al. (2009) found that knee and shoulder fatigue did not affect postural control as much as ankle or back fatigue, suggesting that the effects of fatigue on postural stability may be muscle group specific. Hence, it is important that the effects of exercise on postural stability are not generalised but that different training programmes are researched independently, and the exercise stimulus is clearly reported. The effects of MIV-RT on postural stability in OAs have yet to be explored but could provide important information about its safety and suitability for this population. For instance, examining the acute effects of different MIV-RT interventions on postural stability alongside neuromuscular fatigue and perceptions of fatigue, DOMS and falls risk in OA both immediately post-exercise and in the days following would provide both objective and subjective information about the safety of MIV-RT and guide future programming.

2.5.3 Section Summary

These findings suggest that the safety of MIV-RT for OAs remains unclear. Although MIV-RT is considered safe based on the absence of adverse events reported in research studies, this relies on the accuracy and consistency of the measurement and reporting of adverse events, which is inconsistent. Some evidence suggests that OAs may experience acute physical impairments after MIV-RT; however, practical and sensitive measurement tools are needed to better understand the duration and severity of any impairments experienced, and thus understand its safety. The measurement of postural stability before and after MIV-RT could provide important information about risk of falls and recovery durations required for OAs and guide future programming, however, this has yet to be explored.

2.6 Summary of Literature Review and Gaps in Current Knowledge

Globally, the number and proportion of older adults (OAs) is increasing (United Nations, 2019). Older age is associated with significant declines in muscle mass and function which affect the ability to perform activities of daily living (ADLs), independence, quality of life (QoL), risk of mortality, and healthcare costs, implicating these changes in muscle as a major health issue for individuals and society (Lanza *et al.*, 2003; Maden-Wilkinson *et al.*, 2015; Beaudart *et al.*, 2017; Kim *et al.*, 2018). Therefore, the development of interventions to reverse or attenuate age-related decline in muscle mass and function is imperative to aid healthy ageing, improve QoL, and reduce social and economic burdens.

Resistance training (RT) is an established and effective method to improve muscle mass and function in all people, including healthy OAs and those with chronic diseases or mobility limitations (Kraemer *et al.*, 2017; Fragala *et al.*, 2019; Katsoulis, Stathokostas and Amara, 2019). The efficacy of RT relies on the structuring or design of the training stimulus (i.e., training programme or intervention) (Fleck and Kraemer, 2014) and therefore, requires careful consideration. This includes the manipulation of training variables, such as load, volume, or time under tension, the application of fundamental RT principles, and consideration of factors affecting adherence such as risks associated with the training (Kraemer and Ratamess, 2004; Toigo and Boutellier, 2006).

Recently, advocacy for OAs to participate in RT involving maximal intentional velocity has increased considerably (Cadore *et al.*, 2018; Fragala *et al.*, 2019; Izquierdo *et al.*, 2021; Schaun, Bamman and Alberton, 2021). It has been strongly suggested that this RT modality known as maximal-intentional velocity resistance training (MIV-RT), power training, explosive, high-speed or high-velocity RT (De Vos *et al.*, 2005; Sayers, Gibson and Bryan Mann, 2016; Richardson *et al.*, 2019; Pearson *et al.*, 2022) is an optimal method for improvements in functional ability, improves muscle mass and function and thus, should be prioritised for OAs (Cadore *et al.*, 2018; Orssatto *et al.*, 2019).

However, despite existing evidence to support MIV-RT as an effective method to improve muscle mass and function in OAs (Blazevich *et al.*, 2020; Rodriguez-Lopez *et al.*, 2022; Morrison *et al.*, 2023), methodological issues in research studies preclude the ability to draw definitive conclusions about the efficacy and safety of MIV-RT. This includes heterogeneity in study designs, inconsistencies in terminology and programme design and the use of suboptimal methods to understand the risks associated with this training type.

Therefore, a critical investigation of the implementation of MIV-RT for OAs is required to enhance future RT interventions to identify the most effective methods to address age-related loss of muscle mass and function, ultimately improving the lives of OAs.

2.7 Thesis Aims and Objectives

The aim of the work presented in this thesis was to investigate and critically evaluate the evidence base and implementation of MIV-RT for older adults, and to provide recommendations to improve the design and dissemination of future MIV-RT interventions.

Specifically, the following objectives were developed:

1. To evaluate the current evidence base surrounding MIV-RT for OAs. Specifically, to evaluate the design, evaluation and dissemination of MIV-RT interventions in research (chapters 2 and 4).
2. To provide clarification on the terminology used to describe rapid force production and the application of said phenomenon (chapter 3).
3. To explore the implementation of MIV-RT in applied practice and compare with the application in research (chapter 5).
4. To enhance knowledge of the risks associated/safety of MIV-RT for OAs including the exploration of novel methods to measure safety/feasibility in research and practice (chapters 5 and 6).

Chapter: 3 Understanding Terminology and Clarifying the Methods Used to Describe and Measure the Ability to Produce Force Rapidly in Resistance Training for Older Adults.

In RT related research, inconsistent and ambiguous terminology is being used to describe the ability to perform exercise. Primarily, power, RFD, impulse and explosive strength are used interchangeably to describe the ability to produce force rapidly. However, when applied according to the laws of physics and SI (Bureau International des Poids et Mesures, 2019), these terms differ in both meaning and application. As such, when interpreting research, confusion could arise if the intended meaning of a term is not made clear or in agreement with other publications. Clarification is therefore needed to ensure clear understanding of the phenomena being discussed and measured in the programme of research that is presented in the thesis.

For several decades, researchers have suggested that the utilisation of physics and units of the SI in exercise science would allow for effective and unambiguous cross-disciplinary communication (Winter et al., 2016, Knuttgen and Kraemer, 1987). Yet, recent publications have highlighted the ongoing use of inconsistent terminology and units of measurement in the sport and exercise science field, emphasising the need for further communication on this topic (Staunton et al., 2022). Primarily, previous work has highlighted the inconsistent use of the term power in sport and exercise science related research (Winter et al., 2016, Cronin and Sleivert, 2005, Knudson, 2009). As described by these authors, possessing ‘power’ or being ‘powerful’ is often used to describe ability in ‘short, dynamic or impulsive movements like a maximal effort jump’ (Knudson, 2009, page 1903) which is not consistent with the mechanical definition of power: the rate of performing work (Rodgers and Cavanagh, 1984) which is expressed in the SI-derived unit watts (W) (Winter et al., 2016).

As discussed in Chapter 2.4.1.3, the interchangeable and inaccurate use of terms related to rapid force production and the adoption of colloquial and general terms such as ‘muscle power’ and ‘explosive strength’ are also commonplace in research concerning MIV-RT for OAs. For example, RFD and power have been used interchangeably to describe ‘explosive strength’ with RFD suggested as a direct alternative to measuring power (Bardstu et al., 2022). Further, Sklivas et al. (2022) discussed links between deficits in ‘muscle power’ and declines in ADLs with reference to research from Izquierdo et al. (1999). However, in this study, Izquierdo et al. (1999) did not measure power output and measured RFD and jump height, collectively calling them measures of explosive strength. Furthermore, a meta-analysis by Moran, Ramirez-Campillo and Granacher (2018) found that ‘jumping exercise’ resulted in improvements in ‘muscular power’. However, the outcome of ‘muscular power’ in this study involved the combination of 7 different outcome variables with only one of them directly measuring power output (W): CMJ (cm), Wingate peak power output (W kg lean mass-1), 30s-STS test (repetitions), RFD (N·s − 1) and hop impulse (N/s). Situations like this could lead to inaccurate conclusions being made about the efficacy of this training type on power output when in fact the effects were on other qualities. Consequently, when designing and evaluating RT programmes, researchers and practitioners may overlook the most relevant outcome variables or fail to target desired outcomes.

To date, discussions of terminology related to force production have been predominantly in the context of athletic performance and aimed at strength and conditioning professionals (Winter et al., 2016, Knudson, 2009, Turner et al., 2020). However, it is evident that inconsistent and misapplied terminology relating to rapid force production is also commonplace in research concerning RT for OAs, suggesting the need for clarification. Addressing this issue would facilitate better communication, accurate interpretations of research findings, and ultimately lead to the development of interventions that effectively target the desired outcomes to benefit both research and real-world applications.

Therefore, this narrative review aims to define terms typically used in OA literature to measure and describe the ability to produce force rapidly, to propose standard applications of each term and to discuss their function in the design and evaluation of RT interventions for OAs.

3.1 Rate of Force Development (RFD)

RFD, expressed in newtons per second ($N \cdot s^{-1}$) is calculated as the slope of the force-time curve or **Δ**force/**Δ**time (Aagaard et al., 2002) and indicates how quickly the force being applied is increasing during a time period.

RFD can be calculated for the entirety of muscle action (Figure 3.1-A), for several individual time periods along the force-time curve (Figure 3.1-B) or as peak RFD (Figure 3.1-C); an instantaneous value of the maximum rate of change in force (Maffiuletti et al., 2016).

Figure 3.1 - Illustrative examples of rate of force development calculations for various time periods: entire muscle actions (A), individual time periods along the force-time curve (B), and peak rate of force development (C). Abbreviations: ΔF = change in force; Δt = change in time; N = newtons; s = seconds. [Figure removed due to copyright restrictions. Adapted from Cleather (2021).]

Absolute RFD may be increased by producing greater force in a set time frame or by reaching a specified force in less time. Therefore, an increased RFD may result in a greater likelihood of success in activities with limited available duration, such as recovering from a trip before falling to the ground (Kamo *et al.*, 2019), or decreasing the time required for activities where force requirements are constant (e.g., climbing stairs at a standardised step height) (McFadyen and Winter, 1988). RFD is influenced by both neural and muscular properties; however, recent publications suggest that RFD is predominantly mediated by the rate of motor unit recruitment (Del Vecchio, 2023). Therefore, a training programme that is predominantly concerned with increasing RFD or that aims to improve the performance of activities known to benefit from increased RFD may benefit from targeting motor unit recruitment rates.

However, for many ADLs, RFD is not the only element of force production that influences performance. For example, stair climbing involves the propulsion of body mass through one leg and thus depends on the individual's ability to generate sufficient force to complete the task (McFadyen and Winter, 1988). RFD as a stand-alone value does not describe the actual force expressed; therefore, as a solitary measurement, it is unlikely to provide the necessary information about the force required to complete various ADLs. This means that despite the potential performance benefits of improved RFD, an increase following an intervention may not necessarily result in improved ADL performance if the training intervention and testing methods are not reflective of that activity. RFD can be calculated from the force-time curve collected during isometric or dynamic muscle actions (Maffiuletti et al., 2016). However, it has been highlighted that the choice of muscle action for a measurement can have significant effects on RFD and that values from isometric tests, although reliable, may not relate to dynamic movements (Wilson and Murphy, 1995). Moreover, it has been shown that RT isometrically leads to adaptations that are specific to the joint angle trained (Lanza et al., 2019). Therefore, it would be most practical to measure RFD during the performance of the desired activity itself (taking into account other force requirements such as peak force and duration of force) and design interventions that sufficiently overload RFD specific to that application of force i.e., the net impulse required.

3.2 Impulse

Impulse is the product of the magnitude of force as well as the duration for which it is applied. Impulse is calculated from the area under the force-time curve and is expressed in newton-seconds (N·s) (McGinnis, 2013). Thus, greater net impulse is achieved by increasing the area under the force-time curve by expressing greater peak or average force (Figure 3.2-A), greater RFD (Figure 3.2-B) or by increasing the time that force is applied (Figure 3.2-C).

Figure 3.2 - Illustrative examples of methods to increase net impulse: greater peak or average force (A), greater rate of force development (B), and greater duration of force application (C). Abbreviations: N = newtons; s = seconds. [Figure removed due to copyright restrictions. Adapted from Cleather (2021).]

According to the impulse-momentum theorem, the amount of impulse applied to an object/body is equal to the change in momentum (kg·m/s) of the object (Knudson, 2007). The momentum of an object is a product of its mass (kg) and velocity (displacement⁄time, m⁄s) and as in human movement, mass tends to remain constant, a change in momentum indicates a change in velocity (McGinnis, 2013). Thus, there is a direct relationship between the impulse applied and the change in velocity.

In many common tests of ADLs such as 5STS or stair ascents, the aim is to complete the task as quickly as possible and thus, the greater the change in velocity achieved, the greater the performance. Therefore, the performance of many ADLs can be directly related to the net impulse applied, and so, it would be logical for impulse to be the main outcome variable of interest for interventions aimed at improving the performance of ADLs. Yet, to the surprise of many scientists (Cronin and Sleivert, 2005, Turner et al., 2020), impulse is not readily measured or referred to in practice or research concerning dynamic functional activities and is overshadowed by the use of 'power'. However, in some cases impulse has been measured indirectly and perhaps unknowingly through measurements of jump height. For example, jump height has been used in several maximal-intentional velocity resistance training (MIV-RT) studies but used as a measure of 'power' or 'explosive strength' (Ramirez-Campillo et al., 2014, Correa et al., 2012, Van Roie et al., 2020). However, as jump height is dependent on velocity at take-off, and as previously mentioned, velocity is directly proportional to the net impulse applied, jump height should be considered a measure of impulse (Ruddock and Winter, 2016).

3.3 Power

The mechanical definition of power, or more strictly, 'average power' is the rate of performing work (Rodgers and Cavanagh, 1984) and is expressed in the SI-derived unit, watts (W) (Winter et al., 2016). Work is the total force with respect to the distance moved i.e., displacement and is expressed in the unit Joules (J) (Winter and Fowler, 2009).

The equation for the calculation of power is as follows:

$$Power\ (W) = \frac{Work\ (J)}{time\ (s)}$$

(Rodgers and Cavanagh, 1984)

To calculate work, and therefore power, displacement must occur. So, in contrast to impulse or RFD, power according to its mechanical definition cannot be measured during isometric muscle actions. However, successful performance in many ADLs involves the contribution of isometric actions. For example, during STS, evidence has shown that before leaving the seat, more than 50% of peak force has been expressed (Lindemann et al., 2003, Yamada and Demura, 2010) indicating the necessity for isometric muscle actions and the rapid application of force to overcome inertia. Additionally, whilst seated, weight is transferred between the buttocks and feet (Hirschfeld et al., 1999) and on standing, a period of stabilisation occurs demonstrated by accelerations in mediolateral and anteroposterior directions and fluctuations in ground reaction force around body weight (Hellmers et al., 2019). Taken together this suggests that various applications of force are required to complete a STS, beyond the vertical displacement of the centre of mass. Therefore, focussing on power as the most important variable to measure may prevent insight into physiological underpinnings of performance such as RFD during the early rise in force.

It is suggested that the most appropriate way to use power is to refer to the mean external power output for a specified duration, for example during steady-state cycling (Winter et al., 2016, Knudson, 2009). However, it is common in interventions for OAs for power to be used to mean both mean power output and peak (i.e., maximum) power output (Alcazar et al., 2018), presenting an additional opportunity for misinterpretation. Peak power output is an instantaneous value representing the point of maximum power output and therefore, the highest rate of work done. However, as with peak RFD, peak power provides little insight into the application of force (e.g., rate or magnitude) either side of that point that is required to successfully perform dynamic tasks. Therefore, its suitability to predict performance in functional tasks or to inform training prescriptions is likely to be limited.

As previously discussed by (Cronin and Sleivert, 2005), it is possible that the value of peak power output for prediction of performance may have been overestimated through a lack of consideration for other strength qualities such as RFD and peak force or the misuse of power to describe such qualities. Data presented by Zijlstra et al. (2010) suggest that peak power during STS did not coincide with peak force nor peak acceleration and in fact occurred when both force and acceleration were declining. Thus, it is questionable whether values of peak power would provide worthwhile information about the physiological determinants of successful ADL performance or whether training to improve peak power would translate to improvements.

When communicating with athletes or the general public, the terms ‘power’ and ‘powerful’ may be more readily understood and thus more effective than asking someone to be ‘impulsive’. However, when undertaking scientific analysis and communicating results between researchers and practitioners, the terminology used should be clearly and unambiguously defined.

3.4 Explosive Strength

Explosive strength is a term that has been used to describe each of the aforementioned terms/outcome variables related to rapid force production but most commonly in reference to RFD or power (Ramírez-Villada et al., 2019, Edholm et al., 2017, Hakkinen et al., 1998). However, ‘explosive strength’ has developed as a colloquial term and does not have a unit of measurement in the SI system. In the same way that ‘power’ developed as a colloquial term to describe one’s *ability* to perform impulsive actions in place of the direct measurement of impulse (N-s), explosive strength has been used to describe an individual’s *ability* to increase force rapidly (Balshaw et al., 2022, Aagaard et al., 2002) in place of the outcome variable that directly quantifies how rapidly force is increased: RFD ($N{\cdot}s^{-1}$). As with ‘power’, the use of explosive strength in this way (lacking a scientific definition and SI unit) becomes problematic if its interpretation is varied. For example, explosive strength has been quantified with measurements of peak power output, time to peak power, and isometric RFD (Edholm et al., 2017) as well as jump height and jump mean power output (Hakkinen et al., 1998). The continued use of one term to describe an array of outcome variables that are interrelated but not interchangeable makes it difficult to compare RT intervention studies and the efficacy of those interventions on a given performance outcome. Explosive strength has been defined by some as defined as RFD over the complete time period to reach maximum force (Cronin and Sleivert, 2005). However, this definition has not been widely adopted and considering many ADLs do not require maximal force expression (Alexander *et al.*, 1997), the usefulness of this measurement to provide insight into their performance may be limited. Rather, a more useful definition could be the RFD over the time period required to reach peak force in the particular movement being studied. In addition, as mentioned in the discussion of power, explosive strength or being explosive, may be more readily understood by the general public over instructions to be ‘impulsive’ or to ‘maximise your RFD’ and so, may be a preferred choice for practitioners.

An overview of key terms is provided in Table 3.1.

Table 3.1 - Overview of key terms used to describe rapid force production.

Term	SI Unit	Definition	Function in RT interventions for OAs/ADLs
RFD	Newtons per second ($N \cdot s^{-1}$)	How quickly force is increasing	To measure the effectiveness of interventions aimed at improving activities performed in short time frames
			As an indicator of neural drive/motor unit recruitment ability
Impulse	Newton-seconds ($N \cdot s$)	The total force applied considering both magnitude and duration of force	To measure an individual's total force production / the effectiveness of an intervention on total force production
			To understand an individual's ability to produce force in relation to the force required to perform an ADL
			Visual representation of impulse (force-time curve) can be used to identify changes in the different elements of force production (RFD, peak/avg. force or duration) following an intervention
Power	Watts (W)	The rate of performing work	Potential use to communicate with participants
Explosive Strength	None	Unclear	Potential use to communicate with participants

3.5 The Terminology Used to Describe Resistance Training with Maximal Intentional Velocity.

The terminology used to describe training types aimed at developing rapid force production are also numerous and lack clear definitions. This makes comparisons between studies difficult and may lead to misinterpretation of research findings or ineffective practice. For example, power training, explosive, high-speed, high-velocity and more recently maximal-intent RT are all used synonymously to describe RT involving muscle actions performed with maximum intentional velocity (de Vos et al., 2005, Richardson et al., 2019, Sayers and Gibson, 2010, Pearson et al., 2022). However, these studies vary significantly in training variables (e.g., exercises, load, sets, repetitions, movement velocity), meaning the application of force will also be wide-ranging. This can be problematic for both research and practice as this may lead to the adoption of sub-optimal training types that do not meet desired physiological adaptations.

For example, systematic reviews and meta-analyses aiming to evaluate the effectiveness of 'power training' have used varying and ambiguous definitions to inform the study selection criteria. In one systematic review, studies were deemed eligible if the author's had named the intervention 'power training' or was an intervention aimed at muscle power, movement speed or RFD (El Hadouchi et al., 2022). Elsewhere, power training was simply characterised as "fast concentric velocity" (Orssatto et al., 2020) and in a meta-analysis was defined as training with moderate resistance and as fast as possible (Tschopp et al., 2011). Such ambiguity in the description and definitions of RT means that the studies included in these reviews are likely to involve considerably different training stimuli making it difficult to make meaningful conclusions to inform future research or practice. Similarly, the term explosive RT has been applied in a multitude of ways perhaps due to the absence of a specific definition or desired physiological adaptations. For example, A position statement from the National Strength and Conditioning Association referred to studies that had shown superior functional enhancements following ‘explosive’ RT when compared to RT performed at slower velocities (Fragala et al., 2019). Yet, the titles of the referenced studies contained the terms high-velocity, high-speed or power training which illustrates the use of explosive RT as a general term with no clear definition.

Studies that use ‘high-velocity RT’ have included training where there is an intention to reach a high velocity regardless of the actual velocity achieved. In this instance, any load could be used including relatively high loads such as 80% of 1RM (Bernat et al., 2019). However, ‘high-velocity RT’ has also involved relatively light loads which are then assumed to result in high-velocity movements (Richardson et al., 2019). These two approaches share the intention to produce force as rapidly as possible but would ultimately result in distinct force expressions and thus different adaptations. In addition, velocity is not often measured and therefore, calls into question how it is deemed to be high or not. Similarly, ‘high-speed’ RT has been used to describe training where the intention was to achieve high-speed, however speed was neither controlled nor measured (Ramirez-Campillo et al., 2014). Interestingly, the rationale provided by Ramirez-Campillo et al. (2014) for the prescribed load in the ‘high-speed’ condition was based on evidence for optimal power output yet was not referred to as ‘power training’. Elsewhere, training called ‘high-speed power training’ was described in the methods as performed “at high velocity during the concentric phase of each repetition (“as fast as possible”)” (Sayers and Gibson, 2010).

This highlights an additional problem regarding the conflation of speed and velocity. Whilst both terms relate to how fast a body/object is moving, velocity is a vector quantity meaning it denotes both magnitude and direction whereas speed indicates magnitude only and thus, tend to be appropriate for distinct applications (Winter and Fowler, 2009). However, it seems probable that when used to describe a mode of RT, rather than as an outcome variable that ‘high-velocity’, ‘high-speed’ as well as ‘power’ and ‘explosive’ RT refer to a shared objective: the intent to move as fast as possible. This was conveyed by de Vos et al. (2005) who stated that “Explosive or high-velocity resistance training is a form of power training, the intent of which is to perform maximal velocity concentric muscle contractions against an external resistance…” (p. 638). Recently, Pearson et al. (2022, page 2) used the term maximal-intent RT (MIRT) which they defined as “the purposeful intention of the individual to attempt to move as fast as possible, regardless of the imposed resistance during RT…”. This definition aligns with the words of De Vos and colleagues in capturing the shared intention of ‘power’, ‘explosive’, ‘high-velocity’, and ‘high-speed’ RT without referring to known mechanical concepts and terminology, and therefore eliminating issues of misapplication and confusion. For further clarity, the term maximal-intentional velocity resistance training (MIV-RT) could be used alongside a clear definition to make explicit that the focus of this training type is to perform every repetition with maximal intentional velocity. This would clearly distinguish MIV-RT from other RT types, providing the opportunity for accurate evaluations of its efficacy and comparisons with other training types.

However, it is recognised that MIV-RT could involve a wide array of physiological demands through the choice of training variables such as load or exercise selection. Therefore, it is essential that interventions are reported clearly and in full so that the reader understands the specific physiological demands of the training and how that might lead to improvements in the desired outcome.

To ensure accurate interpretation of research studies, training terminology should be selected carefully to best reflect the training and clearly defined. Moreover, it should be clear to the reader how the training approach will transfer to the desired performance outcome in terms of specific force expression and the related physiological demands.

3.6 Summary

Understanding and consistency in the application of terminology used to describe rapid force production is important for the design and evaluation of RT interventions to effectively target the desired physiological outcomes. Therefore, applying the terms used to describe the ability to produce force rapidly according to their respective mechanical definitions and not interchangeably will enable the effective communication of research findings and reduce the possibility of misinterpretation. Moreover, a greater understanding and consideration of these terms will aid researchers and practitioners to focus on the variables that are most relevant to the desired performance outcomes of RT interventions. Finally, accurate and detailed descriptions of measurement variables and RT modalities will support the development of efficacious and effective RT interventions for OAs and the transfer of research to applied practice.

Chapter: 4 Specificity in Maximal-Intentional Velocity Resistance Training for Older Adults: A Systematic Review of Randomised Control Trials.

4.1 Introduction

The increasing number of interventions investigating MIV-RT has highlighted a diverse range of training variables being employed by researchers and practitioners (Chapter 2.4.1). However, limited discussion has been made about the potential effects of these variables on performance outcomes. Specifically, little attention has been given to the exercises selected by researchers, with some reviews failing to report exercises at all (Balachandran *et al.*, 2022; Guizelini et al., 2018; Lopez et al., 2022). However, the selection of exercises is influential to the specificity of a RT programme, a fundamental principle of effective RT interventions (Chapter 2.3.4).

Specificity has been briefly mentioned in discussions of ADL outcomes following MIV-RT in OAs (Rice & Keogh, 2009; Hazell et al., 2007). For instance, Tschopp, Sattelmayer and Hilfiker (2011) suggested that the selection of ADL outcomes included in their meta-analysis, comparing MIV-RT with TRT (sustained concentric actions), might have influenced the results. This suggests that one training type may have appeared more efficacious due to greater specificity to the included outcomes. This has important implications on the interpretation of their findings and highlights the importance of critically evaluating the nuances of RT interventions in respect to the observed outcomes. This is supported by a more recent review and network meta-analysis that found that MIV-RT was most effective for improving fast walking speed, TUG, and 5STS, while conventional RT was most effective for 30s-STS and the 6MWT, highlighting the need to tailor interventions to the desired outcomes (Lopez *et al.*, 2022). Yet, despite these observations, there has been a lack of systematic examination and discussion regarding the presence of specificity in studies investigating MIV-RT for OAs.

In the 1990s, the concept of dynamic correspondence was introduced as a set of five criteria for evaluating the mechanical specificity of an exercise to a particular sporting skill or outcome (Verkhoshansky and Siff, 2009). Mechanical specificity suggests that the closer exercises are to the performance outcomes in terms of kinetic and kinematic variables (e.g., direction and rate of force application, muscle actions, joint motion) the greater the likelihood of improvement and transfer of training effects (Thepaut-Mathieu, Van Hoecke and Maton, 1988; Wilson, Murphy and Walshe, 1996; Stone, Stone and Sands, 2007b). Thus, in MIV-RT interventions for OAs, the degree of improvement in ADL outcomes may be influenced by the kinetic and kinematic specificity of the exercises employed, making it important to consider in both the design and interpretation of interventions.

The five criteria of dynamic correspondence initially proposed by Verkhoshansky and Siff (2009). Are presented in table 4.1.

Table 4.1 - The five criteria of dynamic correspondence initially proposed by Verkhoshansky and Siff (2009).

The amplitude and direction of movement	The joint angular range (i.e., ROM), joint action (e.g., flexion, extension, abduction) and the direction of force relative to the individual.
The accentuated/most important region of force production	The joint angles at which maximum force production occurs in a given exercise.
The dynamics of the effort	The application of overload (e.g., peak force, volume, time-under-tension, load, RFD).
The rate and time of force production	Overload specifically related to the RFD required for the desired outcome.
The regime of muscular work	The nature of the muscular task as a whole e.g. concentric action, isometric action or transition from rapid concentric to isometric

Verkhoshansky and Siff recommend that the design of RT for specific outcomes should be chosen based on these criteria and that RT based purely on training variables (e.g, loads, sets, reps) is inadequate for producing outcome specific adaptations. While recognised by the strength and conditioning community as an approach to select training exercises that are mechanically similar to sporting movements of interest (Cleather, Goodwin and Bull, 2013; Suarez *et al.*, 2019; Laakso and Schuster, 2021) dynamic correspondence has yet to be applied to interventions concerning OAs and movements of importance such as ADLs. Exploring dynamic correspondence within existing MIV-RT interventions could further enhance our understanding of the effectiveness of this training modality and highlight potential opportunities for improvements in the design of future interventions.

Accurate evaluation of dynamic correspondence requires explicit reporting of the training programme. For example, Verkhoshansky and Siff (2009) recommend that to fulfil the criteria of correspondence for 'amplitude and direction of movement,' the starting position and posture of the individual as well as the direction of force relative to the individual should match the desired performance outcome, as it determines which muscles are involved. Therefore, to assess this criterion, it is crucial to know the range of motion (ROM) of each exercise, which could be achieved through detailed reporting of actual ROM, the start and end positions of movements, or through photographs. Additionally, the type and set up of equipment influences ROM meaning it should be reported in detail. For instance, leg press machines can be used in various positions (e.g., seated, incline, supine) and may be adjusted, affecting body position, joint angles, relationships across the kinetic chain and muscle activation (Escamilla *et al.*, 2001; Da Silva *et al.*, 2008). Therefore, reports that lack these details hinder the assessment of mechanical specificity, making it difficult to accurately interpret the effectiveness of an intervention and prevent accurate replication in practice.

To encourage standardised reporting of exercise interventions, an international panel of experts developed the Consensus on Exercise Reporting Template (CERT) (Slade, Dionne, Underwood, Buchbinder, *et al.*, 2016). The CERT is a 16-item checklist of items deemed necessary to fully describe an exercise intervention to enable accurate interpretation of the results and replicability (Slade, Dionne, Underwood and Buchbinder, 2016). This includes details of the exercise equipment, provider, delivery, location, dosage, tailoring, and compliance of an intervention. The CERT has been used to evaluate the reporting quality of a variety of RT interventions (Christensen *et al.*, 2020; Burton and McCormack, 2022; MacPherson *et al.*, 2023). However, the reporting quality of CERT items remains low, as noted by Hansford et al. (2022), who conducted an overview of systematic reviews investigating the reporting quality of exercise interventions for various health conditions and found the average reporting of CERT items was 24%. Recently, the CERT was used to assess the reporting quality of nineteen studies that directly compared MIV-RT and TRT for OAs (Morrison et al., 2023). These authors found that on average, the studies reported 53% of the CERT items. Items related to the qualifications and experience of exercise deliverers, the supervision provided during the intervention, and study adherence and fidelity were among the least reported. Only studies that involved both MIV-RT and TRT groups were included in this analysis and thus, the reporting quality of studies comparing MIV-RT interventions with non-exercising controls were not assessed. Consequently, some MIV-RT studies might have been missed in this analysis.

In conjunction with the CERT, several studies have used the Toigo and Boutellier (2006) framework for exercise mechanobiological description (TBF) to assess the reporting of more specific training variables (Holden *et al.*, 2018; Christensen *et al.*, 2020; Vlok *et al.*, 2022). Toigo and Boutellier identified 13 descriptors of RT (i.e., training variables) that determine effects on skeletal muscle including the time and distribution of muscle actions per repetition, repetition duration, range of motion, time under tension and anatomical definition of exercises. While the reporting of TBF descriptors has been consistently inadequate among exercise interventions for various populations (Holden *et al.*, 2018; Christensen *et al.*, 2020; Vlok *et al.*, 2022), this has yet to be evaluated in MIV-RT interventions for OAs.

Therefore, this study aims to systematically review the current literature involving MIV-RT interventions for OAs and evaluate the degree of mechanical specificity between training exercises and outcome measurements. A secondary aim is to examine the completeness of intervention reporting.

4.2 Methods

This systematic review is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 guidelines (Page *et al.*, 2021) and was pre-registered with the International Prospective Register of Systematic Reviews (PROSPERO), ID number: CRD42022354132.

4.2.1 Literature Search

The following electronic databases were searched from inception to 6 July 2022: CENTRAL (Wiley), PubMed (NCBI), Scopus (Elsevier), SPORTDiscus (EBSCO) and Web of Science (Clarivate). Additionally, a manual search was conducted of the reference lists of eligible articles and any relevant systematic reviews. The search had no date restriction but was limited to full-text articles published in the English language.

The search terms were grouped into three facets and applied using the Boolean operators 'AND' and 'OR': 1) terms to describe OAs (Older adults, senior, seniors, older, geriatric, geriatrics, elderly, masters, aging, ageing), 2) terms to describe explosive exercise (Explosive, ballistic, fast velocity, high velocity, high speed, power, plyometric, plyometrics, jumping, jump, jumps, hopping, hop, hops, Olympic), 3) terms to describe RT (Weight training, weightlifting, strength training, strength exercise, resistance training, resistance exercise, exercise, training, lifting). The search strategy was developed in consultation with an information scientist and all searches were conducted by the lead author (CK). Full search details are depicted in Appendix. A.

Search results were downloaded to RefWorks (ProQuest), and duplicates removed automatically and then checked manually (CK). The remaining titles and abstracts were exported into the Rayaan web-based platform (Ouzzani *et al.*, 2016) and independently screened by two reviewers (CK & TMW). Any disagreements between reviewers were resolved through discussion. For articles that were deemed suitable by both reviewers, full texts were obtained by the lead author (CK) and independently screened by two reviewers (CK & MJ) using Rayaan. Disagreements were resolved through discussion and consultation with a third reviewer (TMW). Additionally, reference lists of included studies and relevant systematic reviews were manually searched to identify potentially relevant studies (CK). Where necessary, study authors were contacted to clarify study eligibility.

4.2.2 Inclusion and Exclusion Criteria

Inclusion criteria followed the Population, Intervention, Comparison, Outcome and Study design (PICOS) approach as suggested by Amir-Behghadami and Janati (2020).

Population: Men and women aged 60 years and older (mean age) with any health conditions as well as apparently healthy individuals (e.g., reported as free from illness or injury). Studies that included participants <60 years were included providing data for participants aged 60 years and older could be isolated and extracted from the full data set. Studies were excluded if participants were living in care homes, receiving in-patient hospital care or taking supplements or medications that may affect muscle strength or size e.g., creatine, whey protein, Omega-3 fish oils.

Intervention: MIV-RT – RT (exercise requiring muscles to work against an opposing force) where the concentric phase of a movement is performed with maximal intended velocity i.e., as quickly as possible. To be included, training must have involved participants being instructed to perform the concentric phase "as fast as possible" or similar instructions that clearly indicated that exercises involved maximal intended velocity. Interventions involved a minimum of one session per week and did not involve other training modalities (i.e., multimodal/concurrent training) such as hypertrophy or aerobic training or any form of dietary intervention. Water-based training was excluded but stretching or mobility work was permitted if this was to warm up or cool down. Interventions of any duration, intensity, load, sets, repetitions, rest periods, type and number of exercises and equipment were included.

Comparator: Control group that participated in pre- and post-intervention testing but did not engage in any form of RT for the duration of the study, receive diet, supplementation or medical treatment that may affect muscle strength or size e.g., creatine, whey protein, Omega-3 fish oils or receiving exercise treatment or rehabilitation that is not typically considered RT, but could influence muscular adaptation or functional performance e.g., yoga, stretching, water aerobics, balance training.

Outcomes: Included a pre-and post-intervention measurement of maximum strength (e.g., maximal voluntary torque, 1RM), explosive strength/power (e.g., maximum RFD) or physical function/activities of daily living (e.g., sit-to-stand, TUG, stair climb, 6MWT). Following the title/abstract screening stage it was observed that ADLs outcomes were most commonly used across studies and were deemed most relevant to practitioners. Subsequently, the inclusion criteria were modified to only include studies with ADLs for at least one outcome.

Study Design: Randomised Control Trials.

4.2.3 Data Extraction

Population and general study characteristics were extracted by the lead reviewer (CK). Population characteristics included sample size (n), age (years), sex, training, health, and mobility status of the training groups from included studies. Details of ADLs outcomes were also extracted which included whether the testing methods were described in detail (e.g., chair height for STS test). Where multiple similar ADLs were measured in the same study for example, usual-pace, standardised and maximal gait speed, higher intensity tests (e.g., maximal gait speed) were chosen over normal-paced values (e.g., usual-pace gait). Given that the primary focus of this review was not the efficacy or effectiveness of the interventions, detailed outcome data was not extracted, and therefore a meta-analysis was not conducted.

Training prescriptions and general intervention details were extracted by two independent reviewers (CK & DB), according to the CERT (Slade, Dionne, Underwood and Buchbinder, 2016) and TBF (Toigo and Boutellier, 2006). The CERT is described as a 16-item checklist (Slade, Dionne, Underwood and Buchbinder, 2016); however, three items (7, 14 & 16) contain sub-items resulting in 19 total items. Slade et al. (2016) published an explanation and elaboration statement to enhance users' understanding of the CERT by providing the definition and rationale for each item along with examples of good reporting. However, it was deemed that the guidance in the explanation and elaboration statement allowed a degree of interpretation of the CERT items, therefore, the fulfilment requirements of each item were agreed by two reviewers prior to data extraction (CK & DB) (Appendix. B). Two items from the CERT were not used (9 & 10) as the inclusion criteria used during study screening made these non-applicable. The 13-items of the TBF and the requirements to fulfil reporting of each item as agreed by two reviewers (CK & DB) are shown in Appendix. C. For items on the CERT and TBF to be considered complete they must have been explicitly reported and described to an extent which would allow them to be replicated/interpreted.

All data were extracted from the included studies using a standardised excel spreadsheet that was developed and approved by all authors. For each CERT and TBF item, the reviewers extracted any relevant data, decided whether the report fulfilled the requirements for the item (Y/N) and provided the reason for this decision (e.g., criterion met or insufficient detail). Where reports referred to previously published protocols or articles then the relevant information was extracted from these sources. Following independent data extraction, any disagreements between reviewers were resolved through discussion. A blank version of the excel spreadsheet can be found in Appendix. D. If an included study involved multiple training groups that met the inclusion criteria, then data was extracted separately for each intervention. Since one of the purposes of this review was to assess the completeness of reporting, corresponding authors were not contacted for omissions on methods or data.

4.2.4 Methodological Quality Assessment

Methodological quality was assessed using the Physiotherapy Evidence Database (PEDro). The PEDro scale comprises 11 items producing a total score of 0-10 (item 1 is not scored) with more points corresponding to higher quality (Maher *et al.*, 2003). Ratings were extracted from the PEDro database, which have been populated by trained individuals ('Frequently asked questions - PEDro', 2009). To ensure the quality of ratings on the database, PEDro labels a rating 'confirmed' when it has been rated twice with any disagreements resolved via a third rater ('Frequently asked questions - PEDro', 2009). All the ratings obtained from the PEDro database for this review were labelled as 'confirmed'. One study was not available on the PEDro database, and so, the lead reviewer (CK) rated the study. A detailed description of the 11 items can be found elsewhere ('PEDro scale - PEDro', 2016). Corresponding authors were not contacted to obtain information on study quality.

4.2.5 Data Analysis

The percentage of interventions that adequately reported each exercise descriptor was calculated and the frequency of exercises, equipment and outcome measurements across all interventions were tabulated. The extracted data was then used to evaluate the degree of mechanical specificity between RT prescriptions and each of their corresponding performance outcomes using the five criteria of dynamic correspondence established by Verkhoshansky and Siff (2009): the amplitude and direction of movement, the accentuated region of force production, the dynamics of the effort, the rate and time of maximum force production and the regime of muscular work. For each performance outcome per each criterion, a rating of 'Yes', 'No', 'Partially' or 'Unclear' was recorded based on predetermined fulfilment requirements (Appendix. E). The fulfilment requirements were developed based on definitions of each criterion established by Verkhoshansky and Siff (2009). Briefly, for a criterion to be rated as ‘Yes’, sufficient detail must have been provided about the intervention and outcome measurement (e.g., ROM was reported for both exercises and outcome), and it could be determined that they corresponded in all aspects of the criterion in question. For a criterion to be rated as ‘No’, sufficient detail must have been provided about the intervention and outcome measurement, and it could be determined that they did not correspond in any aspect of the criterion in question. A rating of ‘Partially’ indicated correspondence on some aspects of the criterion, but other aspects did not correspond or were unclear. In cases where reports did not include the necessary information to enable evaluation of correspondence (e.g., ROM could not be determined for exercises and/or outcome), it was recorded as ‘unclear’. The evaluation of dynamic correspondence was completed by the lead reviewer (CK). The proportion of ‘yes’, ‘no’ ‘partly’ and ‘unclear’ ratings for each criterion were synthesised and presented visually.

4.3 Results

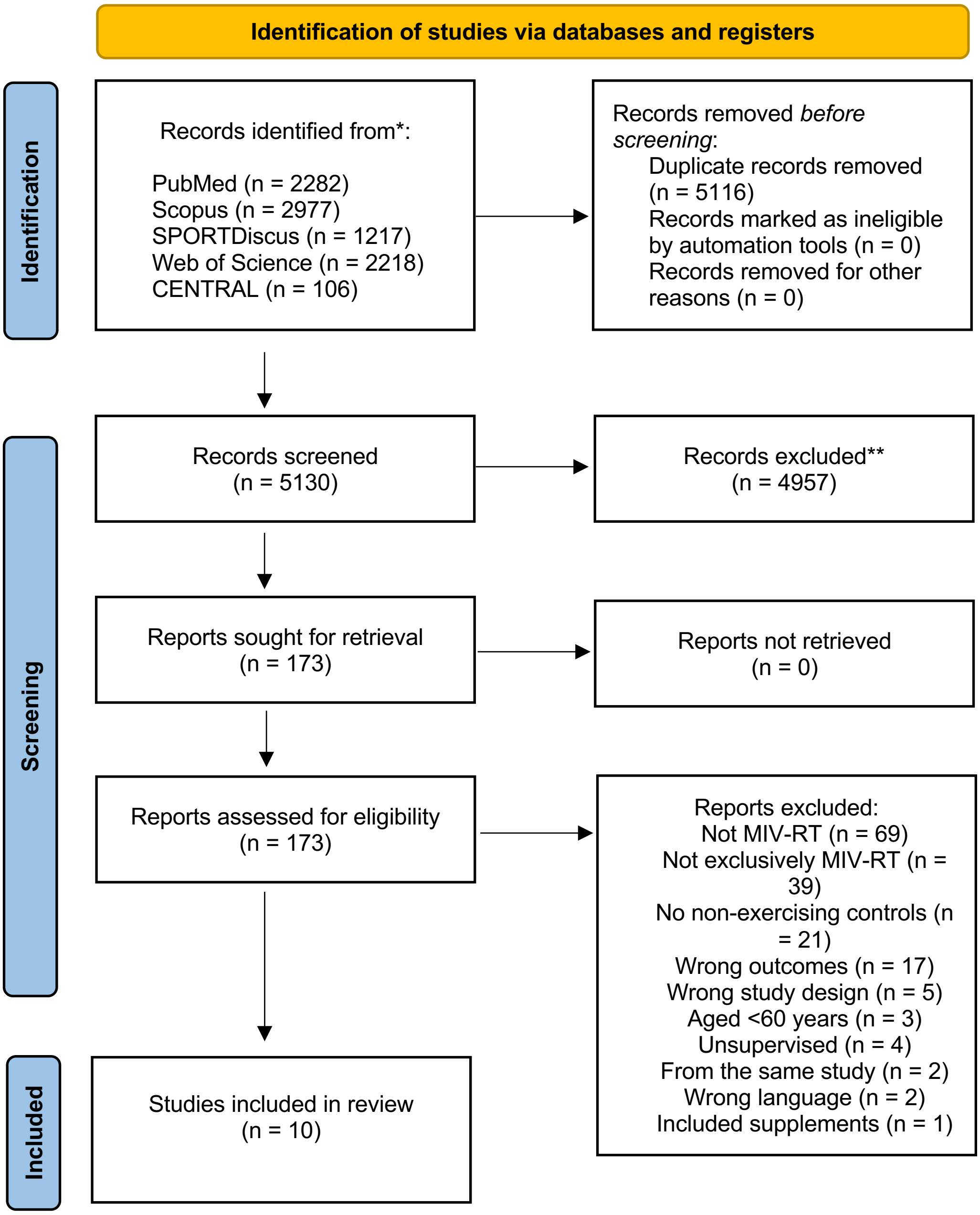


Figure 4.1 - Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 flow chart of literature search and study selection. Abbreviations: MIV-RT, Maximal-Intent Resistance Training. A total of 10 studies met the inclusion criteria and were included in the review.

4.3.1 Methodological Quality Assessment

Methodological quality ranged from 3 to 7 with a mean score of 4.9 out of a possible 10. According to PEDro, a score of 8/10 is considered optimal for studies involving exercise interventions ('Summary of measurement properties of the PEDro scale - PEDro', 2019). All studies reported point estimates and measurements of variability and the criteria for random allocation. Baseline comparability and between group comparisons were met by three studies. Only one study met the intention to treat analysis criteria and two studies had concealment of allocation. The methodological assessment of each study can be found in Appendix. F.

4.3.2 Study Characteristics

Two studies involved two training groups that met the inclusion criteria but undertook different RT prescriptions. Therefore, a total of 12 training interventions were deemed eligible for review (Table 4.2). Hereafter, this review will refer to interventions as opposed to studies. The publication year ranged from 2012 to 2022 and sample sizes from 9 to 23 participants. All participants were described as free from disease or without mobility limitations. In addition, all participants had no recent RT experience except for two groups that had completed progressive RT twice a week for 6 weeks prior to the period included in the current review.

The number of prescribed exercises ranged from 1 to 11 (Table 4.2). Lower body exercises were prescribed in all 12 interventions with 5 of these interventions also prescribing upper body exercises. The most prescribed exercise across all interventions was some form of leg press (e.g., supine/horizontal), included in 8/12 interventions. Leg/knee extension and leg/knee flexion were each included in 7/12 interventions. Single-joint and multi-joint exercises were included 30 and 27 times respectively across all interventions. The nature of two exercises (flexor chair, curl-ups) were unclear and so were omitted from review.

Six different types of equipment were reported (Table 4.2). Four interventions used resistance machines of which one used pneumatic resistance. Additionally, one intervention involved 'abductor and adductor machines' as exercises but did not report the specific equipment used. Two interventions involved isoinertial resistance and two used body weight as resistance. The type of equipment used in three interventions was unclear.

A total of 25 outcome measurements were collected across all interventions with the number of outcomes per intervention ranging from 1-3. Outcomes involving sit-to-stand movements were measured in 10/12 interventions and the most commonly measured outcome was the 30-STS which was included in 7/12 interventions.

Table 4.2 - Study characteristics and reporting scores

Study	Sample size	Health status	Training status	Exercises	Equipment	ADL outcome measures	CERT - 17	TBF - 13	PEDro - 10
Beijersbergen *et al.* (2017)	15	Without mobility limitations	Not participating other exercise (from protocol)	Knee extension, knee flexion, supine leg press, and ankle press	Cybex Eagle NC line weight lifting equipment	Stair ascent and descent power ($W \cdot kg^{-1}$) 6MWT ($m \cdot s^{-1}$), fast 6.5-metre gait velocity ($m \cdot s^{-1}$)	6	4	3
Correa *et al.* (2012) (Machine group)	13	Free from severe endocrine, metabolic, and neuromuscular diseases	Completed progressive RT twice a week for 6 weeks prior to study period	Leg press, knee extension, knee flexion	Not Reported	30s-STS (number of repetitions)	3	3	4
Correa *et al.* (2012) (Machine & Box group)	14	Free from severe endocrine, metabolic, and neuromuscular diseases	Completed progressive RT twice a week for 6 weeks prior to study period	Lateral box jump, knee extension, knee flexion	A box with a predefined height of either 10, 20 or 30 cm	30s-STS (number of repetitions)	3	4	4

Cherup *et al.* (2018)	9	Free from uncontrolled neuromuscular, orthopedic, or cardiovascular disease or significant cognitive impairment	No regular structured physical activity within past 3 months	Chest press, leg press, latissimus dorsi pull-down, hip adduction, overhead press, leg curl, seated row, hip abduction, elbow extension, plantarflexion, elbow flexion	Computerized pneumatic resistance exercise machines (Keiser A420, Keiser Corporation, Fresno, CA, USA)	Mean power during one STS (W)	6	7	4
Dobbs, Simonson and Conger (2018)	23	Free from uncontrolled diabetes or hypertension, previous cardiac event, orthopedic joint replacement surgery, use of any type of mobility aid, or any physical impairment that would limit mobility	No RT during previous 6 months	Squat jumps, single leg bounding, explosive skipping	AlterG treadmill body mass supported treadmill	5STS (time), Stair Climb (time)	8	5	5

Edholm, Strandberg and Kadi (2017)	17	Free from muskuloskeletal problems, cardiovascular, pulmonary, metabolic, rheumatologic or psychiatric disease. No unexplained weight loss in previous 12 months or use of medication. Able to walk.	Recreationally active. No history of structured RT	Knee extension, leg press, squat, seated row, pull-down	Not Reported	5STS (time), TUG (time)	3	4	4
Filho *et al.* (2022)	18	Physically independent in ADLs, free from musculoskeletal limitations that contraindicated the practice of programmed exercises. No clinical diagnosis of uncontrolled arterial hypertension or diabetes. No use of ergogenic resources or hormone replacement	Not participating in any systematic physical activity and no previous RT experience.	Horizontal leg press, low row, flexor chair, articulated bench press, plantar flexion curl-ups	Not Reported	30s-STS (repetitions), 8ftUG (time), 6MWT (distance)	5	5	5

Lopes *et al.* (2016)	12	Free of cardio-vascular problems, osteoarthritis, severe visual impairment, neurological disease, pulmonary disease, uncontrolled hyper-tension, hip fracture	No structured exercise in previous 6 months	Horizontal leg press, bilateral knee extension, bilateral knee flexion, plantarflexion in the step, abductor and adductor machines	Not Reported	30s-STS (repetitions), TUG (time), 6MWT (distance)	6	6	4
Richardson *et al.* (2019) (Training 1/week)	10	Free from cognitive impairment, acute or terminal illness, myocardial infarction, symptomatic coronary artery disease, congestive heart failure, neuromuscular disease, or uncontrolled hypertension (>150/90 mmHg). No upper or lower extremity fracture in the previous six months	No RT in previous 6 months	Leg press, calf raise, leg extension, leg curl, seated row, chest press, tricep extension, bicep curl	Cybex exercise equipment (Cybex, Medway,MA, USA)	8ftUG (time), 30s-STS (repetitions), 6MWT (distance)	10	7	7

Richardson *et al.* (2019) (Training 2/week)	10	Free from cognitive impairment, acute or terminal illness, myocardial infarction, symptomatic coronary artery disease, congestive heart failure, neuromuscular disease, or uncontrolled hypertension (>150/90 mmHg). No upper or lower extremity fracture in the previous six months	No RT in previous 6 months	Leg press, calf raise, leg extension, leg curl, seated row, chest press, tricep extension, bicep curl	Cybex exercise equipment (Cybex, Medway,MA, USA)	8ftUG (time), 30s-STS (repetitions), 6MWT (distance)	10	7	7
(Sañudo *et al.*, 2019)	17	Free from cognitive or functional disorders that adversely impacts skeletal muscle function or manifests in a mobility disorder	No regular exercise for 12 months	Squats	Fly-wheel squat device (kBox 3; Exxentric AB TM, Bromma, Suecia	TUG (time)	6	6	6

(Sañudo, De Hoyo and McVeigh, 2022)	18	Free from self-reported conditions that would impact skeletal muscle function or mobility (e.g., severe rheumatoid or osteoarthritis and cardiac or respiratory conditions)	No regular exercise for 12 months	Squats	Fly-wheel squat device (kBox 3; Exxentric AB TM, Bromma, Suecia	30s-STS (repetitions), 5-metre walk ($m \cdot s^{-1}$)	6	6	7

4.3.3 Completeness of Reporting

Among the included interventions, complete reporting of CERT items ranged from 3-10, with an average of 6 items reported (for individual ratings see Appendix. G). Figure 4.2 depicts the percentage of studies/training groups that adequately reported each item. The items most often reported were ‘whether exercises are generic or tailored’ (100%), ‘how adherence is measured and reported’ (90%) and ‘the decision rule for determining the starting level’ (70%). Three items were not adequately reported in any of the studies. This included ‘whether the exercises were performed individually or in a group’, ‘detailed description of each exercise to enable replication’ and ‘detailed description of the exercise intervention’. For the latter two items, the most common reasons for incomplete reporting were due to a lack of information regarding exercise equipment or the start or end positions of exercises (see Appendix. G).

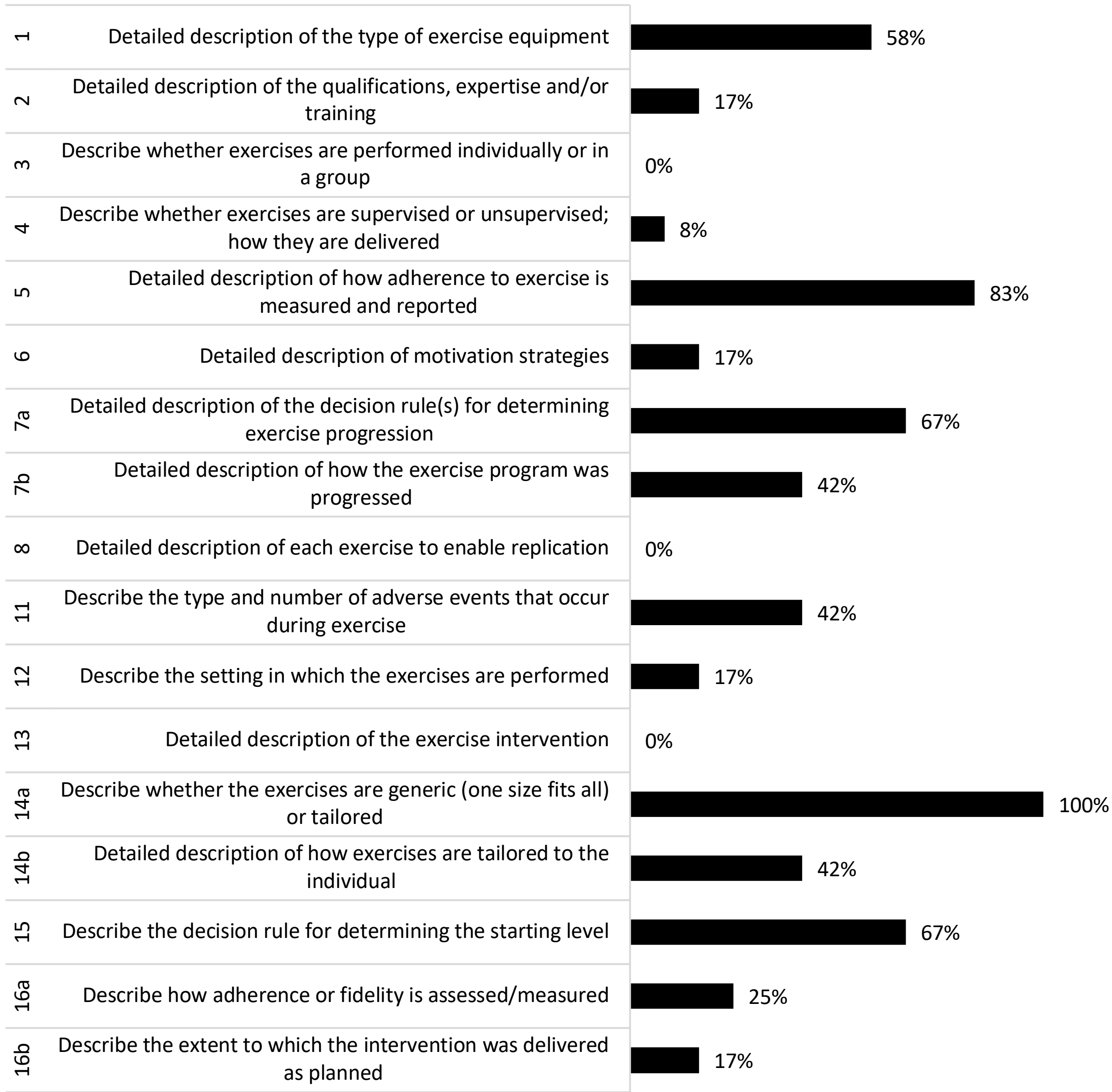


Figure 4.2 - Percentage of interventions with complete reporting of consensus on exercise reporting template items in maximal-intentional velocity resistance training randomised control trials for older adults.

Complete reporting of TBF items ranged from 3-7 with an average of 5/13 items reported (Figure 4.3). Intervention duration was reported for 100% of interventions (12/12) and the number of sets and exercise sessions per day/week were reported for 10/12 (83%). Time under tension ([s] or [min]) was not adequately reported for any interventions and rest in-between reps, range of motion, anatomical definition of the exercise and recovery time in-between sessions which were each reported for 1/12 interventions (8%). A minimum recovery time in-between sessions were reported for an additional 5 interventions; however, this did not meet the requirement of explicit reporting that would enable replication. Similarly, load magnitude and number of repetitions were adequately reported for only 6/12 interventions due to ambiguous or unclear training prescriptions. The content of the TBF items for each intervention is shown in Appendix. H.

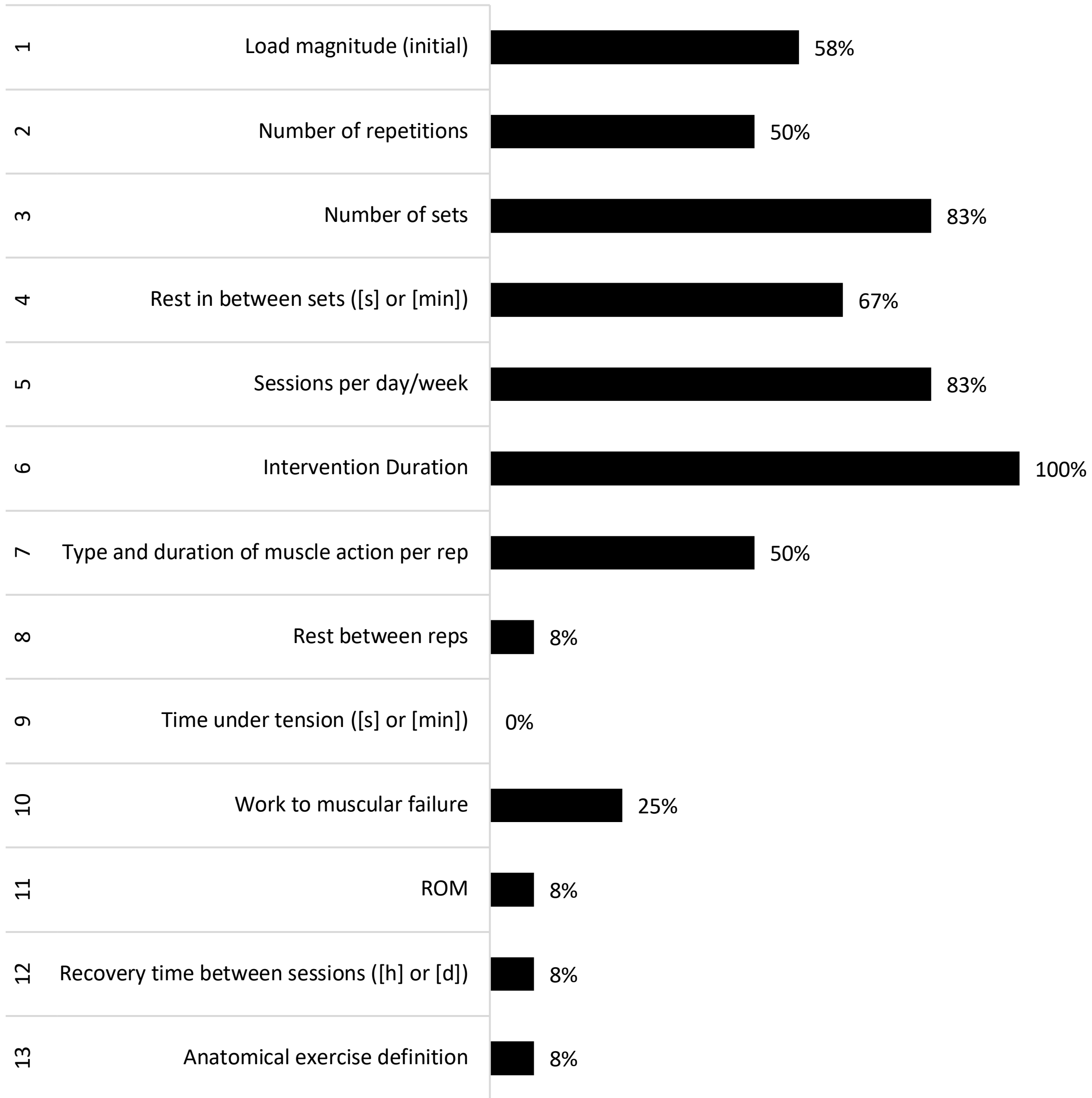


Figure 4.3 - Percentage of interventions with complete reporting of Toigo and Boutellier framework items in maximal-intentional velocity resistance training randomised control trials for older adults. Abbreviations: ROM, Range of motion.

4.3.4 Mechanical Specificity

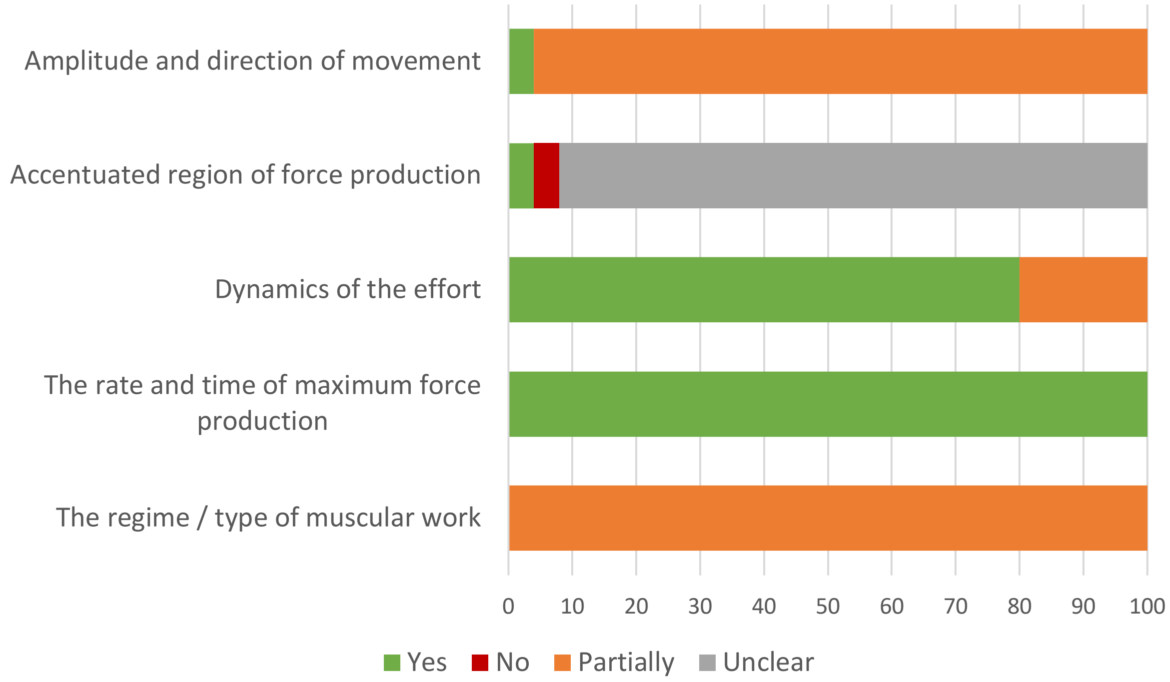


Figure 4.4 - Mechanical specificity in maximal-intentional velocity resistance training randomised control trials for older adults.

The percentage of interventions/outcomes that did or did not present mechanical specificity are shown in figure 4.4. For the criterion of ‘amplitude and direction of movement’, one intervention/outcome met the criteria entirely and 24 interventions/outcomes partially met the criteria. For the criterion of ‘accentuated region of force production’, one intervention/outcome met the criteria while one did not, and 23 interventions/outcomes were unclear. The criterion of ‘dynamics of the effort’ was met by 20 interventions/outcomes and was partially met for the remaining 5. ‘The rate and time of maximum force production’ was met by all interventions/outcome measurements. All 25 interventions/outcomes partially met the criteria for ‘the regime of muscular work’.

4.4 Discussion

This systematic review aimed to evaluate the degree of mechanical specificity between RT programmes and outcome measurements in MIV-RT interventions for OAs. A secondary outcome was to examine the completeness of intervention reporting. The key finding of this review is that interventions and outcomes corresponded well on some criteria such as 'dynamics of the effort' and 'the rate and time of maximum force production' and showed partial correspondence with others including 'amplitude and direction of movement' and 'the regime of muscular work'. This highlights that greater emphasis could be placed on the specificity of MIV-RT interventions for OAs to optimise the specificity of training and thus increase the likelihood of the transfer of training effects (Thepaut-Mathieu, Van Hoecke and Maton, 1988; Wilson, Murphy and Walshe, 1996; Stone, Stone and Sands, 2007a). Critically, insufficient reporting among interventions hindered a comprehensive assessment of several criteria which was most notable for 'the accentuated region of force production'.

In this discussion, the secondary aim, which pertains to the completeness of reporting, is addressed first. This aim was discussed first because the degree of completeness in reporting directly affected the achievement of the primary aim, which was to evaluate mechanical specificity. Therefore, discussing them in this order is intended to improve their clarity and understanding.

4.4.1 Completeness of Reporting

Overall, the reporting of MIV-RT interventions in this review lacked sufficient information for readers to fully understand the exercise intervention or replicate it. For example, most interventions lacked detailed descriptions of the exercises used, which is demonstrated by an average of 5/10 items of the TBF fulfilled (See Appendix. H). While basic details such as the number of sets (TBF item 3), sessions per week (TBF item 5), and intervention duration (TBF item 6) were reported in most studies, certain items such as rest between reps, range of motion, and anatomical definition, were rarely reported (Figure 4.3). Similar findings have been observed in studies concerning interventions for patellofemoral pain and Achilles tendon rehabilitation (Holden *et al.*, 2018; Christensen *et al.*, 2020) highlighting an issue across disciplines. In addition, according to the fulfilment requirements applied in this review, time under tension was not adequately reported by any studies. While the eccentric portion of repetitions was often described, the concentric action was typically reported as "as fast as possible" without actual measurement. It has been reported that self-selected maximal velocity varies considerably in OAs (Sayers, Gibson and Bryan Mann, 2016) and therefore, a certain time under tension should not be assumed. Descriptors such as this provide readers with the information required to understand the physiological stimulus of the exercise and to assess mechanical specificity and so, requires consideration by researchers both in the design and reporting of MIV-RT interventions. Other critical information such as the number of repetitions and load magnitude were not consistently described across interventions (Figure 4.3). In many cases, the authors reported a range instead of a specific number, making the exact intervention stimulus unclear and impossible to replicate. For example, one intervention prescribed 2-3 sets of 8-12 reps, leading to a potential total range of 16-36 reps per exercise. In another intervention, participants were prescribed 8-12 reps of 75-85% 1RM, but the exact volume or intensity undertaken was not reported.

Many studies failed to report basic information about the training environment, such as whether the training was performed individually or in a group (and the number per group), which was reported by no studies (CERT item 3), the level of supervision provided (CERT item 4) or details about the exercise setting (CERT item 12) which were provided by just one and two studies respectively. Similarly, Morrison et al., (2023) who used the CERT to assess the reporting quality of studies that directly compared MIV-RT and TRT for OAs, found that the qualifications and experience of exercise deliverers, the supervision provided during the intervention were among the least reported. This information is particularly important for replication and for understanding the effectiveness of an intervention, as research has shown that exercising in age-matched group-based settings and higher levels of supervision is preferred and can result in greater muscle function outcomes as well as QoL and adherence in OAs (Cyarto, Brown and Marshall, 2006; Beauchamp *et al.*, 2007; Thiebaud, Funk and Abe, 2014; Ramírez-Campillo *et al.*, 2017).

The current findings suggest that researchers are reporting intended training prescriptions but not what actually happened. For example, while eight out of twelve interventions reported "rules for progression," only five reported the specifics of how progression was actually implemented. For instance, Dobbs et al. (2018) reported that participants began the intervention with a load of approximately 65% of their body mass and increased it by 1% once they could complete three sets of ten repetitions with an RPE of 7 to 8. Although this adequately describes the rules for progression, it fails to provide information on how many participants progressed, how often they progressed, and where progressions occurred during the intervention. As a result, it is difficult to determine the exact stimulus of the intervention and whether different participants received different stimuli. Interestingly, among the interventions that did report how participants progressed, four of them had generic (e.g., increased box height every 2 weeks) rather than individual progressions. Individualised progressions allow for the modification of the program to accommodate the specific needs of each participant, which may be particularly relevant to OAs who may have diverse needs. Therefore, despite the progression being reported, it remains unclear whether the intervention provided the same progressive stimulus for each participant and whether participants were able to adhere to the programme.

The limited reporting of adherence and fidelity assessment (CERT items 16a and 16b) further emphasises issues around the accurate interpretation of findings. Fidelity refers to how closely an intervention is implemented according to the planned protocol and allows readers to understand whether all participants received the same stimulus, enabling an accurate assessment of intervention effectiveness (Murphy and Gutman, 2012). Adherence to specific exercises, sets, and repetitions is critical, but other factors that affect outcomes and are essential to the desired outcomes of the intervention must also be considered. For instance, achieving maximal intentional velocity is a primary goal in MIV-RT interventions, yet no studies reported methods to monitor this such as changes in velocity within or between training sessions. A drop in velocity could indicate fatigue (Weakley *et al.*, 2021) and thus, provide information about the appropriateness of an intervention. Moreover, it could highlight variability in the effort being applied in each session. In athletic populations, the measurement of velocity has been used as a feedback tool to motivate athletes and ensure maximum intent was achieved in training sessions (Thompson *et al.*, 2022). Methods such as these could be applied more readily in studies of OAs as a tool to assess the adherence and fidelity of an intervention.

The aforementioned study from Morrison et al., (2023) which assessed the reporting quality of studies that directly compared MIV-RT and TRT for OAs also found that reporting of fidelity and adherence was limited. They reported that just 1/21 studies reported how fidelity or adherence were measured (CERT item 16a) and 50% of studies described the extent to which the intervention was delivered as planned (CERT item 16b). As both the current review and the one conducted by Morrison et al., (2023) included MIV-RT interventions for OAs, there was an overlap in some of the studies included which allowed comparisons in the ratings of reporting quality to be made. For two studies (Correa *et al.*, 2012; Lopes *et al.*, 2016), higher ratings were given by Morrison et al. than in the current review, whereas the opposite was true for another study (Richardson *et al.*, 2019). This indicates differences in the interpretation of the CERT, highlighting the importance of researchers clearly reporting how they applied the CERT in their studies.

The CERT creators published an explanation and elaboration statement aimed at enhancing users' understanding of the CERT (Slade, Dionne, Underwood, and Buchbinder, 2016). This statement provides the definition and rationale for each item along with examples of good reporting. However, in the current review, it was determined that the guidance provided in the explanation and elaboration statement still allowed for interpretation of the CERT items. Therefore, prior to data extraction, two reviewers agreed on specific criteria to fulfil each item, ensuring that sufficient detail was provided in the reports to accurately interpret and replicate the study's intervention (Appendix. B). For instance, the item related to the implementation of progression was only deemed to be fulfilled if the study included a detailed description of how the intervention progressed. These details are crucial for determining the exact stimulus of the intervention and to understand whether different participants received different stimuli, thus ensuring a full evaluation of the intervention's effectiveness. This thorough and transparent application of the CERT is a strength of the current review.

4.4.2 Mechanical Specificity

The first criterion of dynamic correspondence, 'amplitude and direction of movement' concerns the joint angular range (i.e., ROM), joint action (e.g., flexion, extension, abduction) and the direction of force relative to the individual (Goodwin and Cleather, 2016). To meet this criterion, the starting position, posture of the individual, and direction of force relative to the individual should match the desired performance outcome, as this determines which muscles are involved (Verkhoshansky and Siff, 2009). However, the assessment of this criterion was hindered by the poor reporting of equipment and anatomical positions among the interventions in this review (Figure 4.3). For example, many interventions involved leg press exercises (Table 4.2), but critical details such as knee and hip angles, foot placement, equipment set-up, and the type of leg press (supine or seated) were frequently omitted (see Appendices 7 & 8). As a result, the ROM applied in many interventions was unclear, precluding evaluation of similarities in the first element of this criterion, the amplitude of movement. However, assessments of the second element, direction of movement, including joint actions and direction of force were possible from the available information. When considering force in the local coordinate frame, as is recommended by Verkhoshansky and Siff (2009), all interventions included exercises involving vertical ground reaction force (GRF), such as jumps, lunges and leg press. Equally, all the outcomes in the present review are predominated by vertical GRF (table 2.1), therefore correspondence between interventions and outcomes was high on this aspect of the first criterion.

Notably, only one intervention provided a detailed description of the exercise allowing full evaluation of this criterion, including foot placement, starting and ending positions, and knee angles (Sañudo, De Hoyo and McVeigh, 2022). In this study, participants completed flywheel squats with feet shoulder-width apart, starting at approximately 15° knee flexion and reaching a maximum flexion of approximately 140°, with the outcome measurement being a 30s-STS. Knee flexion angles during STS are between approximately 0° (standing) and 90° (seated), and in both the exercise and the outcome, force is directed vertically (Hirschfeld, Thorsteinsdottir and Olsson, 1999), suggesting that this intervention corresponded well to the criteria of 'amplitude and direction of movement'.

Incomplete reporting also affected the ability to evaluate the degree of correspondence for 'the accentuated region of force production'. This criterion refers to the joint angles at which maximum force production occurs in a given exercise (Verkhoshansky and Siff, 2009). To meet this criterion, the joint angles at which peak force is produced should be similar for both the training exercises and outcome measurements and so, requires knowledge of the ROM during both activities. As previously mentioned, most of the interventions in the present review lacked reporting of this information and so correspondence for this criterion was mostly unclear (Figure 4.4). However, in one intervention, the effects of flywheel squats on the ability to STS was measured which indicated good correspondence for ‘the accentuated region of force production’ (Sañudo, De Hoyo and McVeigh, 2022). This is supported by studies showing that peak force during STS is typically generated around the moment of seat-off, which occurs at approximately 90 degrees of knee flexion (where full knee extension is 0 degrees) (Hirschfeld, Thorsteinsdottir and Olsson, 1999) which is similar to that of a squat exercise (Rahmani *et al.*, 2001; Kellis, Arambatzi and Papadopoulos, 2005). It is important to note that the existence of literature detailing the accentuated region of force production for a wide variety of exercises and ADLs is low. As a result, the ability to accurately design interventions that correspond closely in terms of the accentuated region of force production is currently limited.

Most interventions/outcomes in the current review corresponded well in terms of ‘dynamics of the effort’ and ‘the rate and time of maximum force production’. The ‘dynamics of the effort’ pertains to the application of overload (e.g., peak force, volume, time-under-tension, load, RFD), a fundamental principle of RT (Kraemer and Ratamess, 2004). However, "the rate and time of maximum force production" focuses on achieving overload specifically related to the RFD required for the desired outcome (Verkhoshansky and Siff, 2009). Therefore, these two criterions are complementary, particularly if the desired performance outcome is influenced by the ability to produce force rapidly, as is the case in the studies reviewed here. When considering the ‘dynamics of the effort’, Verkhoshansky and Siff specify that the character and duration of the desired outcome should be considered and that the overload applied targets the most crucial elements of performance. For example, it has been shown that the ability to produce force rapidly may be more critical than maximal strength in the performance of certain ADLs including STS and stair climb (Suzuki, Bean and Fielding, 2001; Bean *et al.*, 2003; Puthoff and Nielsen, 2007). In addition, evidence suggests that performance of these ADLs does not require reaching maximal voluntary forces (Alexander *et al.*, 1997). Therefore, to correspond with many ADLs in terms of 'dynamics of the effort', and 'the rate and time of maximum force production' it would be practical for RT to involve moving moderate loads with maximal intended velocity as was the case for all of the interventions in this review.

However, several outcomes only had partial correspondence for 'dynamics of the effort' including the 6MWT which was used in 4 interventions. This test requires participants to walk continuously for 6 minutes as fast as they can, originally developed as a test to measure aerobic capacity and endurance (Kammin, 2022). Due to its submaximal and continuous nature, it is likely that peak force and RFD were greater during the interventions, therefore achieving overload in these respects. However, no interventions in this review involved continuous exercise longer than ~15 repetitions and so, participants were not exposed to overload that was specific in character and duration to the 6MWT. It is worth noting that all interventions that included the 6MWT also involved other outcomes such as stair climb and TUG. It is possible that these interventions were primarily designed to improve one of these outcomes, rather than focusing specifically on the 6MWT. Designing interventions to be mechanically specific for a single performance outcome may limit the specificity and, consequently, the improvements in mechanically dissimilar outcomes. This notion is supported by findings from Lopez *et al.* (2022) who found that fast walking speed, TUG, and 5STS were most improved following MIV-RT while 30s-STS and 6MWT responded more to conventional RT (sustained concentric actions). To maximise improvements in mechanically dissimilar outcomes, training could be periodised in order to simultaneously target different outcomes. This could involve for example, daily undulating periodisation, where specific muscle qualities are addressed in different training sessions within a week (Buskard *et al.*, 2018). However, to the author's knowledge, this approach has yet to be explored. Therefore, further investigation is needed to explore the potential benefits of periodised training programs that address multiple ADLs concurrently.

The criterion of "the regime of muscular work" was partially fulfilled by all interventions. This criterion emphasises that the nature of the muscular work performed during the desired performance outcome should be reflected in the training prescription (Verkhoshansky and Siff, 2009). In most interventions, a common approach was observed, involving rapid concentric muscle actions followed by slow and controlled eccentric actions lasting 2-3 seconds (see Appendix. H, column 9). While rapid concentric muscle actions are also characteristic of the measured ADLs, slow and controlled eccentric actions do not reflect the demands of these outcomes. For instance, in 5STS, participants are required to rise from a chair 5 times as quickly as possible, typically completing the task in under 15 seconds (Bohannon, 2006). As the objective is to perform the task as rapidly as possible, there is no motivation to control the descent into the chair on each repetition. From a general conditioning perspective, sustained eccentric actions may be logical as they can promote significant gains in muscle strength and function (Roig *et al.*, 2009; Kay *et al.*, 2020). However, prolonged eccentric actions have been shown to limit rapid force production and velocity during subsequent concentric muscle actions (Wilk *et al.*, 2019). Therefore, if the main aim of a training program is to increase rapid force production and improve outcomes that rely heavily on this muscular function, then performing sustained eccentric actions may impede the desired adaptations. This further emphasises considering the main outcomes of interest, the biomechanical demands associated with those outcomes, and designing interventions that target those specific demands.

4.4.3 Strengths and Limitations

The present review has several strengths and limitations that should be acknowledged. Firstly, the number of included studies was relatively small. However, the inclusion criteria were designed to select only high-quality studies, which resulted in the exclusion of many studies involving MIV-RT for OAs. For a more comprehensive understanding of mechanical specificity in MIV-RT for OAs, future studies should explore broader inclusion criteria. Additionally, it was beyond the scope of this review to examine the degree of mechanical specificity in relation to intervention outcomes, such as through meta-analyses. The concept of dynamic correspondence was originally developed with athletes in mind, and its significance in the context of OAs remains unclear. However, recent literature demonstrating that ADLs respond differently to training types with distinct mechanical characteristics (Lopez *et al.*, 2022) highlights the likely influence of mechanical specificity on adaptations for OAs.

Despite these limitations, the study also possesses notable strengths. For instance, important gaps in reporting standards within MIV-RT intervention studies for OAs have been identified. In order to enhance the quality and reproducibility of future research in this field, we strongly encourage authors to adopt frameworks such as the CERT and TBF, while urging editors and reviewers to prioritise complete reporting. In addition, to our knowledge, this study is the first to discuss mechanical specificity in this context, with the aim of inspiring researchers working with OAs to incorporate mechanical specificity into their intervention designs and to explicitly outline how it contributes to their study objectives. While acknowledging the study's limitations, these strengths underscore its contributions to the field and lay the groundwork for further advancements in understanding mechanical specificity in MIV-RT interventions for OAs.

4.5 Conclusion

This review highlights that greater emphasis could be placed on the specificity of MIV-RT interventions for OAs to optimise the specificity of training and thus increase the likelihood of the transfer of training effects. Initially, researchers, practitioners and authors must place greater emphasis on adequately reporting training prescriptions to allow comprehensive assessment of specificity. Understanding the specificity of interventions is essential to understand the effectiveness of interventions and ultimately optimising training guidelines for OAs. Moreover, clear and complete reporting of interventions would improve the transparency and replicability of research, enable greater confidence in the validity of the interventions and allow other researchers to build on the findings in their own work.

Chapter: 5 The Implementation of Maximal-intentional Velocity Resistance Training for Older Adults: A Survey of Applied Practitioners.

5.1 Introduction

Recently, advocacy for OAs to participate in RT involving maximal intentional velocity has increased considerably (Cadore *et al.*, 2018; Fragala *et al.*, 2019; Izquierdo *et al.*, 2021; Schaun, Bamman and Alberton, 2021). It has been strongly suggested that this RT modality known as maximal-intentional velocity resistance training (MIV-RT), power training, explosive, high-speed or high-velocity RT (De Vos *et al.*, 2005; Sayers, Gibson and Bryan Mann, 2016; Richardson *et al.*, 2019; Pearson *et al.*, 2022) is an optimal method for improvements in functional ability, improves muscle mass and function and thus, should be prioritised for OAs (Cadore *et al.*, 2018; Orssatto *et al.*, 2019). However, the work in this thesis has highlighted significant variation in the implementation of MIV-RT in the scientific literature along with uncertainty around the risks associated with MIV-RT (Chapter 2), inconsistent and misapplied terminology (Chapter 3) and a lack of comprehensive reporting of intervention details (Chapter 4) all of which hinder the ability to draw definitive conclusions about the safety and efficacy of MIV-RT and thus may influence its uptake in real-world settings.

In Chapter 4, which systematically reviewed MIV-RT RCTs for OAs, all 12 of the included interventions involved similar OA populations free from disease or mobility limitations and typically measured the same outcomes, such as 30-STS, TUG, or 5STS.

However, the training programmes employed varied considerably. The number of prescribed exercises ranged from 1 to 11, repetitions per set varied from 6-14, rest between reps ranged from ~30 seconds to 3 minutes, and six different types of equipment were used. Furthermore, only two interventions described the training setting, and none detailed whether training occurred individually or in a group. This makes it difficult for practitioners to compare results across interventions and to decide whether the training employed in these interventions is applicable or appropriate in their own practice. This could lead to substantial differences in exercise prescriptions employed in research and practice and perhaps, the use of training methods that lack research-backed evidence. At present, it is unclear whether MIV-RT is being implemented by sport, exercise, and health practitioners, such as physiotherapists or fitness instructors and if so, whether the training prescriptions reflect those used in research studies. However, as researchers continue to invest efforts into exploring MIV-RT interventions for OAs, understanding the translation of research to applied practice is important to understand the real-world impact and applicability of this research.

Comprehensive investigation of MIV-RT prescriptions being used by applied practitioners would be a first step to identify whether gaps exist between prescriptions used in research and practice. In other areas of sport and exercise science, this type of investigation has revealed disparities between research and practice, offering important guidance for future research (Buchheit, 2017; Patterson and Brandner, 2017; McGuigan *et al.*, 2020; Gluchowski *et al.*, 2023). For example, in practitioners working with athletes, it was observed that some methods regularly used in research to monitor training (e.g., blood biomarkers) were not typically used in practice (McGuigan *et al.*, 2020). Instead, practitioners preferred to use monitoring methods that were time efficient and easy to administer, highlighting a need for researchers to understand what is practical and feasible in real-world settings and for research to be tailored towards the needs of practitioners (Buchheit, 2017). Additionally, a survey of practitioners who prescribed blood flow restriction training found discrepancies between its use in research and practice (Patterson and Brandner, 2017). They also found that the occurrence of side effects (i.e., adverse events) reported by practitioners, including numbness and DOMS were much greater than those reported in the literature. This suggests that compared to controlled research environments, the real-world application of training methods may introduce additional risks. Recently Gluchowski *et al.* (2023) found that exercise instructors that prescribed RT for OAs were often met with negative reactions from OAs including fear of RT which presented barriers in its implementation. Unlike controlled research environments, where volunteers are informed and willing participants, the real-world implementation of RT interventions may be hindered by specific barriers that have yet to be considered in research.

Collectively, these findings highlight gaps between research and practice which could be attributed to a variety of causes including a lack of applicability in research study designs and other barriers facing practitioners working in real-world settings. Importantly, the information gathered in these studies identify areas for improvement in the design of research studies, highlight critical gaps in knowledge and offer insights into barriers in the translation of research evidence to practical application.

Therefore, the primary aim of this study was to comprehensively explore the current implementation of MIV-RT among practitioners who prescribe exercise for OAs. By documenting MIV-RT prescriptions used in real-world settings, investigating any associated adverse events, and exploring the reasons why practitioners do not prescribe MIV-RT, this research will provide valuable insights into the translation of research to practice, identify potential areas for improvement and guide future research studies.

5.2 Methods

5.2.1 Research Design

A cross-sectional, observational study was conducted with participants completing a self-administered questionnaire developed in-house and distributed using online software (Qualtrics, Provo, UT). The questionnaire included 4 sections: 1) demographics, 2) the prescription of MIV-RT, 3) experience of adverse events and 4) questions related to reasons for not prescribing MIV-RT. Questions included a mixture of multiple-choice, close-ended and open-ended questions to allow for more diverse responses and avoid potential bias from predetermined options (Reja *et al.*, 2003).

The questionnaire was distributed online to sport, fitness and healthcare professionals involved in the prescription of exercise for OAs (i.e., practitioners) for a period of three months from March to May 2021, through social media platforms including Twitter, Facebook, online blogs, and forums, as well as via email using the primary authors network.

Practitioners who chose to take part were required to electronically indicate their informed consent to participate in compliance with the Declaration of Helsinki. All data was collected using online software (Qualtrics, Provo, UT). Ethical approval for this research was provided by Sheffield Hallam University's ethical committee (ER29016401).

5.2.2 Survey Structure and Content

The questionnaire was developed in house by the authors, having examined previously published questionnaires that were used to investigate the practices of applied practitioners in sport and exercise science (Ebben and Blackard, 2001; SIMENZ, DUGAN and EBBEN, 2005; Gee *et al.*, 2011; Jones *et al.*, 2016; Patterson and Brandner, 2017; Heyward *et al.*, 2020). Questions about MIV-RT prescriptions were designed to cover key aspects of RT design, guided by the FITT principles (frequency, intensity, type, time) and RT principles of specificity, overload, and progression (Fleck and Kraemer, 2014). In addition, an open text box was provided for each question allowing respondents to provide answers they felt were not represented in the multiple-choice options.

Before being distributed, the survey was pilot tested to assess its length, clarity, and logistical aspects. To do this, the survey was sent to and completed by four experienced practitioners who prescribed exercise to OAs, an approach adopted in several previous publications (Ebben and Blackard, 2001; Patterson and Brandner, 2017).

The term 'explosive resistance training' was adopted at the time of survey inception as it was deemed the most widely applied term used to describe MIV-RT within the scientific literature. To provide clarity on what was meant by "explosive resistance training," the question was accompanied by the following explanation: "*By explosive resistance training, we mean any type of resistance training that involves maximal intentional acceleration of the* *load. Examples of explosive training include power, plyometric, and ballistic exercises, such as jumping, hopping, throwing, or Olympic lifting*."

Practitioners could choose not to answer questions by proceeding to the next question except for those that confirmed eligibility to participate or determined the direction of subsequent questions. For instance, practitioners' answer to the question "Do you programme, prescribe, or recommend any form of explosive resistance training for OAs (aged ≥60 years)?" informed the direction of subsequent questions. The possible direction of questions is depicted in figure 5.1.

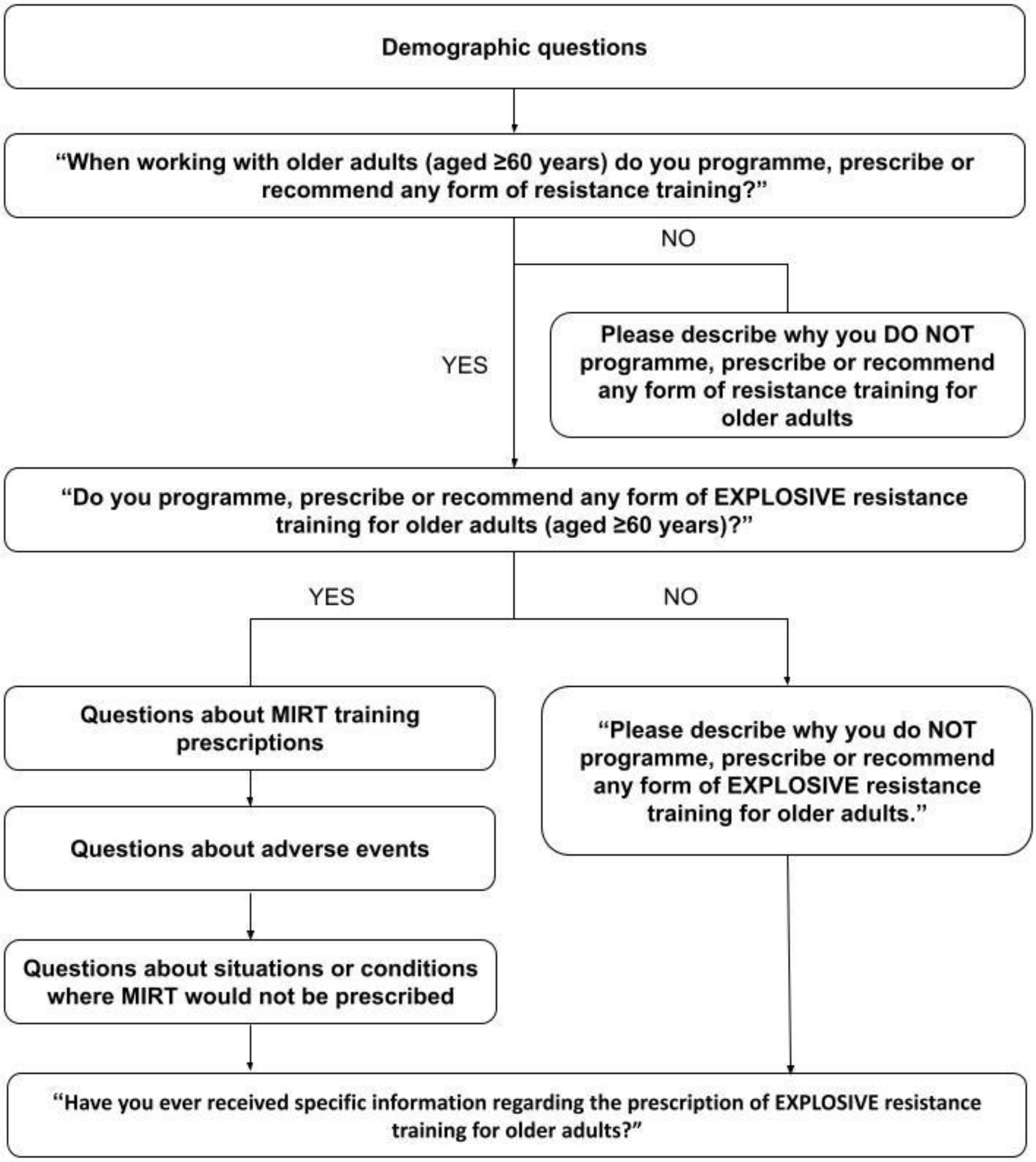


Figure 5.1 - Schematic of the flow of survey questions

5.2.3 Data Analysis

To be included in the analysis, practitioners must have completed the key research question: “Do you programme, prescribe or recommend any form of explosive resistance training for OAs (aged ≥60 years)?" Data were exported from Qualtrics and analysed in Excel (Microsoft Corporation, Redmond, WA). Closed-ended and multiple-choice answers were analysed with descriptive statistics, using absolute and relative frequency counts. Answers to open-ended questions were analysed using inductive and deductive content analysis in order to identify themes representing common patterns in the data. This approach is described in detail by Elo and Kyngäs (2008) and has been applied in studies exploring the practices of applied practitioners (Gee *et al.*, 2011; Jones *et al.*, 2016; Heyward *et al.*, 2020). The exact process taken in this study is summarised in figure 5.2. Frequency analysis was also used for two open-ended questions (prescribed exercises and adverse events).

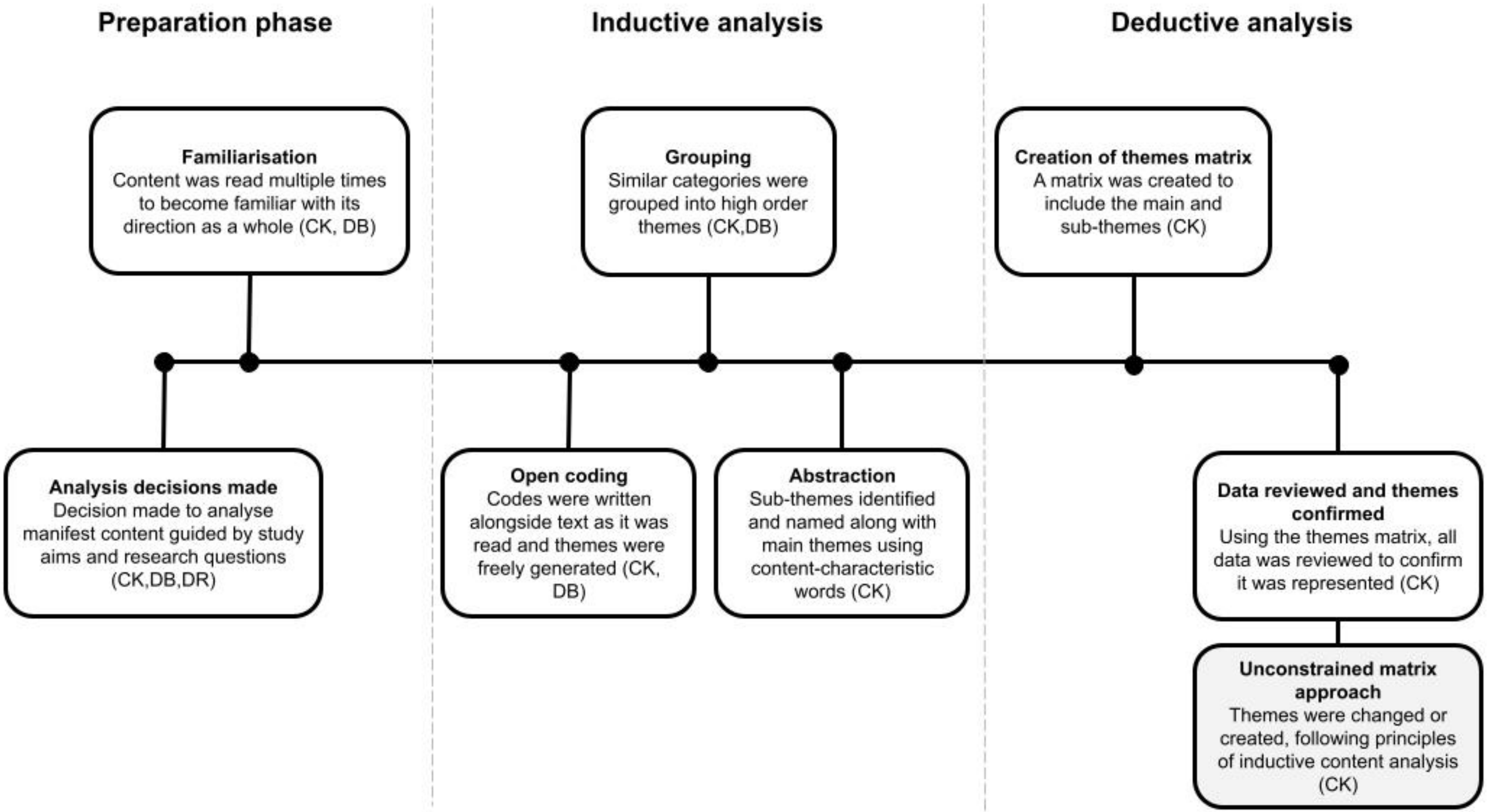


Figure 5.2 - The process of content analysis taken to analyse answers to open-ended questions according to methods detailed by Elo and Kyngäs (2008). The initials of the research team members involved in each element are shown in brackets.

5.3 Results

Two hundred practitioners began the survey and 100% of practitioners indicated that they prescribed RT for OAs. Subsequently, all 200 practitioners completed the key research question “Do you programme, prescribe or recommend any form of EXPLOSIVE resistance training for OAs (aged ≥60 years)?”. Of these, 85 prescribed ERT and 115 did not. One participant was excluded as although they had completed the key research question, they had not answered any other questions. A second participant answered ‘yes’ to prescribing MIV-RT, but subsequent answers indicated that this participant had misunderstood the question and did not prescribe MIV-RT. Therefore, they were included in the group that did not prescribe MIV-RT. Consequently, responses from 199 practitioners were included in the analysis, 83 that prescribed MIV-RT and 116 that did not.

5.3.1 Demographics

One hundred and thirty-nine (69.8%) practitioners were residing in the United Kingdom at the time of survey completion. The geographic regions of the remaining responses were North America (n=30, 15.1%), Europe (n=19, 9.5%), Oceania (n=4, 2.0%), Asia (n=3, 1.5%) and South America (n=3, 1.5%).

Descriptive characteristics of the practitioners are included in table 5.1 accompanied by details of their professions, professional setting, and client populations.

Table 5.1 - Practitioner characteristics

	Full sample		Prescribed MIV-RT		Did not prescribe MIV-RT	
	Absolute frequency (n=199)	**Relative frequency (% of n)**	*Absolute frequency (n=83)*	**Relative frequency (% of n)**	*Absolute frequency (n=116)*	**Relative frequency (% of n)**
Age (yrs.)						
20-29	*36*	**18%**	*14*	**17%**	*22*	**19%**
30-39	*41*	**21%**	*22*	**27%**	*19*	**16%**
40-49	*30*	**15%**	*9*	**11%**	*21*	**18%**
50-59	*45*	**23%**	*19*	**23%**	*26*	**22%**
60-69	*19*	**10%**	*11*	**13%**	*8*	**7%**
70-79	*10*	**5%**	*2*	**2%**	*8*	**7%**
Missing	*17*	**9%**	*6*	**7%**	*11*	**10%**
Gender						
Female	*138*	**70%**	*48*	**58%**	*89*	**77%**
Male	*58*	**29%**	*34*	**41%**	*24*	**21%**
Non-binary	*1*	**0.5%**	*1*	**1%**	*0*	**0%**
Missing	*2*	**1%**	*0*	**0%**	*2*	**2%**
Current profession*						
Fitness Instructor	*84*	**42%**	*27*	**33%**	*57*	**49%**
Personal Trainer	*62*	**31%**	*35*	**19%**	*27*	**23%**
Physiotherapist	*41*	**21%**	*15*	**18%**	*26*	**22%**
Strength and Conditioning Coach	*23*	**12%**	*16*	**19%**	*7*	**6%**
Researcher	*15*	**8%**	*9*	**11%**	*6*	**5%**
Medical Doctor	*1*	**0.5%**	*0*	**0%**	*1*	**1%**
Other	*51*	**26%**	*20*	**24%**	*31*	**27%**
Professional setting*						
Gym/Fitness Centre	*76*	**38%**	*36*	**43%**	*40*	**35%**
Community spaces	*57*	**29%**	*28*	**34%**	*29*	**25%**
Client homes	*45*	**23%**	*26*	**31%**	*19*	**16%**
Online	*46*	**23%**	*21*	**25%**	*25*	**22%**
Hospital / Clinic	*32*	**16%**	*10*	**12%**	*22*	**19%**
Own home	*32*	**16%**	*18*	**22%**	*14*	**12%**
University / Research Institute	*21*	**11%**	*14*	**17%**	*7*	**6%**
Sports Club - Amateur/community level	*13*	**7%**	*8*	**10%**	*5*	**4%**

Sports Club - Professional level	*5*	**3%**	*3*	**4%**	*2*	**2%**
Other	*56*	**28%**	*23*	**28%**	*33*	**28%**
Client group (60+)*						
General population	*157*	**79%**	*76*	**92%**	*81*	**70%**
Special population†	*127*	**64%**	*57*	**69%**	*70*	**60%**
Amateur athletes	*49*	**25%**	*28*	**34%**	*21*	**18%**
Elite athletes	*4*	**2%**	*4*	**5%**	*0*	**0%**

* Practitioners could select more than one answer for current profession (277 responses) and professional setting (383 responses), † Individuals with underlying health conditions such as chronic disease

5.3.2 Professional and Formal Qualifications

The professional and formal sport and exercise related qualifications held by all practitioners are shown in Table 5.2. One hundred and seventy-two practitioners (86.4%) reported holding at least one sport and exercise related professional qualification. The most commonly held qualification for all practitioners was a level 2 fitness instructor qualification or equivalent. This was also true for the practitioners that did not prescribe MIV-RT, however, for the practitioners that prescribed MIV-RT, level 3 personal trainer qualifications or equivalent was the most common. Practitioners were able to list other relevant qualifications that were not listed in the survey by selecting 'Other' and providing details. Responses included "American Council on Exercise (ACE Certified)", "Army PTI and health trainer", "OTAGO exercise programme leader" and "Senior Fitness specialist NASM".

Table 5.2 - Qualifications held by practitioners

	Full sample		Prescribed MIV-RT		Did not prescribe MIV-RT	
Professional qualification*	*Absolute frequency (n=199)*	**Relative frequency (% of n)**	*Absolute frequency (n=83)*	**Relative frequency (% of n)**	*Absolute frequency (n=116)*	**Relative frequency (% of n)**
Level 2 Fitness Instructor (or equivalent)	*69*	**35%**	*20*	**24%**	*49*	**42%**
Level 3 Personal Trainer (or equivalent)	*64*	**32%**	*25*	**30%**	*39*	**34%**
Level 4 Fitness Qualification (e.g. cancer rehabilitation)	*56*	**28%**	*21*	**25%**	*35*	**30%**
Level 3 Exercise Referral	*45*	**23%**	*14*	**17%**	*31*	**27%**
National Strength and Conditioning Association (NSCA) Certified Strength and Conditioning Specialist (CSCS)	*14*	**7%**	*12*	**15%**	*2*	**2%**
Sports coaching qualification	*19*	**10%**	*10*	**12%**	*9*	**8%**
American College of Sports Medicine (ACSM) qualification	*11*	**6%**	*8*	**10%**	*3*	**3%**
Weightlifting qualification	*9*	**5%**	*4*	**5%**	*5*	**4%**
CrossFit qualification	*6*	**3%**	*4*	**5%**	*2*	**2%**
UK Strength and Conditioning Association (UKSCA) Accredited Strength and Conditioning Coach	*3*	**2%**	*2*	**2%**	*1*	**1%**
Australian Strength and Conditioning (ASCA) qualification	*1*	**0.5%**	*1*	**1%**	*0*	**0%**
Other	*98*	**49%**	*44*	**53%**	*54*	**47%**
None	*18*	**9%**	*6*	**7%**	*12*	**10%**
No response	*9*	**5%**	*4*	**5%**	*5*	**4%**

* Practitioners could select more than one answer

5.3.3 Previous Information About Maximal-intent Resistance Training

Practitioners were asked the following question: “Have you ever received specific information regarding the prescription of EXPLOSIVE resistance training for OAs? (For example, in university modules, presentations, professional courses, training in the workplace)”. A response was provided by 152 practitioners of which 51 (33.6%) selected ‘Yes’. Of the practitioners that prescribed MIV-RT, 70.2% had received information whereas only 11.6% of those that did not prescribe MIV-RT had received information (Figure 5.3).

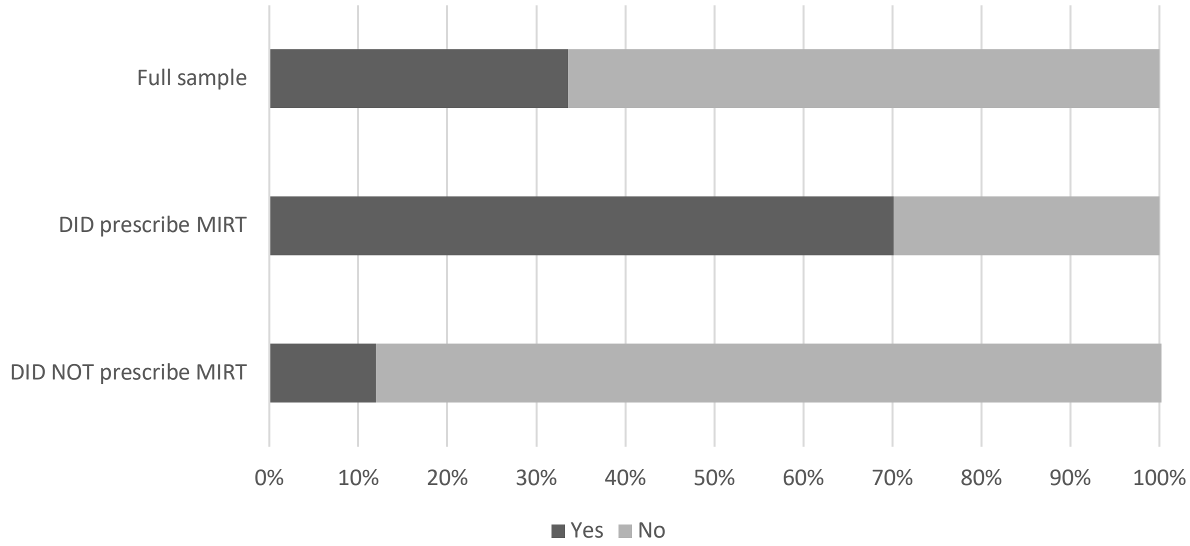


Figure 5.3 - The proportion of practitioners who had previously received specific information regarding the prescription of maximal-intentional velocity resistance training for older adults.

5.3.4 Prescriptions of Maximal-intent Resistance Training

This section (5.3.5) relates only to the practitioners that prescribed MIV-RT (n=83). Practitioners were asked what proportion of the OAs they worked with did they prescribe MIV-RT for. Most practitioners indicated that they prescribed both upper and lower body MIV-RT to 'some' of their clients and it was least common to prescribe to 'all' of their clients

(Figure 5.4). The majority of practitioners (65.6%) indicated that MIV-RT was always supervised.

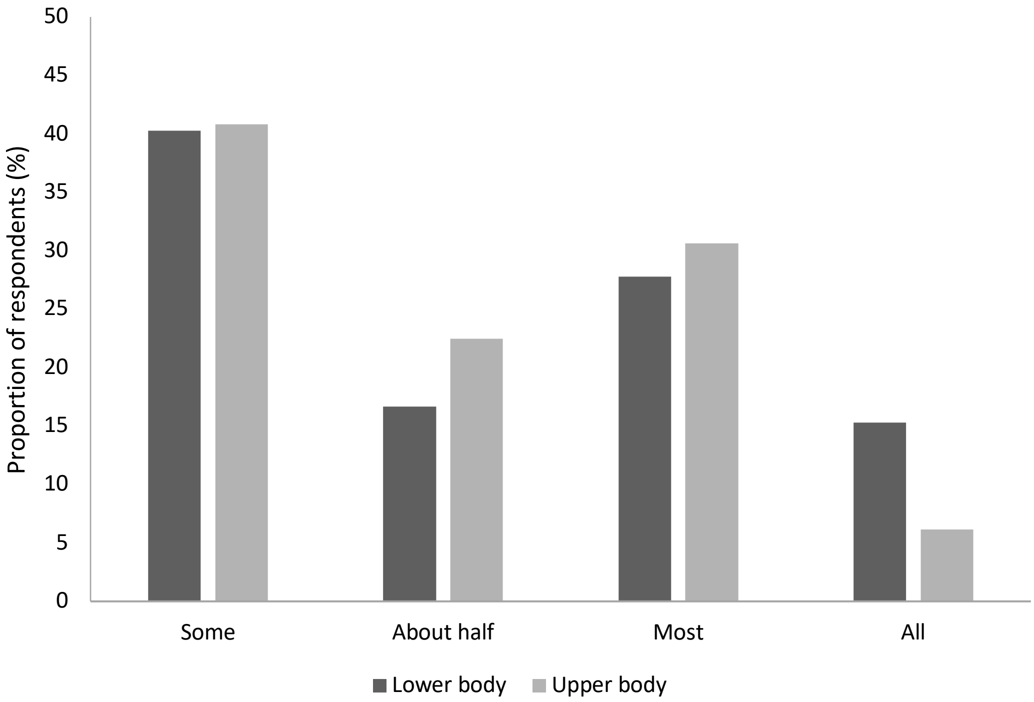


Figure 5.4 - The proportion of clients prescribed maximal-intentional velocity resistance training by practitioners (n=72)

5.3.4.1 Training Variables

Practitioners were asked to select the training variables that they typically prescribed for upper and lower body MIV-RT. The training variables most commonly prescribed were identical for upper and lower body MIV-RT. It was most common to prescribe 2 MIV-RT exercises per training session and the most prescribed frequency was 1-2 days per week. The most common number of sets prescribed for each MIV-RT exercise was 3. The most common number of repetitions prescribed per set was 4-6 and the most prescribed rest period between sets was 1-2 minutes. The numbers of responses for each training variable are displayed in Figure 5.5.

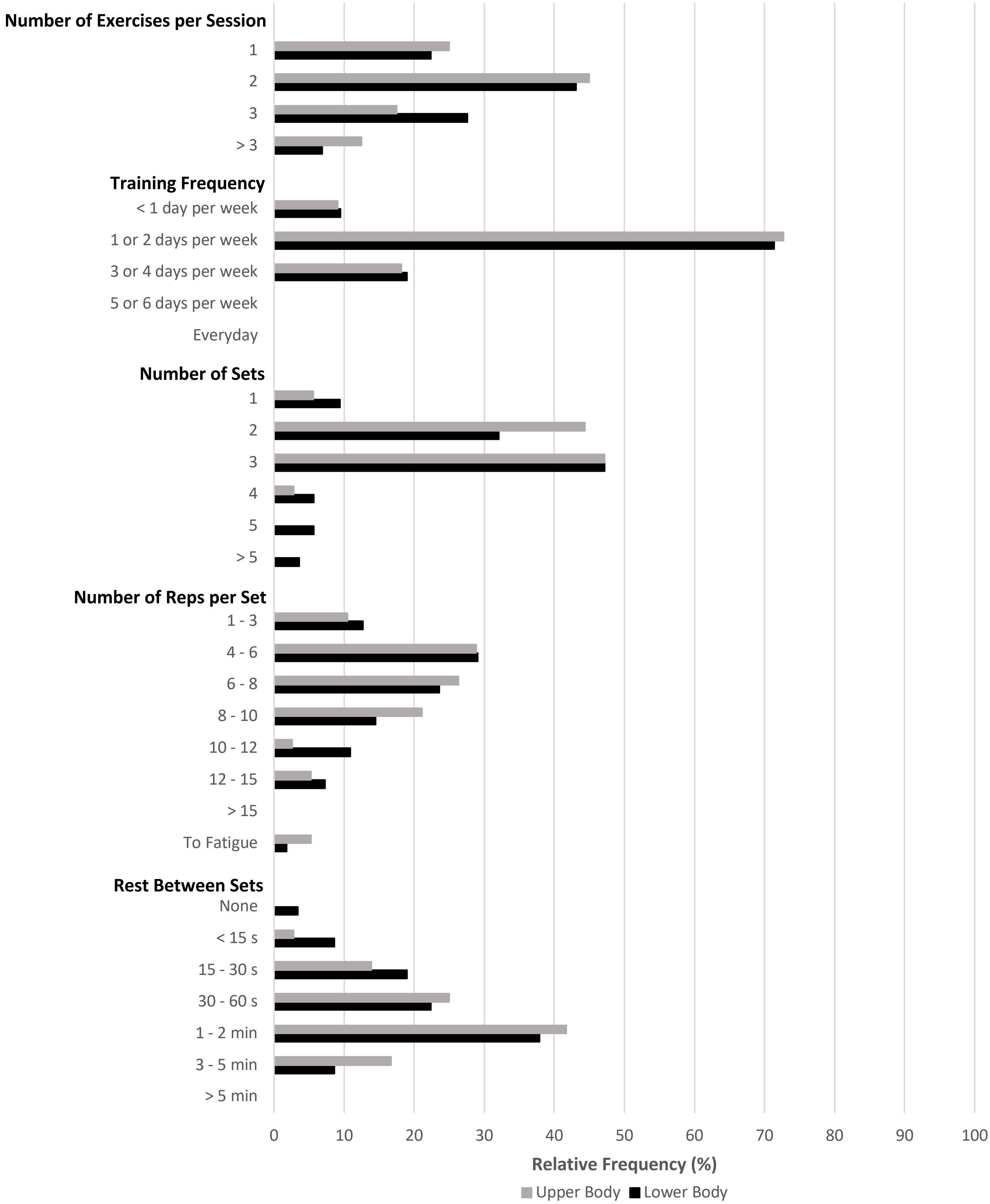


Figure 5.5 - Relative frequency of maximal-intentional velocity resistance training prescription variables for upper and lower body exercise

5.3.4.2 Exercises

Practitioners were asked to list the lower and upper body MIV-RT exercises that they typically prescribed for OAs. Sixty-seven practitioners provided a response for lower body and 45 provided a response for upper body exercises. The most common types of exercises prescribed were jumps (lower body) and throw/slams (upper body). Exercises that did not fit into suitable themes are listed as 'Other' and are shown in Appendix. J. The themes of exercises are presented in table 5.3 (lower body exercises) and table 5.4 (upper body exercises).

Table 5.3 - Lower body maximal-intentional velocity resistance training exercises prescribed for older adults by applied practitioners

Exercise	Total Frequency	Proportion of practitioners
Jumps	82	74%
Sub-themes:		
Just "jumping", "jump" or "jumps"	17	26%
Squat jumps	15	23%
Box jumps	12	17%
Jumping jacks	7	11%
Lunge jumps	7	11%
Other jump^	24	27%
Hops*	25	36%
Squats**	17	24%
Skipping	12	18%
Ball throws/slams	10	15%
Lunges**	9	14%
Step ups**	6	6%
Sprints	5	8%
Sit to stand**	5	8%
Other^	62	55%

^ full list can be found in appendix B

* includes exercises described as single leg jumps

** jumping versions e.g., squat jump, step up jump were categorised separately under 'jumps'

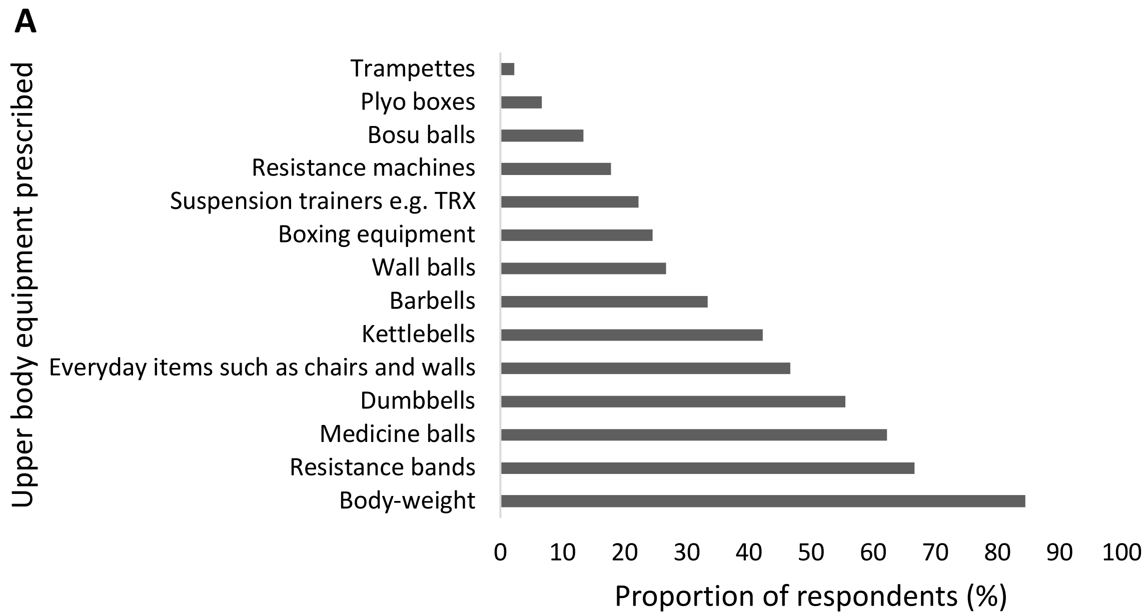
Table 5.4 - Upper body maximal-intentional velocity resistance training exercises prescribed for older adults by applied practitioners

Exercise	Total Frequency	Proportion of practitioners
Throws/slams	32	56%
Sub-themes:		
Medicine ball throws	10	22%
Ball slams	8	18%
Just "throw" or "throwing"	5	11%
Other throw^	9	20%
Pushes/presses	33	53%
Sub-themes:		
Push ups	13	29%
Shoulder press	6	13%
Chest press	5	11%
Other press^	9	11%
Pulls	9	20%
Rows	9	20%
Boxing	5	11%
Other^	23	31%

^ full list can be found in appendix B

5.3.4.3 Equipment

For both upper and lower body ERT exercises, body weight was the most prescribed form of resistance (Figure 5.6). Resistance bands were used by more than 50% of respondents for both upper (n=30) and lower body (n=33). Practitioners were given the option to add any other equipment that was not listed. Other answers included ‘slam balls’, ‘ankle weights’ and ‘Pilates reformer’ for lower body exercises and ‘therabands’ for upper body exercises.



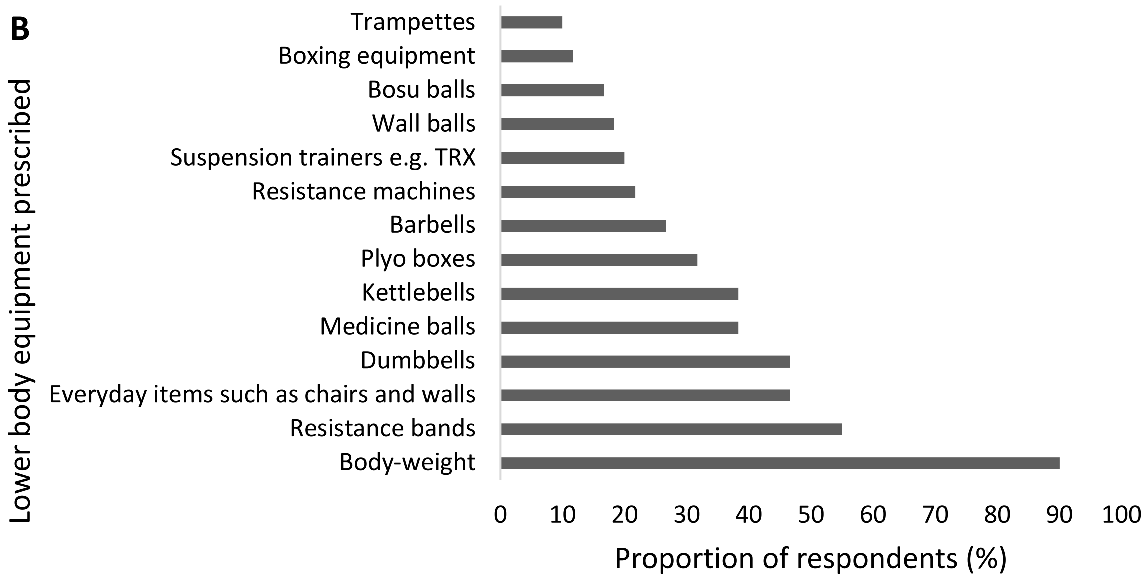


Figure 5.6 - Equipment prescribed for upper (A) and lower (B) body maximal-intentional velocity resistance training for older adults.

5.3.4.4 Selection of Load

Practitioners were asked which methods they used to select loads for MIV-RT exercises for OAs. Responses were provided by 60 and 43 practitioners for lower and upper body exercises respectively. The most common methods to select loads for both upper and lower body were RPE and loads selected by the client (Figure 5.7). Practitioners were provided with an open text box to use if they felt that their answer was not shown in the multiple-choice options. Seven practitioners chose to respond in this way without selecting one of the predetermined options and of these, 3 practitioners reported that they used bodyweight only.

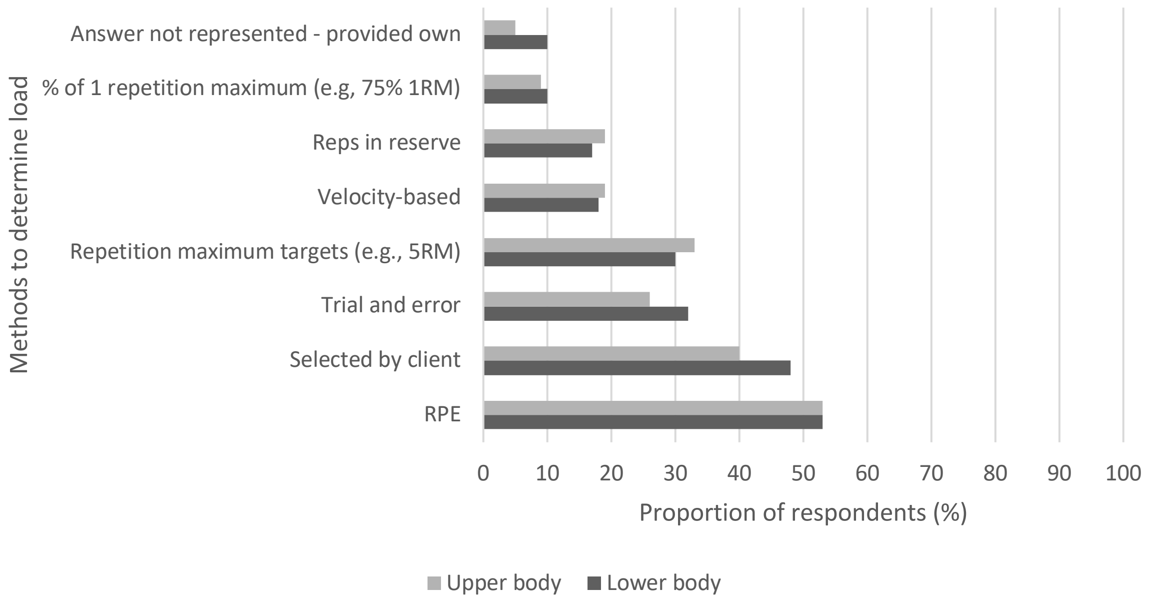


Figure 5.7 - The methods used by practitioners to determine the loads prescribed during maximal-intentional velocity resistance training for older adults.

5.3.4.5 Methods of Progression

Practitioners were asked whether they used any methods to inform the progression of MIV-RT exercises for OAs and if so, to select the methods they typically used. Fifty-nine practitioners provided a response regarding the use of methods of which, 62.7% (n=37) responded 'Yes'. The specific methods employed were provided by 41 practitioners. The most common method was 'changes in RPE' (64.7%, n=22) followed by 'changes in strength' (23.5%, n=8), 'changes in velocity' (5.9%, n=2) and 'decided by client' (5.9%, n=2). Practitioners were provided with an open text box to use if they felt that their answer was not shown in the multiple-choice options. Six practitioners responded in this way and responses included:

> *"Mostly cyclical to cover a range of intensities e.g. 30-60% 1-RM. Two weeks may be 30-40%, next two weeks 40-50% and finally two weeks at 50-60%. Sometimes velocity-based methods are used."*

> *"None that fit the science-based models in the literature. Generally, since I am monitoring for aches, pains and function, I use a PRE model, increasing reps to no more than 15 and sets to 2, after which time I incorporate new, different exercises with the same progression. But session-to-session is more haphazard than the literature would demand."*

> *"Measured the distance people can jump"*

5.3.4.6 Concurrent Training

The practitioners were asked whether the MIV-RT exercises that they prescribed were completed alongside any other training types. Responses were provided by 62 practitioners and 58 (93.5%) responded 'Yes'. Of these practitioners, 57 selected the training types that they prescribed alongside MIV-RT, and the most common response was balance (n=50) followed by aerobic (n=42) and muscular endurance (n=41) (Figure 5.8). 'Other' training types reported by practitioners included "Functional fitness", "Stretching", "Movement and dance" and "Co-ordination and flexibility".

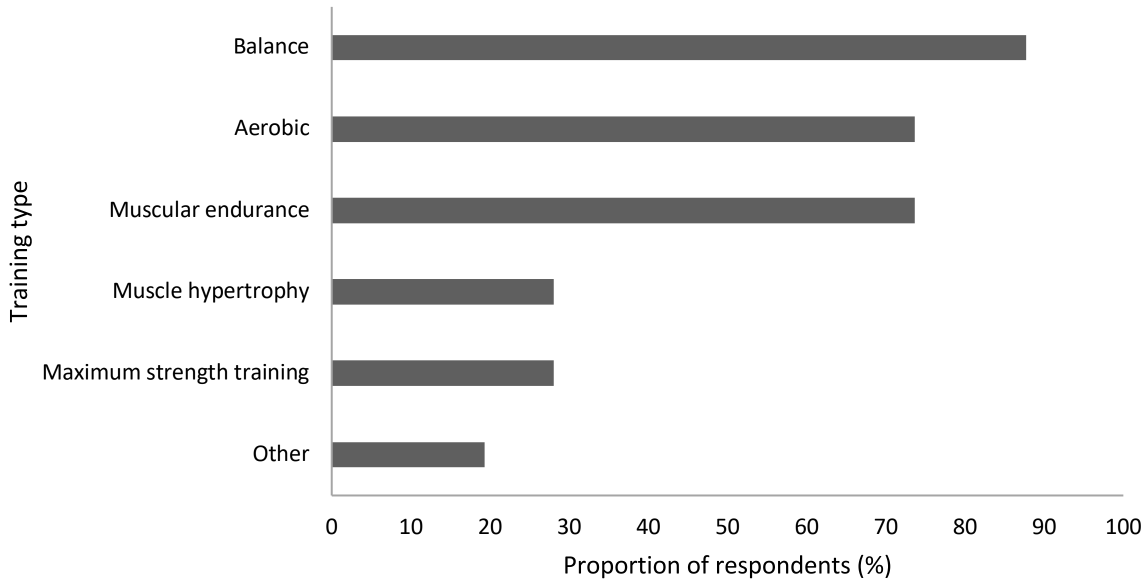


Figure 5.8 - Types of training prescribed alongside explosive resistance training for older adults by applied practitioners.

5.3.5 Adverse Events

Practitioners were asked whether they could recall any adverse events occurring as a result of programming, prescribing or recommending MIV-RT. Sixty-one practitioners provided a response of which, 19 (31.1%) responded 'yes'. Of those practitioners, 17 provided details of the adverse events which were content analysed. A total of 35 adverse events were identified from the responses of which 10 were muscle soreness (listed by 58.8% of respondents). Incidences of pain and exacerbation of existing conditions were each reported 4 times, including 2 specific references to knee pain. Appendix. N presents the remaining responses, each reported once.

5.3.6 Reasons for Not Prescribing Maximal-intent Resistance Training

5.3.6.1 Practitioners Who Prescribed Maximal-intent Resistance Training

Practitioners that prescribed MIV-RT (n=83) were asked whether there were any specific situations or conditions where they would not programme, prescribe or recommend MIV-RT for OAs. Sixty-one practitioners provided a response of which, 54 (89%) responded ‘Yes’. Of those practitioners, 50 provided details of the specific situations or conditions which were content analysed and resulted in 6 main themes (Table 5.5). All responses are provided in Appendix. O.

5.3.6.2 Practitioners Who Did Not Prescribe Maximal-intent Resistance Training

Practitioners that did not prescribe MIV-RT (n=116) were asked to describe why this was the case and 88 practitioners provided a response. The responses were content analysed and resulted in 6 main themes (Table 5.6). All responses are provided in Appendix. P.

Table 5.5 - Situations or conditions where practitioners (who do prescribe maximal-intentional velocity resistance training for older adults) would not prescribe maximal-intentional velocity resistance training for older adults.

Theme	Select raw data representing responses
Low/poor physical ability or fitness Sub-themes: Balance Strength Mobility Frailty and high risk of falls Untrained/novice	"When I have some one new to training and or doesn't have suitable balance."
	"Weaker clients have a hard enough time moving. I don't thnk I would feel they could handle explosive moves"
	"In patients who are too frail or lack balance and coordination"
	"lack of experience - exercises need to be properly introduced (and progressions built) before they can be performed explosively."
Chronic medical conditions/diseases Sub-themes: Bone issues incl. osteoporosis Joint issues incl. arthritis Circulatory and cardiovascular	"Heart conditions, underlying disabilities, previous health history, osteoporosis, osteopaenia, imbalance (virtigo), arthritis, stenosis and other objective criteria depending upon the subject's previous fitness and activity history."
	"Individual circumstances Severe oesteoperosis Severe fatigue, severe RA"
	"With my poorly COPD and heart failure patients"
Acute morbidity and symptoms Sub-themes: Currently or recently received medical treatment Current or recent injury/illness Fatigue, lack of energy and sleep	"If client has not slept well or reacting to any medication or treatment. Blood pressure too high or too low. Blood sugars not controlled. Joint inflammation or due surgery in near future. How the person is feeling physically and mentally."
	"Post some cancer treatments, recent surgical procedures whether general or orthopaedic surgery, and sudden illness. I would want to be clear the person had sufficient fitness to undertake such high energy exercise"
Client psychological phenomena Sub-themes: Fear/lack of confidence Lack of desire/preference	"…where fear of injury especially falling mitigates compliance…"
	"…Lack of confidence…"
	"There is insufficient energy, agility, range, propulsion or desire to do so available."
Other training types take precedent/clients have other training goals	"Clients who have a very low starting point whos time is better spent focusing on their strength first"
	"…client doesn't require these, but some other type of training…"
	"if the clients body is not ready for the explosive training or his/hers goals and nothing to do with explosivity."
Extraneous factors Sub-themes: Decision by health professional Client refusal Inability to supervise/spot effectively	"... doctor's instructions…"
	"They simply do not want to do them."
	"I am also reluctant to engage in ERT if I can't safely spot them."

Table 5.6 - Reasons given by practitioners (who do not prescribe maximal-intentional velocity resistance training for older adults) for not prescribing maximal-intentional velocity resistance training for older adults.

Theme	Select raw data representing responses
Concerns over safety Sub-themes: Risk of injury Risk of medical event Risk of falls Related to inability to supervise/group setting	"The impact force of ballistic training risks damage to the skeleton due to their age-related osteoporosis, as well as the potential impacts from falls, which are likely to increase in likelihood performing explosive movements, whether that be fractures in long bones or the inflammation of joints due to their reduced articular cartilage."
	"Cardiac risk associated with explosive, high intensity movements without prior cardiopulmonary exercise testing."
	"The population I am working in is specialised learning disability, where the clients ability would not allow explosive exercise to be prescribed as this would be unsafe and put patients at risk of falls or injury, many exercises in this population are supported by nursing staff who also may be uncomfortable helping clients with explosive exercise"
	"Safety issues when working in groups trying to supervise these exercises (when running groups, we are expected to have larger numbers to warrant running the class)"
Client health and fitness Sub-themes: Clients are frail or lack sufficient physical ability Clients have comorbidities or injury Clients are of a certain age	"Most of my patients have neurological impairment and recruitment of a rapid burst of activity can be very challenging or impossible", "The exercises I give out are based on individual clients needs. I feel that explosive movements have not been with in a clients capabilities. If I had a client that was capable enough to add this type of training I would give it a go."
	"a lot of clients have osteoarthritis, osteoporosis, osteopenia, hip and knee issues", "My population are frail older adults with multiple co-morbidities and more often than not balance impairments and strength deficits that I believe would prevent them from completing explosive resistance training."
	"Most of my class members are over 85. Really don't think anything "explosive" is appropriate for this age group."
Other training types take precedent/alternative training goals	"No appropriate for the patient group following an acute illness. Initial focus is on regaining function and then progressing strength and challenging proprioception as an outpatient"
Client psychological phenomena Sub-themes: Client reluctancy/preference Client fear	"In my setting I only see very frail patients or those reluctant to engage in physical activity… Patients preconceived notions and expectations of those in their age group leads to resistance to comply. Psychological fears of failure or to not start to avoid risk of failing. Family wanting to 'keep safe' and avoid 'risk'",
	"Most clients wish to do gentler training as they have a fear of injuring themselves or underlaying health conditions."
Practical environment	"lack of suitable facilities eg gym spaces to work in"

Sub-themes: Lack of equipment/facilities Working with groups Teach specific type of exercise e.g., Pilates	“I feel explosive training needs supervision and proper training, that can’t be done in a heterogeneous group setting where some participants have trouble with simple calf raises and others are hesitant and others would be willing to try.”
	“Have classes of 10 or more participants. Would prefer to have smaller numbers with that type of exercise”
	“I follow a program for older adults developed by Washington State University called Stay Active & Independent for Life (S.A.I.L.). To teach this program I have to follow their evidence-based format which does not include explosive exercises.”
Lack sufficient guidance Sub-themes: Against guidelines/recommendations Lack of evidence Instructor lacks relevant qualifications or experience	“Only because they individuals I train are not at that stage to be able to do this and over a certain age it is not recommended unless in sports”, “My client base are usually frail, deconditioned or have underlying health conditions, so these exercises would be contraindicated according to every qualification I have and according to basic risk assessments that are based on this and on individual ability.“
	“There is simply not enough evidence to support such a prescription in within the clinical populations (cardiac, respiratory and stroke) I work with and it is not part of current evidence-based guidelines”
	“Not done any training in this type of resistance training so don't feel confident teaching it”,
	“I would like to add explosive moves to their workouts, but need guidance on how to proceed.”,
	“Because I don't feel it is appropriate for the clientele that I have in my classes, it would be of little or no interest to them. And I have no qualification in such work and am not interested.”

5.4 Discussion

The primary aim of this study was to comprehensively explore the current implementation of MIV-RT among practitioners who prescribe exercise for OAs. Additionally, this study aimed to identify reasons why practitioners did not prescribe MIV-RT. Among the key findings was considerable variation in the educational and professional backgrounds of practitioners prescribing MIV-RT for OAs. Whilst some variation existed in MIV-RT prescriptions, certain practices were common among practitioners, including the prescription of jumping exercises and bodyweight as resistance. Additionally, some practitioners reported adverse events, but these were mainly limited to muscle soreness. For those who did not prescribe MIV-RT, prominent reasons included concerns over safety, the presence of comorbidities or injury and clients having insufficient physical abilities.

The current findings demonstrate that practitioners who prescribe MIV-RT for OAs have diverse educational and professional backgrounds. This includes variations in the professional settings of practitioners who prescribe MIV-RT. For example, 43.4% of practitioners worked in a gym or fitness centre; however, this was closely followed by community spaces (34.9%) and client homes (31.3%), highlighting the need to explore the efficacy of MIV-RT in various settings. However, the number of high-quality studies conducted within community spaces or homes remains low, and much of the evidence supporting MIV-RT for OAs comes from intervention studies conducted in laboratory settings, gyms, or a failure to report the exercise setting at all (Fielding *et al.*, 2002; Richardson *et al.*, 2019; Filho *et al.*, 2022). The limited representation of community spaces or homes may limit the transferability of research findings to real-world settings or could lead practitioners to adapt interventions to suit their environment, possibly reducing their effectiveness or increasing risks. Therefore, to bridge this gap between research and practice, future research should explore the efficacy and feasibility of MIV-RT in a diverse range of settings, considering the available equipment and facilities.

The MIV-RT prescriptions employed by practitioners showed some variation (Figure 5.5), however, certain practices were common among practitioners. For example, the majority of practitioners prescribed MIV-RT exercises 1-2 times per week (71.4%), along with 2 or 3 sets per session (79.3% for lower body), and 4-6 or 6-8 repetitions per set (52.7% for lower body) (Figure 5.5). While some of these prescriptions align with those typically utilised in research studies, there are also differences. For example, a narrative review of MIV-RT interventions for OAs reported that 35 out of 37 MIV-RT interventions in healthy and mobility-limited OAs involved 2-3 sets per exercise, which aligns with the prescriptions from the practitioners in this survey (Schaun, Bamman and Alberton, 2021). However, most studies in the review also utilised 8-12 repetitions, as opposed to the 4-8 repetitions more commonly prescribed by the practitioners in this survey, highlighting a difference between research and practice.

Published guidelines on repetitions for MIV-RT for OAs are lacking (Fragala *et al.*, 2019), highlighting the need for further investigation in this area. However, general RT recommendations for OAs as well as guidelines for novice adults recommend 8-12 repetitions per set (American College of Sports Medicine, 2009; Izquierdo *et al.*, 2021). In this survey, practitioners were not asked about their reasons for prescribing a certain number of repetitions, therefore reasons why the number of repetitions prescribed by practitioners in this survey is lower than those typically used in MIV-RT research (4-8 versus 8-12) are unclear. However, several factors could contribute to the disparities including differences in the prescribed magnitude of load, the type of exercises or the desired physiological adaptations. Several studies have demonstrated superior improvements in muscle mass and function with the use of fewer repetitions per set, challenging the need for >8 repetitions per set. For instance, Rodriguez-Lopez et al., (2022) found that low repetition high-load MIV-RT (6 sets of 6 repetitions at 80% 1RM) resulted in greater gains in 1RM than higher repetition low-load MIV-RT (6 sets of 12 repetitions at 40% 1RM) and promoted similar increases in peak power output and muscle hypertrophy. In addition, MIV-RT interventions in OAs adopting fewer repetitions per set through cluster sets have demonstrated superior improvements in muscle function when compared to 'traditional sets' (e.g., 8 - 10 repetitions) which may be through mechanisms including fatigue mitigation and the maintenance of maximal velocity across a training session (Latella *et al.*, 2021). These examples demonstrate that the 8-12 repetitions typically adopted in MIV-RT interventions and within general RT recommendations for OAs may not be necessary to elicit improvements in muscle mass and function. However, further investigation into the role of repetitions in MIV-RT for OAs is warranted to develop comprehensive evidence-based recommendations. In addition, exploration of the reasons behind practitioner prescriptions would provide valuable insight into factors influencing their choices and help bridge gaps between research and practice.

Jumps were the most prescribed lower body exercise, with at least one type of jump listed by 74.2% of practitioners (Table 5.3) which is considerably more than the second most prescribed lower body exercise, hops (36.4%). Research has shown that jumping, both as the only exercise in an intervention as well as within MIV-RT interventions containing multiple different exercises, can result in improvements in peak force, impulse, postural sway, and performance of activities of daily living, while having a low incidence of injury among healthy OAs (Correa *et al.*, 2012; Moran, Ramirez-Campillo and Granacher, 2018; Vetrovsky *et al.*, 2021). Assisted jumping, which reduces impact forces compared to bodyweight jumps, has also been found to be effective (Vetrovsky *et al.*, 2021; Tufano *et al.*, 2022).

In contrast to many published MIV-RT interventions, which involve machine-based exercises such as leg press or extension (Rice and Keogh, 2009; Rodriguez-Lopez *et al.*, 2022; Schaun *et al.*, 2022), the use of machines for lower body exercises was reported by just 21.7% of practitioners, while body weight and resistance bands were used by 90% and 66.7% of practitioners, respectively (Figure 5.6). In Chapter 4, which identified peer-reviewed MIV-RT interventions with robust study designs (randomised controlled trials, non-exercise controls, not multimodal), no interventions involved resistance bands and just one intervention utilised bodyweight as the main resistance (Correa *et al.*, 2012). Improvements in ADLs have been observed in non-controlled trials involving bodyweight exercises performed with maximal intentional velocity (Jaque *et al.*, 2021) and a community-based programme involving 'high-velocity movements'' with bodyweight and resistance bands (Tan *et al.*, 2018). However, meta-analyses concerning MIV-RT for OAs, which provide more robust estimates of intervention effectiveness than individual studies, involve predominantly machine-based exercises or fail to report exercises and equipment at all (Guizelini *et al.*, 2018; Da Rosa Orssatto *et al.*, 2019; Orssatto, Bezerra, Shield, *et al.*, 2020; Lopez *et al.*, 2022). Therefore, despite practitioners prescribing MIV-RT using resistance bands and bodyweight, the lack of robust evidence involving this type of equipment makes it difficult to determine their effectiveness and it is unclear which specific programming variables (e.g., reps, sets, rest) are needed for desired adaptations. Therefore, further research is warranted utilising these types of equipment.

Among the practitioners surveyed, the use of RPE was the most popular method for selecting loads and progressing exercises in MIV-RT (Figure 5.7). This approach is supported by previous research showing RPE was effective and equally beneficial as other methods such as percentage of 1RM (%1RM), repetitions in reserve and repetition maximum (RM) in improving maximum strength and performance of ADLs for OAs (Buskard *et al.*, 2019). Unlike %1RM, RPE does not require maximal strength testing at the beginning or during interventions, reducing participant burden. Additionally, RPE-based progression has been reported as the most tolerable and enjoyable method for OAs (Buskard *et al.*, 2019). RPE allows for session-by-session adjustments in training prescriptions based on factors such as pain, injury or fatigue, known as autoregulation (Shattock and Tee, 2022). This adaptability may improve adherence to MIV-RT, as pain, ongoing injury and feeling too tired are reported barriers to continued RT participation in OAs (Burton *et al.*, 2017). Despite the potential benefits of using RPE to select and progress loads in MIV-RT interventions for OAs, its use in research is limited. While RPE has been utilised in a small number of MIV-RT interventions with OAs (Bean *et al.*, 2009; Zech *et al.*, 2012; Tiggemann *et al.*, 2016; Yoon *et al.*, 2017), it is more common for researchers to use %1RM to select and progress loads and subsequently, expert guidelines and position statements concerning MIV-RT for OAs recommend loads based on %1RM values (Fragala *et al.*, 2019; Izquierdo *et al.*, 2021), suggesting a gap between research and practice.

This study did not explore the reasons why practitioners adopted certain methods, however, practitioners working with athletes have exhibited preference for monitoring methods that were time efficient and easy to administer (McGuigan *et al.*, 2020). Hence, it may be that practitioners working with OAs opt for RPE as it is quick and easy to administer (Buckley and Borg, 2011) which could be driven by preference or necessitated by time or resource constraints. Exploring factors that influence practitioners' decisions, including perceived barriers or benefits to adopting various methods would enable researchers to tailor their interventions towards the needs of practitioners, potentially leading to greater adoption of safe and effective evidence-based interventions in real-world settings.

The most commonly reported adverse event in the present study was muscle soreness, reported by 58.8% of respondents and accounted for 28.6% of all the adverse events provided. This is a significant proportion of respondents and contrasts with the literature where the reported occurrence of adverse events in MIV-RT interventions for OAs is low (Radaelli *et al.*, 2023). However, it has been highlighted that insufficient reporting of adverse events is common in MIV-RT studies for OAs (Balachandran *et al.*, 2022; see Chapter 4) making it difficult to accurately compare between research and practice. Moreover, it is unclear how often muscle soreness is evaluated or classified as an adverse event. In a survey of practitioners who prescribed blood flow restriction training, the occurrence of adverse events reported by practitioners, which was predominantly DOMS, were greater than those reported in the literature (Patterson and Brandner, 2017). It is possible that as a commonly expected result of unfamiliar exercise (McHugh *et al.*, 1999), muscle soreness may not be classified as an adverse event by researchers. However, reporting guidelines such as the CONSORT statement recommend that all adverse events are reported, including those that are expected

(Ioannidis, 2004). Considering DOMS has been shown to occur alongside decreases in postural stability, the performance of ADLs, increased fear of falling and reductions in non-exercise physical activity (e.g., housework) in OAs (Gray *et al.*, 2018; Naderi *et al.*, 2021) the degree of DOMS experienced may provide valuable insights into both physical and psychological risks associated with MIV-RT, informing its safety, tolerability and feasibility.

The current findings demonstrate that the prescription of MIV-RT was influenced by client psychological phenomena such as fear, lack of confidence and reluctance to engage in exercise (Table 5.5 and 5.6) and is demonstrated by the following quote:

> *“In my setting I only see very frail patients or those reluctant to engage in physical activity… Patients preconceived notions and expectations of those in their age group leads to resistance to comply. Psychological fears of failure or to not start to avoid risk of failing. Family wanting to 'keep safe' and avoid 'risk'.”*

Similarly, Gluchowski *et al.* (2023) who interviewed exercise instructors that prescribed RT for OAs, found that those practitioners experienced negative reactions from OAs including fear of RT. These findings suggest that for interventions to be adopted in practice, investigating the safety and acceptability of RT interventions among the target population may need to be considered as critical as assessing their efficacy.

Eight nine percent of practitioners that did prescribe MIV-RT indicated that there were certain situations or conditions where they wouldn’t prescribe MIV-RT (Table 5.5). The reasons for not prescribing MIV-RT shared many similarities to the reasons given by practitioners who never prescribed MIV-RT (Table 5.6). This included low or insufficient physical fitness, particularly poor strength and balance, as well as clients having existing health conditions. In particular, bone and joint issues (e.g., osteoporosis, arthritis) were frequently mentioned and risk of injury was identified as a common reason why practitioners did not prescribe MIV-RT (Table 5.6). However, these reasons for not prescribing MIV-RT do not necessarily align with published evidence. For example, MIV-RT interventions have taken place in people with osteoarthritis, osteopenia and osteoporosis with favourable outcomes (Von Stengel *et al.*, 2007; Hermann *et al.*, 2016; Aquino *et al.*, 2020). A 12-month MIV-RT intervention involving an individual with osteoporosis and increased risk of falling reported no adverse events and resulted in significant improvements in bone mineral density and balance (Aquino *et al.*, 2020). However, the investigators did implement an 8-week preparatory training phase involving TRT designed to improve baseline strength and ensure proper form was learned. Elsewhere, 49 postmenopausal women (23 classed as osteoporotic and the remainder osteopenic) completed 8 months of twice-weekly, 30-minute, supervised 'high-intensity resistance and impact training' where impact loading involved jumping chin-ups performed with maximal intentional velocity and drop landings (Watson *et al.*, 2018). Only one adverse event was recorded during the 2600 training sessions which was not related to the portion of the RT involving maximal-intentional velocity. Although some studies have reported cases of injury in MIV-RT interventions including dropouts due to exacerbation of osteoarthritis (Fielding et al. 2002) and joint pain (Marsh et al., 2009) similar events occurred in TRT groups suggesting MIV-RT poses similar risks to OAs as other training types. In addition, although international expert consensus guidelines on exercise for OAs suggest that the presence of frailty or poor balance may preclude the performance of plyometric training such as jumping onto boxes, they suggest that alternative exercises performed with maximum intentional velocity, can still be performed, such as rising from a chair as quickly as possible which can be progressed according to improvements (Izquierdo et al., 2021). However, despite these findings, the number of studies focussed on OAs with various mobility limitations or comorbidities remains low and as previously mentioned, the confidence in existing studies may be affected by methodological flaws or lack of reporting of adverse events. Hence it may be that practitioners require more robust evidence around safety before adopting certain training types.

It has been observed previously that exercise instructors that prescribed RT for OAs held preconceived ideas of what OAs could or should do with RT perceived by some as too challenging for OAs (Gluchowski et al., 2023). Similarly, it may be that the practitioners surveyed in the current study have misconceptions about MIV-RT as a training modality or have preconceived ideas of what OAs are able to do. This is demonstrated by the following quotes:

> *"My population are frail older adults with multiple co-morbidities and more often than not balance impairments and strength deficits that I believe would prevent them from completing explosive resistance training."*

> *"Because I don't feel it is appropriate for the clientele that I have in my classes, it would be of little or no interest to them. And I have no qualification in such work and am not interested. FLexercise classes give people the benefit from exercise to lead a life of physical and mental wellness rather than an intense work out. Enjoyment and physical and mental benefits are more important to us."*

In addition, chronological age was identified as a reason for not prescribing MIV-RT (Table 5.6) which presents a further example of preconceived ideas around the capability of OAs which may be misplaced. This is demonstrated by the following quotes:

> *“Most of my class members are over 85. Really don't think anything "explosive" is appropriate for this age group.”*

> *“Looking at maintenance of existing strength and mobility in a gentle form as most of my participants are over 70 years of age”*

> *“My only currant clients are a lovely married couple in their 90s, previously I worked with mixed ability groups of clients aged between 70 and 90 - explosive training would obviously be highly inappropriate for these people.”*

Feeling too old has been reported as a commonly perceived barrier to RT participation for OAs (Burton *et al.*, 2017). However, previous MIV-RT interventions in OAs aged over 80 years, including frail, institutionalised OAs have been well tolerated and elicited improvements in ADLs, RFD, maximal strength and impulse (Caserotti *et al.*, 2008; Cadore *et al.*, 2018). Therefore, although advancing age may be associated with increased comorbidities or mobility limitations requiring consideration, evidence suggests that age alone should not be used as a reason to avoid MIV-RT in OAs.

These findings have highlighted psychological aspects such as fear of RT as well as preconceived and perhaps misplaced ideas around MIV-RT as potential barriers to its implementation in practice, highlighting critical areas for future investigation in this field.

5.4.1 Strengths and Limitations

The present study has several limitations that should be acknowledged. Firstly, the predominantly quantitative data collection approach, while allowing for the collection of a wide range of variables and outcomes, may have limited the depth and richness of the data. For example, practitioners were not asked about the rationale for prescription choices. A multitude of factors such as time and resource limitations may have influenced their decisions, and therefore, including qualitative methods such as interviews alongside the survey could have provided greater insights into their practices. Also, practitioners may have been hesitant to report adverse events, potentially resulting in an underestimation of the frequency and nature of adverse events experienced with MIV-RT. Furthermore, the sample size was relatively small and consisted predominantly of practitioners from the UK. Therefore, the results may not be generalisable to other populations or globally. Nonetheless, this study is novel, provides valuable insights into MIV-RT practices among practitioners working with OAs, offering insights into barriers in the translation of research evidence to practical application and highlights critical gaps in knowledge in this field.

5.5 Conclusion

In conclusion, this study highlights disparities between research and applied practice, including the utilisation of different equipment and exercises and the occurrence of adverse events. Moreover, practitioners' reasons for not prescribing MIV-RT for OAs were identified, including a perceived lack of safety or risk of injury, that MIV-RT was unsuitable due to age or existing medical conditions, and that clients were reluctant to engage in MIV-RT due to fear, highlighting potential barriers to its implementation in real-world settings and critical areas for future research.

It is hoped that these findings can serve as a foundation to influence future research and encourage collaboration between researchers, practitioners and OAs, to tailor research studies to the needs of practitioners and OAs, ultimately enhancing the implementation of evidence-based RT for OAs.

Chapter: 6 Could postural stability be used to assess the safety of Maximal-Intentional Velocity Resistance Training? The Validity and Reliability of Inertial Measurement Units and Pressure Insoles.

6.1 Introduction

Minimising the risk of adverse events is an important consideration when designing RT interventions, requiring evidence-based information about the safety of a training type. This is essential for its adoption among health and exercise practitioners working with OAs. This is evidenced in Chapter 5, where practitioners reported that reasons for not prescribing MIV-RT to OAs included a perceived lack of safety or risk of injury, that MIV-RT was unsuitable due to age or existing medical conditions and that clients were reluctant to engage in MIV-RT due to fear.

However, chapter 2.5 highlighted that the safety of MIV-RT for OAs remains uncertain. MIV-RT has been considered safe based on the absence of adverse events reported in research studies (Vetrovsky *et al.*, 2019; Radaelli *et al.*, 2023). However, this approach relies on the accuracy and consistency of the measurement and the explicit reporting of adverse events. Yet, the findings in Chapter 4 indicate that within the current body of evidence, this may be insufficient, as only 42% of the studies adequately reported the type and number of adverse events that occurred during MIV-RT RCTs. Therefore, a more comprehensive assessment of the safety of MIV-RT is required.

As discussed in chapter 2.5.1, evidence suggests that OAs may experience acute physical impairments following MIV-RT, including reductions in maximal strength, RFD, and elevated markers of muscle damage (Rodriguez-Lopez *et al.*, 2021; Pinto *et al.*, 2022). However, findings regarding the nature and extent of these impairments are inconsistent. For instance, Rodriguez-Lopez *et al* (2021) observed significant decreases in maximal strength and RFD immediately after MIV-RT, along with elevated creatine kinase levels 24 h later, indicating potential physical impairments. However, these changes were not reflected in the time needed to complete 5STS which only increased ~0.4s, which is below the minimal detectable change previously reported for this test (2.5 s) (Goldberg et al., 2012). In contrast, Pinto *et al.* (2022) found that MIV-RT negatively affected the 6MWT at 24 h post-exercise, suggesting that acute impairments in ADLs may occur. However, in the same participants, performance in both the 5STS and TUG improved in the 48h following MIV-RT, indicating a potential learning effect in these tests which may render them unsuitable for detecting acute changes in muscle function.

Additionally, OAs may adopt less stable movement patterns to maintain speed during ADLs (Helbostad *et al.*, 2007; Esbjörnsson and Naili, 2020). Therefore, despite the ease of administration and minimal equipment requirements, time-based tests such as 5STS and TUG may not be sufficiently sensitive to identify potential adverse events following MIV-RT. Consequently, identification of practical and sensitive measurement tools is necessary to better assess the safety of MIV-RT for OAs.

As discussed in chapter 2.5.1, precise measurement of postural stability, typically acquired as the centre of pressure (COP) and its trajectory (i.e., postural sway), may offer a solution. COP is the point where the combined forces from all forces applied to a contact area (e.g. foot) on a surface (e.g. the ground) are concentrated and has been predictive of fall risk in OAs (Maki, Holliday and Topper, 1994; Piirtola and Era, 2006; Johansson *et al.*, 2017; Watt, Clark and Williams, 2018; Quijoux *et al.*, 2020). Evidence suggests that exercise, particularly, fatiguing exercise may subsequently increase COP trajectories in OAs (Baudry *et al.*, 2007; Egerton, Brauer and Cresswell, 2009; Morrison *et al.*, 2016; Naderi *et al.*, 2021) and thus, pose an increased fall risk. For instance, as previously mentioned (ch. 2.5.1), Naderi et al. (2021) found that in OAs, a single bout of calf muscle RT designed to induce muscle damage significantly increased COP area which remained elevated 72 h after the training session. This suggests that OAs may suffer from impairments in postural stability for several days after RT. Therefore, the measurement of postural stability before and in the days following a bout of MIV-RT is a potentially valuable tool for assessing its safety and suitability. The effects of MIV-RT on postural stability in OAs have yet to be explored but could provide important information about its safety and suitability for this population. For instance, examining the acute effects of different MIV-RT interventions on postural stability alongside fatigue, pain and falls risk in OA both immediately post-exercise and in the days following would provide both objective and subjective information about the safety of MIV-RT and guide future programming.

However, to ensure that an investigation of this kind yields accurate conclusions, prior identification of valid and reliable measurement tools is required. In addition, the ability to use equipment in the field at a clinic or within the home could improve the ecological validity of an exercise intervention study (i.e., the extent to which the findings of a study can be applied to real-world environments, (Schmuckler, 2001). Currently, the measurement of COP and its trajectory is commonly collected using force plates, which whilst considered the gold standard for capturing COP, are often restricted to laboratories, requiring expertise to operate and are costly. Therefore, using force plates to assess the acute effects of a MIV-RT intervention on postural stability would require participants to travel to a laboratory before and after each training session. This would present a burden to the participant, may not be feasible for studies with large sample sizes (e.g., group training sessions) and would have limited applicability in real-world settings. Therefore, the identification of alternative measurement tools that are valid, reliable and have real-world applicability is necessary.

Potential alternatives to force plates include wearable devices such as pressure insoles and inertial measurement units (IMU). Pressure insoles, such as the Tekscan F-scan (Tekscan, Inc., South Boston, MA, USA) (INS), provide pressure, force, and timing feedback via ultra-thin sensors secured inside the shoe (Tekscan, no date). The INS system is portable, has software designed for clinician use, and offers automated COP analysis, increasing its appeal for use in practice. Using INS, reliable measurements of peak pressure have been observed during treadmill walking in healthy adults (Patrick and Donovan, 2018) and when using machines designed to replicate foot contact areas. However, to the authors' knowledge, no studies have established the validity and reliability of the INS system to measure COP and its trajectory during a range of static balance tasks meaning its current applications may be limited. INS has been used to measure changes in standing balance in healthy adults following disturbed sleep, where significant increases in COP area, amplitude, and standard deviation were observed (Montesinos *et al.*, 2018). Although Montesinos et al. (2018) did not examine the validity or test-retest reliability of these measures, they found no significant COP deviations in a control group, suggesting a reliable INS measurement that is able to detect change in

COP. However, Montesinos et al. (2018) only evaluated balance during a two-foot eyes-open balance; therefore, the generalisability of their findings to other balance activities is limited.

In OAs, more challenging balance activities, such as balancing with eyes closed or on a single leg, as well as semi-tandem and full-tandem balance tasks are commonly assessed (Drey *et al.*, 2012; Edholm, Strandberg and Kadi, 2017; Omaña *et al.*, 2021) and may be superior at discriminating fallers from non-fallers (Watt, Clark and Williams, 2018). Therefore, investigating the validity and reliability of INS in more challenging balance activities, particularly those commonly assessed in OAs, would provide a robust evaluation of its suitability as a force plate alternative and guide the selection of appropriate measurement tools for assessing postural stability in OAs.

It should be noted that the INS insoles must be cut to size for each individual and have limited uses, presenting potentially restrictive factors for community settings. Alternatively, IMUs are small, chargeable devices that may be worn on the body or built into commonly used devices, such as smartphones, which may offer greater applicability in practical settings. IMUs are typically comprised of tri-axial accelerometers, a magnetometer, and a gyroscope and research suggests that data captured using these devices may provide an accurate measurement of postural stability in healthy OAs during a variety of balance tasks (Hsieh *et al.*, 2019; De Groote *et al.*, 2021). In multiple studies, acceleration data captured using smartphone embedded IMUs have shown moderate to strong correlations with force plate-derived COP variables (Hsieh *et al.*, 2019; De Groote *et al.*, 2021). In addition, these studies found that more challenging balances (e.g., single-leg, semi-tandem, full-tandem) were better correlated with force plate outcomes than less challenging balances (e.g., dual-legged, eyes open), suggesting semi-tandem balance as the best choice for smartphone-based assessments of postural stability (De Groote *et al.*, 2021).

These studies demonstrated the potential of using IMU derived acceleration data to measure postural stability. However, participants were required to either hold a smartphone at the sternum and maintain the correct orientation of the phone during the tasks or have the phone attached to their lower back, both of which required assistance or monitoring from researchers. Consequently, errors may occur without supervision, which limits the feasibility of utilising smartphones in community / free-living conditions.

Alternatively, RunScribe™ footpods (Scribe Labs Inc. San Francisco, CA, USA) (RS) are commercially available IMUs that are worn on the laces or heel of the shoe, and therefore, are not a concern for the wearer (Runscribe, no date). RS capture kinematic, kinetic, and spatiotemporal data of each step taken and data are collected via Bluetooth to an application on the user's smartphone, smartwatch, or web browser. This allows the wearer to move freely in their natural environment (Runscribe, no date), and thus could be a promising alternative for collecting data at low-cost and with low participant burden in a real-world setting. The RS have shown good to excellent validity for the measurement of spatiotemporal parameters such as maximum foot pronation velocity, contact time and cycle time during running (Koldenhoven and Hertel, 2018; García-Pinillos *et al.*, 2020). However, the validity and test-retest reliability of RS for measuring postural stability during standing balance have not yet been examined.

Therefore, the aim of this study was to examine the potential of RS and INS to measure postural stability by assessing their concurrent validity and reliability compared with gold standard force plates. A secondary aim was to identify the most valid and reliable combination of COP variables and balance activities. The outcomes of this study were intended to inform the design of a study aimed at measuring the acute effects of MIV-RT on postural stability in OAs and a subsequent RCT. However, the unexpected challenges posed by the two-year global COVID-19 pandemic made this unattainable. Further details about the impact of the COVID-19 pandemic on this thesis can be found in chapter 1.3..

6.2 Methods

6.2.1 Study Design

An experimental, repeated measures design was used with all data collected for each participant during two testing sessions, separated by a minimum of 48 hours and a maximum of one week. The second session took place at approximately the same time of day and participants were asked to refrain from vigorous physical activity in the 24 hours before each testing session to avoid any effects on postural stability.

6.2.2 Participants

Fourteen healthy volunteers participated in this investigation. An additional three individuals were recruited however due to the COVID 19 restrictions that were enforced in March 2020, data collection for this study was stopped prior to their participation.

Participants were recruited according to convenience by sampling from university staff and students. Exclusion criteria included lower body musculoskeletal injury, visual impairment, balance problems, or any other conditions that may affect balance. All participants provided written informed consent prior to participation. Ethical approval was granted by Sheffield Hallam University's Research Ethics Committee (ER16756304).

6.2.3 Experimental Set-up

6.2.3.1 Equipment

Force plate: Kistler force plates (9281CA, 400mmx600mm) (FP) sampling at 400 Hz captured ground reaction forces and COP data. Data was collected using BioWare software installed on a desktop computer.

Pressure insoles: INS with 3000E sport insoles sampling at 200 Hz captured COP data. The ultra-thin insoles (0.15mm) containing approximately 954 sensors (Tekscan, no date b) were cut to size according to the manufacturer's guidelines to fit the participants shoe size. The INS system includes a hub connected to ankle-worn transmitters via Ethernet cables by which the insoles are connected. The system was connected to a laptop computer via USB cable and data were collected using the F-Scan Research 7 software.

IMU sensors: RS sampling at 500 Hz captured acceleration data. Initially, the sensors were secured using cradles attached to the heel of the participant's shoe. However, mid-way through data collection, this approach was no longer supported by the RunScribe™ application, therefore the sensors were subsequently attached to the laces of the shoe for all remaining participants. In all instances, the orientation of the sensor was aligned parallel to the force platform surface ensuring the direction of axes were comparable between devices. Data were captured as raw acceleration data using the RunScribe™ application installed on an Apple iPad.

Running shoes (Kalenji, run ONE) were used for all participants. The following shoe sizes were used: UK 5.5, 6.5, 8.5, 9.5.

6.2.3.2 Preparation

Participants' stature (m) and body mass (kg) was recorded at the start of the first testing session. Subsequently, participants were asked to put on the provided shoes and secure them comfortably, avoiding any trailing laces. Each shoe was pre-fitted with a pair of pressure insoles secured with double-sided tape to avoid movement inside the shoe. The insoles were then connected to the transmitters secured to the participant's ankles using straps before being connected to the hub. To avoid the risk of trips, the Ethernet cables were run up the back of the participant's lower limbs and kept in place with a waist belt. The researcher checked that the cables were secure prior to any activity performed by the participant. The RS were then attached to the shoes and were not felt by the participant.

6.2.3.3 Calibration

All devices were calibrated according to the manufacturer's instructions prior to data collection for each participant. This involved the participant performing two-footed and single-footed standing balances. The researcher stood next to the participant during balance activities to provide support if necessary.

6.2.4 Data Collection

The name and order of balance activities performed during testing sessions are shown in figure 6.1. Balances were selected to represent a range of conditions to challenge the base of support and include those assessed within the short physical performance battery (SPPB) (Guralnik *et al.*, 1994).

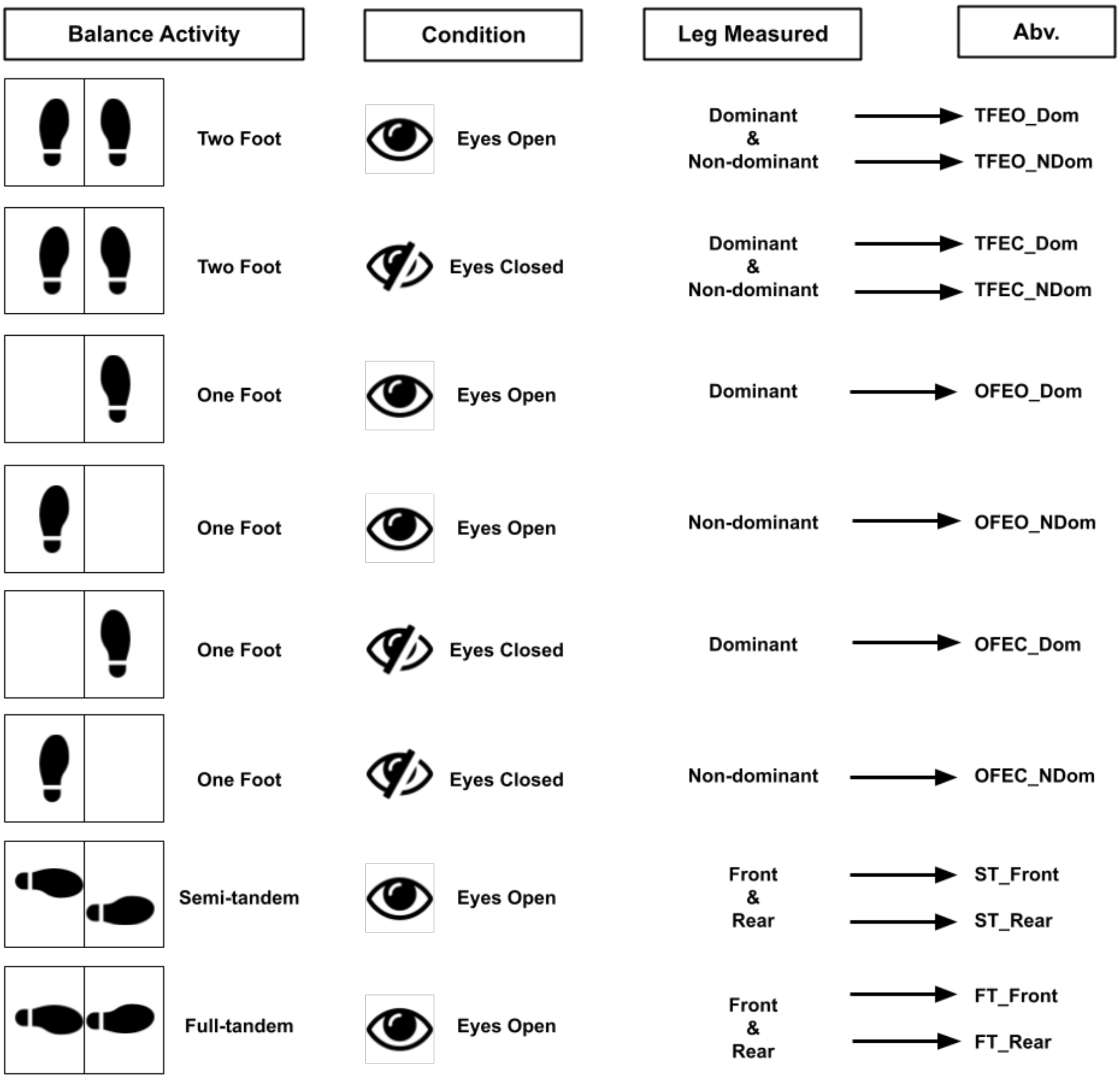


Figure 6.1 - Balance activity order from top to bottom. The twelve resultant abbreviations used for each combination of activity, condition and measured leg are shown. Each footprint in the diagram corresponds to each of the twelve abbreviations.

All activities were performed once, and a period of rest (2-5 minutes) was allowed between each activity whilst data was downloaded from the RS. To allow synchronisation of all devices during data processing, participants were asked to step onto the force plates and jump at the start of each activity.

Each balance activity lasted for 10 seconds. A duration of 25-40 s is recommended by The International Posture and Gait Research Society as postural control may require a period of adjustment (Scoppa *et al.*, 2013). However, 10 seconds was chosen in this instance to reflect the real-world application of the SPBB where participants perform two-foot and tandem balances for a maximum of 10 seconds (Guralnik *et al.*, 1994). Before data was collected for each activity, the researcher demonstrated the correct technique to the participant who then practised the required movements until they felt accustomed to the activity and were able to perform it correctly. During each balance activity, participants were instructed to face forwards and to refrain from talking. Participants were allowed to use their arms to retain balance if required as this is permitted in the SPPB (Guralnik *et al.*, 1994). To begin each balance, the researcher asked the participants if they were ready to start before giving them a countdown of "3, 2, 1, go". On the command "go", the three devices were manually started to capture data and the participant stepped onto the force plate and jumped. Following this, participants moved into the required balance position with verbal guidance from the researcher. When participants were in the correct balance position, the researcher monitored a stopwatch to ensure a minimum of 10 seconds was completed before stopping the devices then informing participants to return to a relaxed position. If participants were unable to keep their balance for 10 seconds, then the process was repeated for a maximum of three attempts.

COP displacement data in both anterior-posterior (AP) and medial-lateral (ML) direction was exported from the FP and INS for each leg separately. For the RS, acceleration data from each foot was exported as local linear acceleration in the AP and ML direction corresponding to the force plate.

6.2.5 Data Processing

6.2.5.1 Data Cropping and Import

To synchronise the data from all three devices, the point of touchdown after jumping was identified using the vertical ground reaction force for the FP and INS, and vertical acceleration for the RS. This was done for left and right feet independently on all devices. Subsequently, FP data was used to identify and crop 10 seconds of static balance from the end of the data and an excel spreadsheet was used to calculate the corresponding frames required from INS and RS.

Using a custom-built MATLAB script (R2022b, Mathworks, Natick, Massachusetts, USA), all cropped data in both AP and ML directions was imported to MATLAB. Simultaneously, it was normalised by subtracting the mean value and filtered using a Butterworth, zero-lag 4^{th} order, 10 Hz low pass filter (Winter, 2009). In addition, data from the FP and INS were resampled to a uniform length of 5000 data points to match the data from the RS.

6.2.5.2 Calculation of Variables

For each combination of balance activity, condition and leg; outcome variables were calculated in MATLAB according to equations presented by (Prieto *et al.*, 1996) (Table 6.1). The FP and INS outcome variables were chosen as they have previously been shown to be predictive of falls in OAs (Piirtola and Era, 2006).

Table 6.1 - Outcome variables and the MATLAB code used for their calculation.

Device	Outcome Variable	Abv	MATLAB code
FP & INS	Total Mean Absolute Velocity of COP	MVtot	`(sum(sqrt(diff(COPap).^2+diff(COPml).^2)))/T`
	AP Mean Absolute Velocity of COP	MVap	`(sum(abs(diff(COPap))))/T`
	ML Mean Absolute Velocity of COP	MVml	`(sum(abs(diff(COPml))))/T`
RS	AP Mean Absolute Acceleration	MACCap	`mean(abs(ACCap))`
	ML Mean Absolute Acceleration	MACCml	`mean(abs(ACCml))`
	AP RMS Acceleration	RMSap	`sqrt(mean(ACCap.^2))`
	ML RMS Acceleration	RMSml	`sqrt(mean(ACCml.^2))`

COPap = centre of pressure displacement in the AP direction; **COPml** = centre of pressure displacement in the ML direction; **T** = total time in seconds; **ACCap** = linear acceleration in the AP direction; **ACCml** = linear acceleration in the ML direction

6.2.6 Statistical Analysis

Data were exported into and statistically analysed using SPSS v24 (IBM Corp, Armonk, NY). Data were checked for normal distribution using the Shapiro-Wilk test for normality. As some data were found to be not normally distributed yet still monotonic in nature, concurrent validity (INS and RS vs FP) and test-retest reliability (Day 1 vs Day 2) was assessed with Spearman rank order correlations for all combinations of balance activity, condition, and leg (Figure 6.1). Correlations coefficients of 0.1 were considered weak, 0.4 were considered moderate, and 0.7 were considered strong (Dancey and Reidy, 2007). The correlation coefficients 95% confidence intervals were also estimated (Fieller and Pearson, 1957).

6.3 Results

Fourteen healthy volunteers participated in this investigation. However, in two cases, significant equipment malfunction occurred with the INS system and so, data was unable to be collected. Therefore, data for twelve participants were analysed (8 males and 4 females, mean age 28 ± 12 years; body mass 75.8 ± 16.2 kg; stature 173.2 ± 7.7 cm).

6.3.1 Validity

Spearman's correlations between FP and insoles and FP and RS are depicted in figure 6.2 (two-foot balance activities), figure 6.3 (one-foot balance activities) and Figure 6.4 (tandem balance activities).

6.3.1.1 Insoles

Correlations for INS vs FP mostly ranged from weak to strong (Figures 6.2 - 6.4). Between balance activities, the one-foot activities showed the strongest correlations and in particular during eyes-closed conditions (Figure 6.3). Two-foot balances were mostly moderately correlated and total and AP mean velocity showed stronger correlations than ML (Figure 6.2). During one-leg balances, total, AP and ML velocities showed similar strength of correlations. Tandem balances showed weak to strong correlations for total and AP mean velocities and no to moderate correlations for ML mean velocity (Figure 6.4).

6.3.1.2 Inertial Measurement Units

Correlations for RS vs FP mostly ranged from none to moderate (Figures 6.2 - 6.4). The strongest correlations were observed during one-leg eyes closed activities which were more consistent in ML directions than AP (Figure 6.3). Correlations for two-foot balance activities were mostly none-to-weak but were stronger during eyes closed conditions (Figure 6.2). During tandem balances, correlations were mostly weak but were strongest during eyes closed conditions measured in AP directions (Figure 6.4).

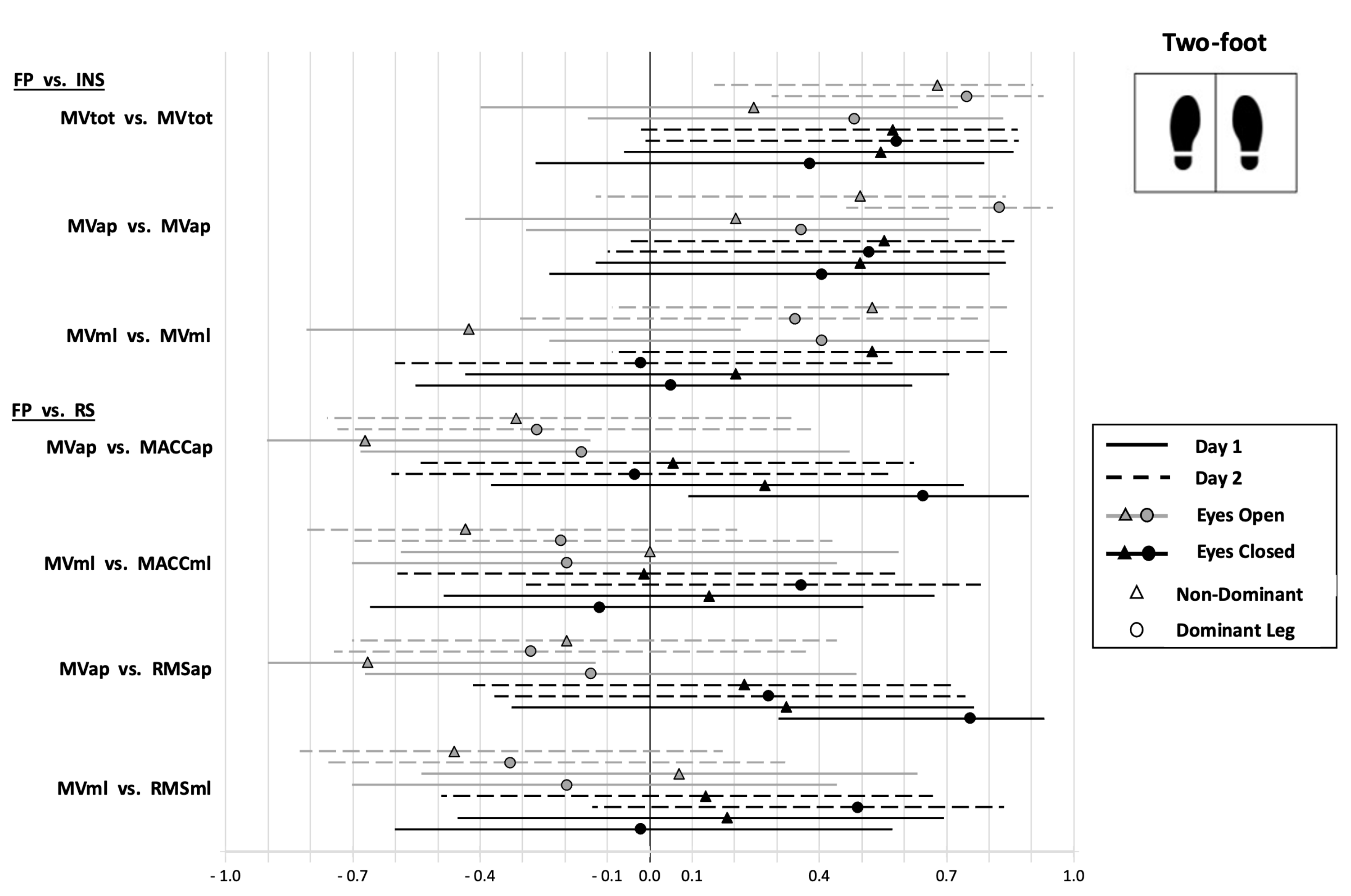


Figure 6.2 - Spearman correlation coefficients with their 95% confidence intervals for Force Plate vs Insoles and Force Plate vs Inertial Measurement Units outcome variables in all two-foot activities for each day, condition, and leg.

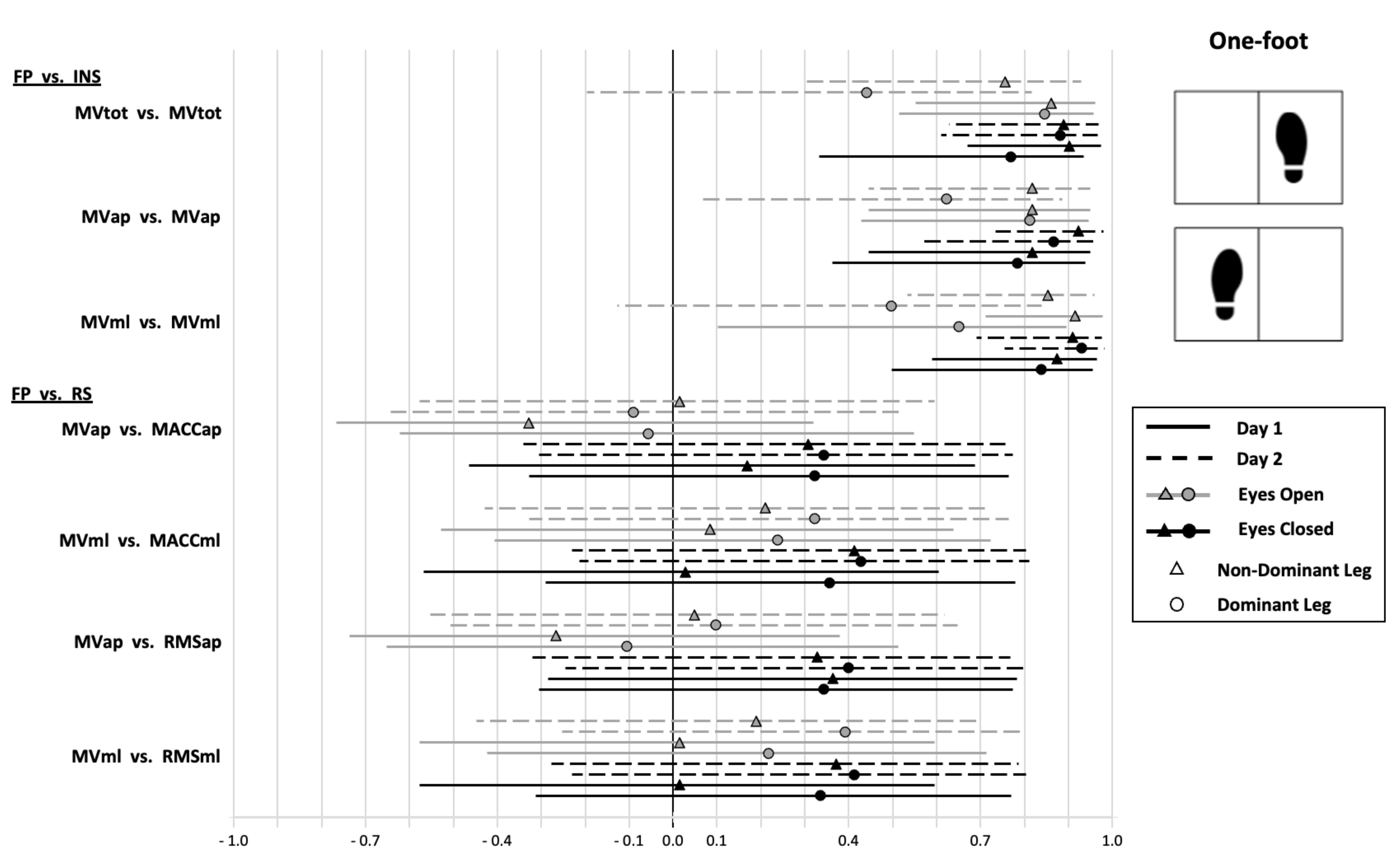


Figure 6.3 - Spearman correlation coefficients with their 95% confidence intervals for Force Plate vs Insoles and Force Plate vs Inertial Measurement Units outcome variables in all one-foot activities for each day, condition, and leg.

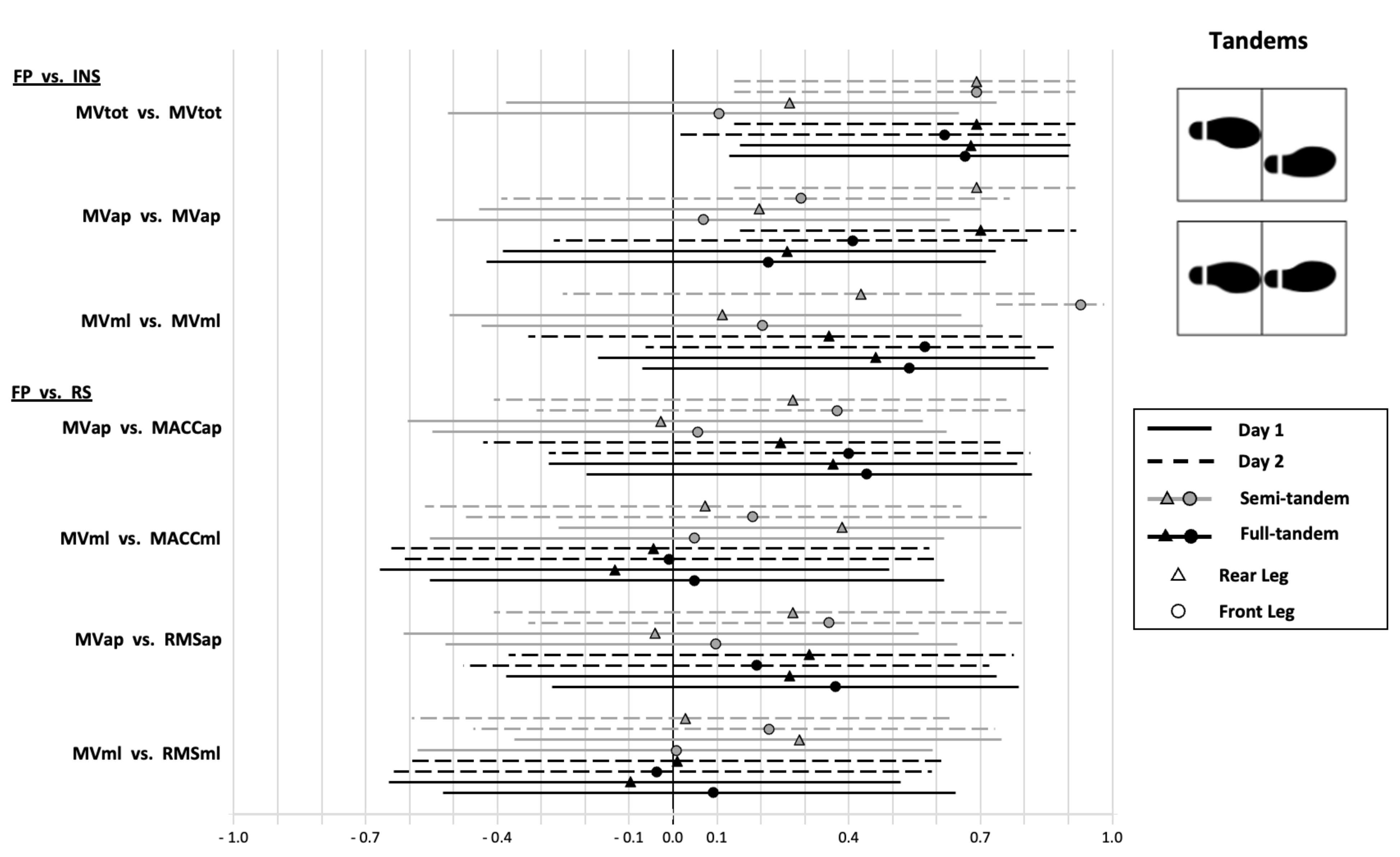


Figure 6.4 - Spearman correlation coefficients with their 95% confidence intervals for Force Plate vs Insoles and Force Plate vs Inertial Measurement Units outcome variables in all tandem activities for each day, activity, and leg.

6.3.2 Test-retest Reliability

Figure 6.5 depicts the Spearman's correlations between day one and day two for all devices.

6.3.2.1 Force Plates

Correlations ranged from weak to strong (Figure 6.5-A). All two- and one-foot activities showed moderate to strong correlations for total and ML mean velocities. Eyes closed conditions for the non-dominant leg showed consistently strong reliability across all outcome measures. The front leg for semi-tandems showed consistently weak reliability across all outcome measures, whereas the rear leg showed strong correlations for the total and ML mean velocities. The total mean velocity displayed the highest number of strong correlations.

6.3.2.2 Insoles

Correlations ranged from weak to strong (Figure 6.5-B). Except for one outcome (one-foot eyes open dominant ACCml), all outcome variables for one-foot balance activities showed moderate to strong correlations. One-foot eyes open on the non-dominant leg had strong correlations for all outcome variables. Two-foot balances showed weak to strong correlations across all outcome variables and conditions, however strong correlations were observed during eyes closed conditions and measured in AP directions. The front and rear legs during semi-tandem had moderate to strong correlations for all outcome variables. The front leg during full tandem had strong correlations for all outcome variables, whereas the rear leg had moderate to strong correlations. Total mean velocity displayed the greatest number of strong correlations.

6.3.2.3 Inertial Measurement Units

Correlations ranged from none to strong (Figure 6.5-C). Two-foot (ML), semi-tandem (AP), and full-tandem (AP) activities on the dominant or front leg showed no to weak reliability. However, all other activities ranged from moderate to strong across all the outcome measures. All one-foot balance activities showed moderate to strong correlations. The mean accelerations exhibited stronger correlations than the RMS accelerations in both the AP and ML direction.

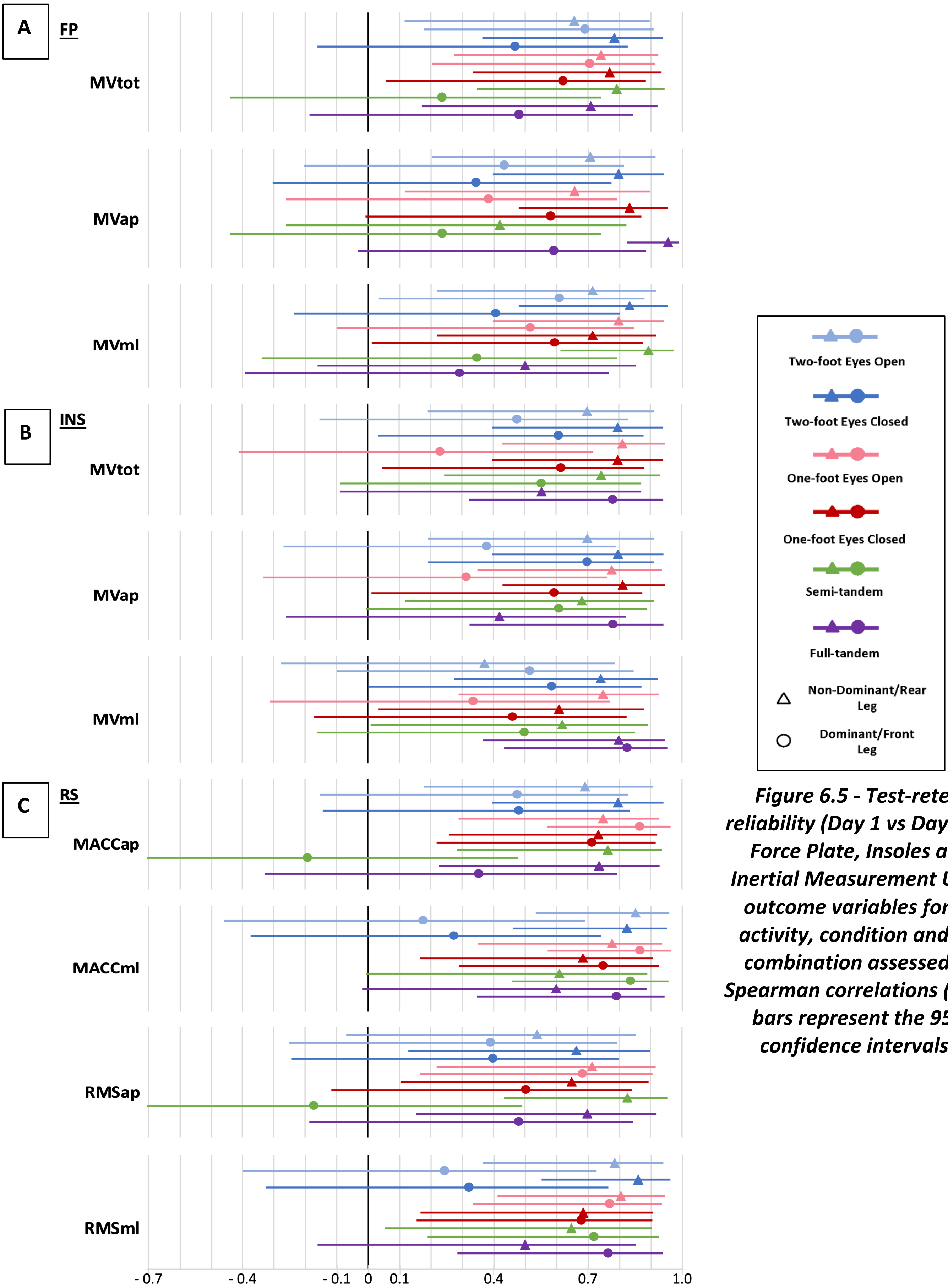


Figure 6.5 - Test-retest reliability (Day 1 vs Day 2) of Force Plate, Insoles and Inertial Measurement Units outcome variables for all activity, condition and leg combination assessed by Spearman correlations (error bars represent the 95% confidence intervals).

6.4 Discussion

The aim of this study was to evaluate the concurrent validity and reliability of RS and INS in measuring postural stability, compared to the gold standard, FP. A secondary aim was to identify the most valid and reliable combination of outcome variables and balance activities.

The main findings of this study suggest that the INS demonstrates both validity and reliability, although this may depend on the balance activity and outcome variable measured. In contrast, the RS was found to be reliable but not valid in assessing postural stability. Among the different balance activities tested, one-foot balances on the non-dominant leg with eyes open or closed was the most valid and reliable.

The results indicate that INS may be a valid and reliable tool to measure postural stability. Correlations between INS and FP outcomes ranged mostly from weak to strong, however, the results revealed consistently strong correlations for one-foot balance activities in both eyes open and closed conditions (Figure 6.3). In addition, regarding test-retest reliability, one-foot balances exhibited strong correlations between day 1 and 2 for both INS and FP with the greatest consistency observed on the non-dominant leg. Therefore, one leg balances on the non-dominant leg with eyes open or closed appears to be both a valid and reliable activity when using INS.

Two-foot and tandem balances showed poorer correlations and were mostly weak to moderately correlated between INS and FP (Figures 6.2 and 6.4). In addition, the strength of reliability varied between conditions and outcome variables measured, suggesting the INS may not provide precise and consistent measurement during these activities. However, this was also the case for FP test-retest reliability which means that reliability may have been affected by day-to-day variability in the task itself. In this study, participants balanced for 10 seconds, however it has been recommended that a period of at least 25 s is required for COP trajectories to become stable and reliable (Scoppa *et al.*, 2013). The period of 10 seconds was chosen in this instance to reflect the common real-world application of balance activities such as during the SPBB where participants perform two-foot an tandem balances for a maximum of 10 s (Guralnik *et al.*, 1994). However, it is possible that balances of longer duration are required to provide more reliable outcomes during these activities.

Nevertheless, the similar levels of test-retest reliability observed between FP and INS across all activities, conditions, and COP variables suggests that the INS could serve as a viable substitute for FP in measuring postural stability. In addition, for both INS and FP, the three COP outcome measurements (total, AP and ML mean velocity) showed similar reliability across all balance activities indicating their potential utility. However, total mean velocity, which incorporates both AP and ML trajectories, exhibited the highest number of strong correlations and demonstrated the most consistent reliability during one-foot balance activities, making it a potentially favourable option.

The correlations between RS and FP outcome variables were mostly weak, suggesting the RS is not a valid tool to measure postural stability during standing balance (Figures 6.2, 6.3, 6.4). However, the RS exhibited more strong correlations than FP or INS in terms of test-retest reliability. This suggests that the RS may produce consistent outcome measurements but fails to capture subtle changes in postural stability detectable by FP and INS, resulting in lower validity. Previous studies have reported moderate to strong correlations between accelerations from smartphone embedded IMUs and FP COP variables, which contrasts with the current findings (Hsieh *et al.*, 2019; De Groote *et al.*, 2021). These studies also found semi-tandem to be a reliable and valid balance activity, whereas in the current study, semi-tandem balance activities showed mostly weak correlations (Figure 6.4). However, the contrasting outcomes may be attributed to the location of the IMU sensor, as the RS attaches to the participant's shoe while the smartphone studies positioned the device at the chest or back. Therefore, the validity of IMUs to measure postural stability appears to be dependent on the location of the sensor.

The RS have previously shown good to excellent validity for the measurement of spatiotemporal parameters such as maximum foot pronation velocity, contact time and cycle time during running (Koldenhoven and Hertel, 2018; García-Pinillos *et al.*, 2020). However, the current study indicates that despite offering a promising alternative for collecting data at low-cost, low participant burden in real-world settings, the RS is not a viable replacement for FP for the measurement of postural stability. In contrast, the INS may offer a valid and reliable alternative to the use of FP, however they have potentially restrictive factors for community settings such as limited uses and the need to be cut to size for each individual.

Therefore, at present, in situations that require practical and sensitive measurement tools such as research investigating the acute effects of RT protocols on OAs, alternative methods, such as smartphone embedded IMUs which have shown moderate to strong validity and reliability may offer the best available solution.

6.4.1 Strengths and Limitations

This study provides a novel contribution as to the authors knowledge this is the first to investigate the validity and reliability of the INS system in measuring COP compared to the gold standard. Also, to the author's knowledge, this is the first evaluation of commercially available shoe worn IMUs for assessing postural stability. Additionally, the assessment of various balance activities provides valuable insights into the validity and reliability of single leg versus two-foot balances.

However, the sample size was relatively small, and the participants mainly represented a young demographic which may limit the generalisability of the results to other population groups. Additionally, it is important to consider that the study was conducted under controlled laboratory conditions, which may not fully reflect real-world environments. Furthermore, the change in the location of the RS from the heel to the laces during data collection, although unavoidable, could have influenced the results, as previous evidence has shown that the placement of sensors can affect outcome accuracy (García-Pinillos *et al.*, 2020).

6.5 Conclusion

Based on the combination of strong correlations between INS and FP outcome measurements, as well as comparable test-retest reliability, the INS could serve as a valid and reliable alternative to FP. However, the choice of balance activities plays a role in the strength of this validity and reliability. Among the different balance activities tested, one leg balances on the non-dominant leg with eyes open or closed appears to be the most valid and reliable. In contrast, RS were found to be reliable but not valid in assessing postural stability, which may be attributed to their location on the foot or a lack of sensitivity to detect small changes in postural stability.

However, the INS have several practical limitations which may limit their suitability for community settings. Therefore, at present, in situations that require practical and sensitive measurement tools such as research projects aimed at measuring the acute effects of RT protocols on OAs, alternative methods, such as smartphone embedded IMUs which have shown moderate to strong validity and reliability may offer the best available solution.

Chapter: 7 General Discussion

This final chapter summarises the main findings of this thesis. In addition, the limitations of the programme of work are discussed alongside suggestions for future research.

7.1 Summary of the Research

The aim of the work presented in this thesis was to investigate and critically evaluate the evidence base and implementation of MIV-RT for older adults, and to provide recommendations to improve the design and dissemination of future MIV-RT interventions.

Globally, the number and proportion of OAs is increasing (United Nations, 2019). Older age is associated with significant declines in muscle mass and function which affect the ability to perform activities of daily living (ADLs), independence, quality of life (QoL), risk of mortality, and healthcare costs, implicating that these changes in muscle as a major health issue for individuals and society (Lanza *et al.*, 2003; Maden-Wilkinson *et al.*, 2015; Beaudart *et al.*, 2017; Kim *et al.*, 2018). RT is an established and effective intervention to improve muscle mass and function (Kraemer *et al.*, 2017; Fragala *et al.*, 2019; Katsoulis, Stathokostas and Amara, 2019) and in recent years, RT performed with maximal-intentional velocity (i.e., MIV-RT) has emerged as an effective and endorsed modality to improve muscle mass, function and ADLs in OAs (Cadore *et al.*, 2018; Orssatto *et al.*, 2019; Blazevich *et al.*, 2020b; Schaun, Bamman and Alberton, 2021; Rodriguez-Lopez *et al.*, 2022; Morrison *et al.*, 2023).

Despite the supposed plethora of benefits from undertaking MIV-RT, the literature review (chapter 2) highlighted that methodological issues in research studies preclude the ability to draw definitive conclusions about efficacy and safety influencing the possibility of establishing best practices in the field. Therefore, the programme of research presented in this thesis was devised to investigate and critically evaluate the implementation of MIV-RT for OAs and to provide recommendations for the use of MIV-RT in research and practice to counteract age-related declines in muscle mass and function.

The narrative review, presented in Chapter 3, aimed to address the issue of interchangeable and inaccurate use of terms related to rapid force production, which is an issue in all areas of sports and exercise science (Winter et al., 2016, Cronin and Sleivert, 2005, Knudson, 2009) including MIV-RT for OAs (Chapter 2.4.1.3). Building upon previous attempts to clarify terminology in the field of athletic performance (Winter et al., 2016, Knudson, 2009, Turner et al., 2020), this chapter provided clarity and standardisation of terms used to measure and describe the ability to produce force rapidly specifically in RT interventions for OAs. This narrative review has the potential to enhance understanding and consistency in the application of terminology, facilitating effective communication of research findings. This is crucial for reducing the possibility of misinterpretation and ensuring that accurate conclusions can be drawn from studies in this area. In addition, by defining the terms typically used in the literature, proposing standard applications for each term/variable, and discussing their function in RT research for OAs, this narrative review offers guidance to researchers and practitioners to identify the variables that are most relevant to the desired performance in their interventions and thus, develop effective RT interventions.

The literature review highlighted that in MIV-RT interventions for OAs, a wide range of training variables and stimuli are being employed by researchers (Chapter 2.4.1). While many authors have acknowledged variation in intervention characteristics, limited discussion has been made about the potential effects of different intervention designs on frequently measured outcomes such as ADLs, making it difficult to determine which specific variables or combinations of variables are responsible for the observed effects and hindering the establishment of clear recommendations. In particular, little attention had been given to the exercises or equipment selected by researchers, despite the influential role exercise selection plays in the specificity of a RT intervention, a fundamental principle of effective RT (Chapter 2.3.4). Understanding the specificity of RT interventions is essential for understanding their effectiveness and optimising training guidelines for OAs.

Therefore, a systematic review (Chapter 4) was conducted to evaluate the degree of specificity between RT programmes and outcome measurements in MIV-RT interventions for OAs. This review utilised the concept of dynamic correspondence, a set of five criteria first introduced in the 1990s to evaluate the mechanical similarity of an exercise to a particular sporting skill or outcome (Verkhoshansky and Siff, 2009). Mechanical specificity suggests that the closer exercises are to the performance outcomes in terms of kinetic and kinematic variables (e.g., direction and rate of force application, muscle actions, joint motion), the greater the likelihood of improvement and transfer of training effects (Thepaut-Mathieu, Van Hoecke and Maton, 1988; Wilson, Murphy and Walshe, 1996; Stone, Stone and Sands, 2007). Thus, in MIV-RT interventions for OAs, the degree of improvement in ADLs outcomes may be influenced by the kinetic and kinematic specificity of the exercises employed, making it important to consider in both the design and interpretation of interventions. While recognised by the strength and conditioning community as an approach to select training exercises that are mechanically similar to sporting movements of interest (Cleather et al., 2013; Suarez *et al.*, 2019; Laakso and Schuster, 2021), dynamic correspondence has yet to be applied to interventions concerning OAs and movements of importance, such as ADLs. Thus, this study's novel application of dynamic correspondence in MIV-RT interventions for OAs provided new and much needed insights into the effective implementation of MIV-RT.

A key finding of this review was that interventions and outcome measures corresponded well on some criteria of dynamic correspondence and showed partial correspondence with others. This highlights that greater emphasis could be placed on the specificity of MIV-RT interventions for OAs to optimise the specificity of training and thus increase the likelihood of the transfer of training effects (Thepaut-Mathieu, Van Hoecke and Maton, 1988; Wilson, Murphy and Walshe, 1996; Stone, Stone and Sands, 2007). However, it was beyond the scope of the review to examine the degree of mechanical specificity in relation to intervention outcomes, such as through meta-analysis. In addition, the concept of dynamic correspondence was originally developed with athletes and competitors in mind. Therefore, the significance of dynamic correspondence has yet to be established in the context of OAs and ADLs, and further research is warranted to fully establish its importance and impact in this context. However, recent literature demonstrates that ADLs respond differently to training types with distinct mechanical characteristics, suggesting the likely influence of mechanical specificity on adaptations for OAs (Lopez et al., 2022).

To the author's knowledge, this study is the first to discuss mechanical specificity in this context, and thus, may inspire researchers working with OAs to incorporate mechanical specificity into their intervention designs and explicitly outline how it contributes to their study objectives. This would improve reporting practices within the literature and potentially enhance the effectiveness of the interventions developed. Furthermore, the availability of literature outlining the biomechanical and physiological demands for a wide range of exercises and ADLs for OAs is currently limited, which may hinder the ability to implement interventions that accurately reflect these demands. Addressing this knowledge gap and exploring the effectiveness of MIV-RT interventions that are optimally designed with mechanical specificity in mind could significantly advance the field and lead to the development of targeted and effective interventions for OAs.

Critically, insufficient reporting among the interventions hindered the comprehensive assessment of dynamic correspondence in this study. The secondary aim of this study, which was to evaluate the quality of reporting within studies, highlighted that the reporting of MIV-RT interventions was insufficient to evaluate its effectiveness or replicate it. For example, descriptions of training variables and the training environment lacked detailed or consistent reporting (Figure 4.2). This prevents understanding of the stimulus of the exercise and thus, ability to evaluate its effectiveness on the measured outcomes. In addition, limited reporting of adherence and the fidelity of interventions was observed which aside from allowing readers to understand whether all participants received the same stimulus, enabling an accurate assessment of intervention effectiveness (Murphy and Gutman, 2012), hinders understanding of the appropriateness of an intervention. Similar issues have been observed in studies relating patellofemoral pain and Achilles tendon rehabilitation (Holden et al., 2018;

Christensen et al., 2020) as well as in studies comparing MIV-RT to TRT in OAs (Morrison et al., 2023), suggesting a broader problem in sport and exercise science and related research.

Both the current systematic review and the one conducted by Morrison et al., (2023) utilised the CERT to evaluate the quality of reporting. Since both reviews included MIV-RT interventions for OAs, there was an overlap in some of the studies included which allowed comparisons in the ratings of reporting quality to be made. This highlighted differences in the interpretation of the CERT and underscored the importance of clear and transparent reporting of how the CERT is used. This is demonstrated in the current review through the use of specific predetermined criteria reported in full (Appendix. B).

Overall, this systematic review identified important gaps in reporting standards within MIV-RT intervention studies for OAs which must be addressed to improve the transparency and replicability of research. Doing so would enable greater confidence in the validity of the interventions and allow other researchers to build on the findings in their own work.

Despite evidence to support MIV-RT as an effective method to improve muscle mass and function in OAs (Blazevich *et al.*, 2020; Rodriguez-Lopez *et al.*, 2022; Morrison *et al.*, 2023) and advocacy from academics for the implementation of this training type (Cadore *et al.*, 2018; Fragala *et al.*, 2019; Orssatto *et al.*, 2019) it is unclear whether MIV-RT was being applied in real-world settings by sport, exercise, and health practitioners. Official exercise guidelines from worldwide governing bodies such as the World Health Organization and national consensus guidelines such as those from the UK do not include explicit recommendations for MIV-RT for OAs ('UK Chief Medical Officers' Physical Activity

Guidelines', 2019; World Health Organization, 2020). In addition, the work in this thesis has highlighted significant variation in the implementation of MIV-RT in the scientific literature along with suboptimal methods used to understand the risks associated with this training type (Chapter 2), inconsistent and misapplied terminology (Chapter 3) and a lack of comprehensive reporting of intervention details (Chapter 4) all of which hinder the ability to draw definitive conclusions about the safety and efficacy of MIV-RT. As a result, it is difficult for practitioners to compare results across interventions and to decide whether the training employed in these interventions is applicable or appropriate in their own practice. This could lead to substantial differences in exercise prescriptions among practitioners as well as the use of training methods that are not evidence-based.

Therefore, a survey (Chapter 5) was conducted to comprehensively explore the implementation of MIV-RT among practitioners who prescribe exercise for OAs as a first step to identify whether gaps exist between prescriptions used in research and practice. By documenting MIV-RT prescriptions used in real-world settings, investigating any associated adverse events, and exploring the reasons why practitioners do not prescribe MIV-RT, this research provides valuable insights into the translation of research to practice and identifies potential areas for improvement to guide future research studies to ensure the efficacious implementation of MIV-RT for OAs.

Among the key findings was considerable variation in practitioner job types, professional settings, and client groups. Whilst some variation existed in MIV-RT prescriptions, certain practices were common among practitioners, including the prescription of jumping exercises and bodyweight as resistance. Additionally, some practitioners reported adverse events, but these were mainly related to muscle soreness that is manageable, not life threatening and arguably a natural occurring phenomenon as a result of stimulating physiological adaptations to muscle.

When these practitioner insights were compared with research evidence, several disparities between research and applied practice were identified, including the utilisation of different equipment and exercises and the occurrence of adverse events. For instance, practitioners opted for resistance bands and bodyweight exercises such as jumps as opposed to the machine-based exercises commonly prescribed in research studies (Rice and Keogh, 2009; Rodriguez-Lopez *et al.*, 2022; Schaun *et al.*, 2022). In addition, RPE was the preferred method for selecting loads and progressing exercises, contrasting with the common use of %1RM in research Edholm, Strandberg and Kadi, Rodriguez-Lopez. Limited representation of exercise settings, equipment or exercises used in practice may limit the transferability of research findings to real-world settings or could lead practitioners to adapt interventions to suit their environment, possibly reducing their effectiveness or increasing risks. Gaps between research and practice have been observed in various other areas of sport and exercise science including discrepancies in programming, monitoring methods and the occurrence of adverse events (Buchheit, 2017; Patterson and Brandner, 2017; McGuigan *et al.*, 2020; Gluchowski *et al.*, 2023), suggesting this is not unique to MIV-RT for OAs and is a broader issue in sport and exercise science. The current study did not explore the reasons why practitioners adopted certain methods or prescriptions, and thus cannot draw any conclusions about the reasons for gaps between research and practice. However, it is hoped that these findings can serve as a foundation to guide future research and encourage collaboration between researchers, practitioners and OAs, to tailor research studies to the needs of practitioners and OAs and ultimately enhance the implementation of evidence-based RT for OAs.

Moreover, practitioners' reasons for not prescribing MIV-RT for OAs were identified, including a perceived lack of safety or risk of injury, that MIV-RT was unsuitable due to age or existing medical conditions, and that clients were reluctant to engage in MIV-RT due to fear, highlighting potential barriers to its implementation in real-world settings. However, it was identified that some of these reasons do not fully align with the current evidence base and raises the possibility that practitioners hold misconceptions about MIV-RT as a training modality or have preconceived ideas of what OAs are able to do. Previously, it has been observed that exercise instructors working with OAs may have preconceived ideas of what OAs could or should do with RT perceived by some as too challenging for OAs, reflecting a form of 'compassionate ageism' (Gluchowski et al., 2023). Further exploration of practitioners' perceptions and possible misconceptions is warranted to understand the underlying factors influencing their perceptions and devise targeted communications or education.

Safety is an essential element of RT design and having evidence-based information about the safety of a training type is essential for its adoption among health and exercise practitioners working with OAs. This is evidenced in Chapter 5, where practitioners reported that reasons for not prescribing MIV-RT to OAs included a perceived lack of safety or risk of injury, that MIV-RT was unsuitable due to age or existing medical conditions and that clients were reluctant to engage in MIV-RT due to fear.

However, the literature review (Chapter 2) highlighted that the safety of MIV-RT for OAs remains uncertain. MIV-RT has been considered safe based on the absence of adverse events reported in research studies (Vetrovsky *et al.*, 2019; Radaelli *et al.*, 2023). However, this approach relies on the accuracy and consistency of the measurement and reporting of adverse events and the findings in Chapter 4 suggested that this may be insufficient, highlighting the need for a more comprehensive and accurate assessment of the safety of MIV-RT. Some evidence suggests that OAs may experience acute physical impairments after MIV-RT (Rodriguez-Lopez *et al.*, 2021; Pinto *et al.*, 2022); however, findings regarding the nature and extent of these impairments are inconsistent which may be due to the absence of methods sufficiently sensitive to identify potential adverse events following MIV-RT. Consequently, the identification of practical and sensitive measurement tools is needed for future research studies to better understand the duration and severity of any impairments experienced following MIV-RT and thus understand its safety.

The measurement of COP and its trajectory (i.e., postural sway) which is a strong predictor of fall risk (Piirtola and Era, 2006; Johansson *et al.*, 2017; Watt, Clark and Williams, 2018; Quijoux *et al.*, 2020), and has shown to increase following fatiguing exercise in OAs (Egerton, Brauer and Cresswell, 2009; Morrison *et al.*, 2016; Naderi *et al.*, 2021), offers a potential solution. However, COP is often captured using force plates (Naderi et al., 2021), which whilst considered the gold standard are often restricted to laboratories, require expertise to operate and are costly, making them unsuitable for clinic, community, or home use.

The use of wearable devices such as Tekscan F-scan pressure insoles and Runscribe IMUs are a promising alternative for collecting data at low-cost and with low participant burden in real-world settings (De Groote *et al.*, 2021). However, the validity and reliability of these devices had yet to be evaluated for a variety of balance activities including those commonly used to assess postural stability in OAs (Drey *et al.*, 2012; Edholm, Strandberg and Kadi, 2017; Omaña *et al.*, 2021), which can be used as a proxy measure for increased fall risk following fatiguing exercise (Naderi *et al.*, 2021), such as MIV-RT.

Therefore, Chapter 6 examined the potential of RS and INS to measure postural stability by assessing their concurrent validity and reliability compared with gold standard force plates. A secondary aim was to identify the most valid and reliable combination of COP variables and balance activities. This study found that based on the combination of strong correlations between INS and FP outcome measurements, as well as comparable test-retest reliability, the INS could serve as a valid and reliable alternative to FP. However, the choice of balance activities plays a role in the strength of this validity and reliability. For example, one leg balances on the non-dominant leg with eyes open or closed was the most valid and reliable balance activity and two-foot and tandem balances showed poorer validity and reliability.

However, as similar test-retest correlations were observed with FP this suggests that reliability may have been affected by day-to-day variability in the task itself or due to limitations in the study design. In this study, participants balanced for 10 seconds, however it has been recommended that a period of at least 25 s is required for COP trajectories to become stable and reliable (Scoppa *et al.*, 2013). The period of 10 seconds was chosen in this instance to reflect the common real-world application of balance activities such as during the

SPBB where participants perform two-foot and tandem balances for a maximum of 10 s (Guralnik *et al.*, 1994). However, it is possible that balances of longer duration are required to provide more reliable outcomes during certain activities.

In contrast, the correlations between RS and FP outcome measurements were mostly weak, suggesting the RS is not a valid tool to measure postural stability during standing balance (Chapter 6.3.1.2). However, the RS exhibited more strong correlations than FP or INS in terms of test-retest reliability (Chapter 6.3.2), suggesting that the RS may produce consistent outcome measurements but fail to capture subtle changes in postural stability detectable by FP and INS, resulting in lower validity. These results contrast with studies utilising smartphone embedded IMUs (Hsieh *et al.*, 2019; De Groote *et al.*, 2021) which may be attributed to the location of the IMU sensor. Hence, the validity of IMUs to measure postural stability appears to be dependent on the location of the sensor.

This study showed that despite offering a promising alternative for collecting data at low-cost, low participant burden in real-world settings, the RS is not a viable replacement for FP for the measurement of postural stability. In contrast, the INS may offer a valid and reliable alternative to the use of FP, however they have potentially restrictive factors for community settings such as limited uses and the need to be cut to size for each individual.

Therefore, at present, in situations that require practical and sensitive measurement tools such as research projects aimed at measuring the acute effects of RT protocols on OAs, alternative methods, such as smartphone embedded IMUs which have shown moderate to strong validity and reliability (Hsieh *et al.*, 2019; De Groote *et al.*, 2021) may offer the best available solution.

Collectively, this thesis advances understanding of MIV-RT for OAs, highlighting significant gaps in the design, implementation and dissemination of interventions and providing specific and practical recommendations for researchers conducting RT interventions with OAs to develop the studies necessary to draw definitive conclusions about the efficacy and safety of MIV-RT and ultimately translate it to real-world practice.

7.2 Strengths and Limitations

As discussed in chapter 1.3, an original objective of this PhD was to carry out several experimental studies to evaluate the safety and effectiveness of MIV-RT for OAs. However, the unexpected challenges posed by the two-year global COVID-19 pandemic made this unattainable and the programme of research was adjusted to reflect the conditions imposed on the world at that time. Although the absence of intervention studies may be viewed as a limitation, this provided the opportunity to conduct novel research that challenges conventional thinking in this field. By focusing on critical underpinning factors that inform the design of interventions and practice, often overlooked in research, this thesis lays the groundwork for future studies and advancements in this field. The approach taken in this thesis not only enhances our understanding of this training modality but also highlights the need for a more thorough and transparent approach to research.

7.3 Future Work

Future work should be conducted to build on the work in this thesis and implement the insights gathered here. Future research should explore the importance of specificity and dynamic correspondence for OAs at greater depth. Experimental studies involving training programmes with varying degrees of dynamic correspondence would help confirm the influence of mechanical specificity on adaptations for OAs. Moreover, gaining a more comprehensive understanding of the biomechanical and physiological demands of ADLs and various exercises would facilitate the implementation of interventions that accurately reflect these demands.

The survey of applied practitioners (Chapter 5) identified various opportunities for future research to align more closely with applied practices such as the use of community settings. In addition, deeper exploration of barriers to programming or participating in MIV-RT is critical to the development of strategies to overcome barriers and implement effective RT programmes. More qualitative lines of enquiry will need to be conducted and an appropriate analytical method selected.

Future research should also explore collaborations among researchers, practitioners, and OAs, utilising methods such as co-design and patient and public involvement to enable all stakeholders to actively contribute to the intervention's design and implementation, resulting in interventions that address the needs and preferences of OAs and applied practitioners.

7.4 Conclusion

This thesis provides a novel contribution to the field of RT for OAs by taking a critical lens to understand and address methodological issues hindering our understanding of MIV-RT for OAs. By focusing on critical yet overlooked underpinning factors that inform the design of interventions and practice, such as the use of terminology, intervention specificity, real-world implementation, and novel measurement tools, this work challenges conventional thinking in this field and lays the groundwork for future studies. The work in this thesis has the potential to influence researchers to design interventions that target the desired and most relevant physiological adaptations, reduce barriers to real-world implementation and effectively communicate their findings through accurate and thorough reporting.

It is hoped that future research will enable accurate conclusions to be made about the efficacy and safety of MIV-RT and establish best practices and evidence-based recommendations to help counteract age-related declines in muscle mass and function and improve the overall well-being of OAs.

vi. References

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vii. Appendices

Appendix. A - Search Details

Who	Database	Search terms
CK	PubMed (NCBI)	(((((((("older adults"[Title/Abstract]) OR (senior?[Title/Abstract])) OR (older[Title/Abstract])) OR (geriatric?[Title/Abstract])) OR (elderly[Title/Abstract])) OR (masters[Title/Abstract])) OR (aging[Title/Abstract])) OR (ageing[Title/Abstract])) AND (((((((((((explosive[Title/Abstract]) OR (ballistic[Title/Abstract])) OR ("fast velocity"[Title/Abstract])) OR ("high velocity"[Title/Abstract])) OR ("high speed"[Title/Abstract])) OR (power[Title/Abstract])) OR (plyometric?[Title/Abstract])) OR (jumping[Title/Abstract])) OR (jump?[Title/Abstract])) OR (hopping[Title/Abstract])) OR (hop?[Title/Abstract])) OR (Olympic[Title/Abstract]))) AND (((((((("weight training"[Title/Abstract]) OR (weightlifting[Title/Abstract])) OR ("strength training"[Title/Abstract])) OR ("strength exercise"[Title/Abstract])) OR ("resistance training"[Title/Abstract])) OR ("resistance exercise"[Title/Abstract])) OR (exercise[Title/Abstract])) OR (training[Title/Abstract])) OR (lifting[Title/Abstract]))
CK	CENTRAL (Wiley)	#1 "older adults" OR senior? OR older OR geriatric? OR elderly OR masters OR ag?ing:ti,ab #2 explosive OR ballistic OR "high velocity" OR "high speed" OR "fast velocity" OR power OR plyometric? OR jumping OR jump? OR hopping OR hop? OR Olympic:ti,ab

		#3 "weight training" OR weight-training OR weightlifting OR "strength training" OR strength-training OR "strength exercise" OR "resistance training" OR resistance-training OR "resistance exercise" OR exercise OR training OR lifting:ti,ab #1 AND #2 AND #3
CK	Scopus (Elsevier)	(TITLE-ABS({older adults}) OR TITLE-ABS({senior}) OR TITLE-ABS({seniors}) OR TITLE-ABS({older}) OR TITLE-ABS({geriatric}) OR TITLE-ABS({geriatrics}) OR TITLE-ABS({masters}) OR TITLE-ABS({aging}) OR TITLE-ABS({ageing})) AND (TITLE-ABS({explosive}) OR TITLE-ABS({ballistic}) OR TITLE-ABS({fast velocity}) OR TITLE-ABS({high velocity}) OR TITLE-ABS({high speed}) OR TITLE-ABS({power}) OR TITLE-ABS({plyometric}) OR TITLE-ABS({plyometrics}) OR TITLE-ABS({jumping}) OR TITLE-ABS({jump}) OR TITLE-ABS({jumps}) OR TITLE-ABS({hop}) OR TITLE-ABS({hops}) OR TITLE-ABS({hopping}) OR TITLE-ABS({Olympic})) AND (TITLE-ABS({weight training}) OR TITLE-ABS({weightlifting}) OR TITLE-ABS({strength training}) OR TITLE-ABS({strength exercise}) OR TITLE-ABS({resistance training}) OR TITLE-ABS({resistance exercise}) OR TITLE-ABS({exercise}) OR TITLE-ABS({training}) OR TITLE-ABS({lifting}))
CK	SPORTDiscus (EBSCO)	(TI("older adults" OR senior OR seniors OR older OR geriatric OR geriatrics OR elderly OR masters OR aging OR ageing) OR AB ("older adults" OR senior OR seniors OR older OR geriatric OR geriatrics OR elderly OR masters OR aging OR ageing)) AND (TI(explosive OR ballistic OR "fast velocity" OR "high velocity" OR "high speed" OR power OR plyometric OR plyometrics OR jumping OR jump OR jumps OR hopping OR hop OR hops OR Olympic) OR AB (explosive OR ballistic OR "fast velocity" OR "high velocity" OR "high speed" OR power OR plyometric OR plyometrics OR jumping OR jump OR jumps OR hopping OR hop OR hops OR Olympic)) AND (TI("weight training" OR weightlifting OR "strength training" OR "strength exercise" OR "resistance training" OR "resistance exercise" OR exercise OR training OR lifting) OR AB ("weight training" OR weightlifting OR "strength training" OR "strength exercise" OR "resistance training" OR "resistance exercise" OR exercise OR training OR lifting))

CK	Web of Science (Clarivate)	#1 (TI = ("older adults" OR "senior" OR "seniors" OR "older" OR "geriatric" OR "geriatrics" OR "elderly" OR "masters" OR "aging" OR "ageing")) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=All years #2 (AB = ("older adults" OR "senior" OR "seniors" OR "older" OR "geriatric" OR "geriatrics" OR "elderly" OR "masters" OR "aging" OR "ageing")) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan=All years #3 (TI=("weight training" OR "weightlifting" OR "strength training" OR "strength exercise" OR "resistance training" OR "resistance exercise" OR "exercise" OR "training" OR "lifting")) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=All year #4 (AB = ("weight training" OR "weightlifting" OR "strength training" OR "strength exercise" OR "resistance training" OR "resistance exercise" OR "exercise" OR "training" OR "lifting")) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=All years #5 (TI = ("explosive" OR "ballistic" OR "fast velocity" OR "high velocity" OR "high speed" OR "power" OR "plyometric" OR "plyometrics" OR "jumping" OR "jump" OR "jumps" OR "hopping" OR "hop" OR "hops")) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=All years #6 (AB=("explosive" OR "ballistic" OR "fast velocity" OR "high velocity" OR "high speed" OR "power" OR "plyometric" OR "plyometrics" OR "jumping" OR "jump" OR "jumps" OR "hopping" OR "hop" OR "hops")) AND LANGUAGE: (English) Indexes=SCI-EXPANDED, CPCI-S Timespan=All years (#1 OR #2) AND (#3 OR #4) AND (#5 OR #6)

Appendix. B - Consensus on exercise reporting template items and fulfilment requirements

	CERT Item	**Definitions / Fulfilment Requirements**
1	Detailed description of the type of exercise equipment (e.g., weights, exercise equipment such as machines, treadmill, bicycle ergometer, etc).	The type of exercise equipment that was used is identifiable by the reader so that it could be replicated. The report includes the type, make, model and brand of the equipment. May also include specific set up of equipment e.g. starting position.
2	Detailed description of the qualifications, teaching/ supervising expertise and/or training undertaken by the exercise instructor.	The report includes the professional or disciplinary background (e.g., physiotherapist, personal trainer, gym instructor). May also include duration of experience, qualifications, verification of skills and / or any intervention specific training received, whether involvement was part of usual practice or specific recruitment for the study or consideration of cultural contexts (e.g., equivalency of qualifications).
3	Describe whether exercises are performed individually or in a group.	The report includes whether the intervention was provided one-on-one or to a group AND includes group size. May also include whether this was face-to-face or online/remote.
4	Describe whether exercises are supervised or unsupervised and how they are delivered.	The report includes whether the intervention was supervised AND also what the supervision involved (e.g., observed exercise, ensured correct technique, modifies exercise as required). May also include the number of supervisors per participant. Observing a work out DVD or online fitness class is not deemed as supervision. There needs to be direct face to face contact.
5	Detailed description of how adherence to exercise is measured and reported.	The report includes a description of how participant adherence to the intervention was measured and reported (e.g., researchers kept a log of attended sessions)
6	Detailed description of motivation strategies.	The report includes a description of whether the participants received any form of motivation during the intervention/exercise (e.g., verbal encouragement).

7a	Detailed description of the decision rule(s) for determining exercise progression.	The report includes a description of how it was determined when the exercise should be progressed. e.g., when >8 reps could be completed in the final set.
7b	Detailed description of how the exercise programme is progressed (e.g., numbers of repetitions, resistance, load, speed, etc).	The report includes a description of how the intervention was progressed. It is possible to determine the degree of progression that took place.
8	Detailed description of each exercise to enable replication (e.g., photographs, illustrations, video, Smartphone app, website, protocol paper, etc).	The report includes enough information to allow accurate replication including information about starting position (e.g., lying, standing, joint angles), position of equipment relative to body (e.g., position of leg extension pad) and the range of movement (e.g., from 90-degree knee angle to full extension), whether it was bi-lateral/unilateral. Some information may be derived from the type of equipment reported (e.g., bilateral/unilateral, or lying/seated leg press).
9	Detailed description of any home programme component (e.g., other exercises, stretching, functional.	N/A – excluded during screening
10	Describe whether there are any non-exercise components (e.g., training or information materials, education, cognitive–behavioural therapy, massage, etc).	N/A – excluded during screening
11	Describe the type and number of adverse events that occur during exercise	The report describes the type and number of adverse and serious adverse events that occurred as a result of exercise. Should also report if there were no adverse events.
12	Describe the setting in which the exercises are performed.	The report describes the setting that the exercises were performed in (e.g., laboratory, commercial gym, community centre or swimming pool).
13	Detailed description of the exercise intervention including, but not limited to, number of exercise repetitions/ sets/sessions, session duration, programme duration, etc	The report includes every item on the T&G checklist (see below on page 6).

14a	Describe whether the exercises are generic (one size fits all) or tailored.	The report describes whether the participants all received the same prescription (same exercises and relative load) or individualised prescriptions (could include individualised progression). This could be obvious from the reporting for example – "The training group completed 3 sets of 10 leg press at 60% 1RM" – this is a generic prescription despite not being explicitly stated.
14b	Detailed description of how exercises are tailored to the individual.	Only applies if individualised - The report describes how it was individualised (e.g., load was increased by 10% when >10 reps were achieved in the final set).
15	Describe the decision rule for determining the starting level at which people start an exercise programme (e.g., beginner, intermediate, advanced, etc).	The report describes how the starting level of the exercise intervention was determined relative to the individual (e.g., based on %1RM or RPE).
16a	Describe how adherence or fidelity to the exercise intervention is assessed/measured.	The report describes how the researchers **assessed/measured** whether the intervention was implemented as it was intended. How did the researchers assess whether the intervention was delivered as planned? e.g., The report describes how the researchers measured/ensured that the prescribed exercise was completed (e.g., all reps completed were recorded by the researcher). And/or the report describes how the researchers measured/ensured that the intended exercise intensity was achieved (e.g., velocity was maintained above … m/s). And/or the report describes how overall adherence to exercise sessions was measured (e.g., researchers kept a log of attended sessions). May also include information about any strategies to improve/guarantee fidelity (e.g., staff training, researcher documenting adherence to protocol).
16b	Describe the extent to which the intervention was delivered as planned.	The report describes whether the intervention was delivered as planned.

		Must include overall adherence to sessions AND information about compliance (e.g., "all participants completed the prescribed sets, reps and intensity"). Information suggesting that they guaranteed fidelity (e.g., instructors ensured exercise intensity was maintained') is sufficient to fulfil this item. Provided adherence is also reported.

Appendix. C - Toigo and Boutellier (2006) framework for exercise mechanobiological items and fulfilment requirements

	TBF Item	**Definitions / Fulfilment Requirements**
1	Load magnitude	The report describes the prescribed load in terms of actual load or RPE.
2	Number of repetitions	The report describes the number of prescribed reps.
3	Number of sets	The report describes the number of prescribed sets.
4	Rest in-between sets ([s] or [min])	The report describes the prescribed inter-set rest.
5	Number of exercise interventions (per [d] or week)	The report describes the number of prescribed sessions per day/week.
6	Duration of the experimental period ([d] or weeks)	The report describes the prescribed duration of the intervention.
7	Fractional and temporal distribution of the contraction modes per repetition and duration [s] of one repetition	The report describes the type of muscle actions (eccentric/concentric/isometric etc) and also the time spent doing each type.
8	Rest in-between repetitions ([s] or [min])	The report describes the prescribed inter-rep rest.
9	Time under tension ([s] or [min])	The report describes the time under tension. Must describe both concentric and eccentric if applicable. If participants were asked to do the concentric as quickly as possible that is fine as long as it could be replicated.
10	Volitional muscular failure	The report describes whether participants worked to muscular failure.
11	Range of motion	The report describes actual ROM or starting and finishing positions or other ways to enable replication (e.g., height of chair used).
12	Recovery time in-between exercise sessions ([h] or [d])	The report describes the prescribed time between exercise sessions.
13	Anatomical definition of the exercise (exercise form)	CERT number 8.

Appendix. D - Blank data extraction spreadsheet

Bibliographic		Study Code:	
Author(s)		Year	
Title			
Training Group name (if more than one IRT group in the same study):			

Participant Details			
N		Training Status	
Mean Age (yrs)		Geographical Location	
Sex		Height (cm)	
Ethnicity		Body Mass (kg)	
Health Status		BMI	[illegible]

CERT	CERT Item	Data	Rating	Reason for rating
1	Detailed description of the type of exercise equipment			
2	Detailed description of the qualifications, expertise and/or training			
3	Describe whether exercises are performed individually or in a			
4	Describe whether exercises are supervised or unsupervised; how			
5	Detailed description of how adherence to exercise is measured and			
6	Detailed description of motivation strategies			
7a	Detailed description of the decision rule(s) for determining exercise			
	CERT Item	Data	Rating	Reason for rating
7b	Detailed description of how the exercise program was progressed			
8	Detailed description of each exercise to enable replication			
9	Detailed description of any home programme component			
10	Describe whether there are any non-exercise components			
11	Describe the type and number of adverse events that occur during			
12	Describe the setting in which the exercises are performed			
13	Detailed description of the exercise intervention			
14a	Describe whether the exercises are generic (one size fits all) or tailored			
14b	Detailed description of how exercises are tailored to the individual			
	CERT Item	Data	Rating	Reason for rating
15	Describe the decision rule for determining the starting level			
16a	Describe how fidelity is assessed/measured - how they measured			
16b	Describe the extent to which the intervention was delivered as planned			
		Total CERT score	0	

TIB Framework	TB Item	Data	Rating	Reason for rating
1	Load magnitude (initial)			
2	Number of repetitions			
3	Number of sets			
4	Rest in between sets ([s] or [min])			
5	Sessions per day/week			
6	Intervention Duration			
7	Type and duration of muscle action per rep			
8	Rest between reps			
9	Time under tension ([s] or [min])			
10	Work to muscular failure?			
11	ROM			
12	Recovery time between sessions ([h] or [d])			
13	Anatomical exercise definition (joint position, movement velocity)			
		Total TB Score	0	
Additional question	TB Item	Data	Rating	Reason for rating
	Is a rationale for training prescription choices provided?			
	PEDro Score			

Dynamic Correspondence	Outcome 1	
Name of outcome measurement		
Notes		
Training exercises		
Testing procedures	**Verdict**	**Comments**
Are the details of the outcome measurements and testing procedures clearly described? [illegible]		
Amplitude and direction of movement	**Verdict**	**Comments**
Are the joint actions in the training programme similar to the outcome measurement? *Are they similar in amplitude? Are they similar in direction? Is the direction of force (relative to the individual) in the training programme similar to the outcome measurement?*		
Accentuated/most important region of force production	**Verdict**	**Comments**
Is the joint angle at which maximum force produced similar for both training and outcome? *Requires: knowledge of the accentuated region of force production, Requires: knowledge of ROM, speed of movement*		
Dynamics of the effort	**Verdict**	**Comments**
Does the training programme provide the possibility of overload specific to this outcome measurement? [illegible]		
The rate and time of force production / the time available	**Verdict**	**Comments**
Is the time available to generate impulse in the training programme similar or greater than the outcome measurement? *Must also consider whether the total amount of impulse/peak/average force is similar to the outcome?*		
The regime / type of muscular work	**Verdict**	**Comments**
Are the muscle actions in the training programme similar to the outcome measurement? [illegible]		
	Total DC Score	0

Appendix. E - Mechanical specificity items and fulfilment requirements

	Criterion	**Definitions / Fulfilment Requirements**
1	Amplitude and direction of movement	Are the joint movements in the training programme similar to the outcome measurement outcome? - Are they similar in amplitude? - Are they similar in direction? - Is the direction of force (relative to the individual) in the training programme similar to the outcome measurement? Yes = All of above are similar (for 1 or more exercises) No = None of the above are similar (for 1 or more exercises) Partially = 1 or 2 are similar *(e.g., just direction is similar for 1 or more exercises)* Unclear = unclear whether any are similar *(e.g., exercise description is not clear enough to judge, for 1 or more exercises)*
2	Accentuated/most important region of force production	Is the accentuated region of force production the same for both training and outcome? - Do you know the ROM for both training and outcome? - Can the accentuated region of force production be determined? - If yes, are they similar? Yes = Sufficient detail is provided about the exercises and outcome *(e.g., ROM is known for both exercise and outcome), and it can be determined that they are similar (for 1 or more exercises)* No = Sufficient detail is provided about the exercises and outcome *(e.g., ROM is known for both exercise and outcome), and it can be determined that they are NOT similar (for 1 or more exercises)* Partially = In multi-joint movements, one or more angles may be similar but others not *(e.g., training involved leg press and knee angle accentuated region of force corresponded to outcome but hip angle did not)* Unclear = Insufficient detail is provided about the exercises and outcome *(e.g., ROM is unknown for either exercise or outcome)*

3	Dynamics of the effort	Does the training programme provide the possibility of overload specific to this outcome measurement? - Is there overload via peak force? - Is there overload via RFD (could be early phase) - Is there overload via movement velocity? - Is there overload via repetitions/time under tension Yes = the duration and character of effort are similar in both training and outcome plus one or more elements is being overloaded *(e.g., outcome involves low-moderate loads at high velocity, and training (1 or more relevant exercises) is done with similar loads but at higher velocity or same velocity but higher loads)* No = no element of the outcome measurement is being overloaded during the training (e.g., outcome measurement *involves low-moderate loads at high velocity, and training (1 or more relevant exercises) is done with lighter loads and at low velocity.* Partially = there is one or more elements of overload relevant to the outcome measurement but not completely specific to the outcome measurement *(e.g., outcome involves low-moderate loads at high velocity, and training (1 or more relevant exercises) is done with similar loads but at lower velocity or same velocity but lighter loads)* Unclear = cannot determine whether overload is achieved in any way *(e.g., insufficient detail about load/reps/ROM/velocity)*
4	The rate and time of force production / the time available	Is the time available to generate force in the training programme similar or less than the outcome measurement? - Is peak force reached in similar or less time during training? - Or is there intent to produce force maximally? - Do the training and outcome measurement also correspond in terms of peak force? Yes = Can be determined that force was generated in similar or less time during the training (1 or more relevant exercises) compared to the outcome measurement. Or training done AFAP but outcome not done AFAP e.g., TUG No = Can be determined that force was generated in greater/slower time during the training (1 or more relevant exercises) compared to the outcome measurement *(e.g., slow and controlled for training vs AFAP for outcome)* Partially = some elements of force were generated in similar or less time during the training (1 or more relevant exercises) compared to the outcome measurement, but some elements are not similar or cannot be determined *(e.g., peak force or time to peak force)*

		Unclear = Cannot be determined how quickly force was applied/intended during training or outcome.
5	The regime / type of muscular work	Are the muscle actions in the training programme similar to the outcome measurement? Yes = The type of muscular work can be determined for both exercises and outcomes and are similar (for 1 or more exercises) No = The type of muscular work can be determined for both exercises and outcomes and no exercises are similar (for 1 or more exercises) Partially = some elements of the regime are similar but not all (e.g., both involve rapid concentric actions but one involves SSC). Unclear = The type of muscular work cannot be determined for either exercises or outcomes.

Appendix. F - Methodological quality assessment per study

ID	Study	1*	2	3	4	5	6	7	8	9	10	11	Total/10
1	Beijersbergen et al. 2017^	Y	N	N	Y	N	N	N	Y	N	N	Y	3
2	Correa et al. 2012	Y	Y	N	N	N	N	N	Y	N	Y	Y	4
3	Cherup et al. 2018	N	Y	N	Y	N	N	N	N	N	Y	Y	4
4	Dobbs et al. 2018	N	Y	N	Y	N	N	N	Y	N	Y	Y	5
5	Edholm et al. 2017	N	Y	N	Y	N	N	N	N	N	Y	Y	4
6	Filho et al. 2022	N	Y	N	Y	N	N	Y	N	N	Y	Y	5
7	Lopes et al. 2016	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
8	Richardson et al. 2019	N	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
9	Sanudo et al. 2019	N	Y	N	Y	N	N	Y	Y	N	Y	Y	6
10	Sanudo et al. 2020	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7

Abbreviations: 1, Eligibility; 2, Random allocation; 3, Concealed allocation; 4, Baseline comparability; 5, Blind subjects; 6, Blind therapists; 7, Blind assessors; 8, Adequate follow-up; 9, Intention-to-treat analysis; 10, Between group comparisons; 11, Point estimates and variability; Y, yes; N, No; ^, Scored by reviewers; *, Item does not contribute to total score.

Appendix. G - Consensus on exercise reporting template reporting – per study

ID	Study	1	2	3	4	5	6	7a	7b	8	11	12	13	14a	14b	15	16a	16b	Total/17
1	Beijersbergen et al. 2016	Yes	No	No	No	Yes	No	Yes	Yes	No	No	No	No	Yes	No	Yes	No	No	**6**
2a	Correa et al. 2012 (Machine group)	No	No	No	No	No	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	**3**
2b	Correa et al. 2012 (Machine & Box group)	No	No	No	No	No	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	**3**
3	Cherup et al. 2018	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	**6**
4	Dobbs et al. 2018	Yes	No	No	No	Yes	No	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	**8**
5	Edholm et al. 2017	No	No	No	No	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	No	**3**
6	Filho et al. 2022	No	Yes	No	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No	**5**
7	Lopes et al. 2016	No	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	No	Yes	No	No	**6**
8a	Richardson et al. 2019 (Training 1/week)	Yes	No	No	No	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	**10**
8b	Richardson et al. 2019 (Training 2/week)	Yes	No	No	No	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	**10**
9	Sanudo et al. 2019	Yes	No	No	No	Yes	Yes	No	Yes	No	Yes	No	No	Yes	No	No	No	No	**6**
10	Sanudo et al. 2020	Yes	No	No	No	Yes	Yes	No	Yes	No	Yes	No	No	Yes	No	No	No	No	**6**

Abbreviations: 1, Detailed description of the type of exercise equipment; 2, Detailed description of the qualifications, expertise and/or training; 3, Describe whether exercises are performed individually or in a group; 4, Describe whether exercises are supervised or unsupervised; how they are delivered; 5, Detailed description of how adherence to exercise is measured and reported; 6, Detailed description of motivation strategies; 7a, Detailed description of the decision rule(s) for determining exercise progression; 7b, Detailed description of how the exercise program was progressed; 8, Detailed description of each exercise to enable replication; 11, Describe the type and number of adverse events that occur during exercise; 12, Describe the setting in which the exercises are performed; 13, Detailed description of the exercise intervention; 14a, Describe whether the exercises are generic (one size fits all) or tailored; 14b, Detailed description of how exercises are tailored to the individual; 15Describe the decision rule for determining the starting level; 16a, Describe how adherence or fidelity is assessed/measured; 16b, Describe the extent to which the intervention was delivered as planned.

Appendix. H - Toigo and Boutellier framework – actual values

ID	1	2	3	4	5	6	7	8	9	10	11	12	13
1	40-60% of 3RM	6-10	3	0	3/wk	10 wks	0	10s	0	0	0	Unclear - just stated 3/wk	0
2a	10–12 RM (weeks 7–9), 8–10 RM (weeks 10–12)	10–12 RM (weeks 7–9), 8–10 RM (weeks 10–12)	3 (weeks 7–9), 4 (weeks 10–12)	0	0	6 weeks	Con AFAP, ECC 2-s	0	Con AFAP, ECC 2-s	Rep max each set	0	0	0
2b	10–12 RM (weeks 7–9), 8–10 RM (weeks 10–12), body-weight for jumps	10–12 RM (weeks 7–9), 8–10 RM (weeks 10–12) plus max reps in 15-20s for jumps	3 (weeks 7–9), 4 (weeks 10–12)	0	0	6 weeks	Con AFAP, ECC 2-s	0	Con AFAP, ECC 2-s	Max reps for jumps	0	0	0

3	Chest press (50% 1RM), leg press (60% 1RM), latissimus dorsi pull-down(40% 1RM), hip adduction (70% 1RM), overhead press (60% 1RM), leg curl (60% 1RM),seated row (50% 1RM), hip abduction (70% 1RM), elbow extension (50% 1RM),plantarflexion (60% 1RM), and elbowflexion (50% 1RM)	12	Week 1: 1; week 2: 2; weeks 3-12: 3	32 ± 3 s	3/wk	11 weeks	CON AFAP, ECC 3-sec	0	CON AFAP, ECC 3-sec	0	0	0	0
4	Began at 65% of body weight then increased by 1% until the maximum load was achieved for all sets and reps	10	3	60s	3/wk	8 weeks	0	0	0	0	0	0	0
5	50% of 1RM in first 2 weeks then 75–85% of 1RM for the rest of the intervention.	12-15 in first 2 weeks then 8-12	3	2 mins	2/wk	24 weeks	0	0	0	0	0	0	0

6	50% of 10RM	8-12	2-3	3 mins	2/wk	12 weeks	0	0	CON AFAP, ECC unclear	Stated that they did not work to failure	0	0	0
7	Started at 40% of 1RM	6-8	3-4	3 mins	3/wk	12 weeks	Con AFAP, ECC 2-s	0	CON AFAP, ECC 2-sec	0	0	Mon, Wed, Fri	0
8a	40% 1RM	14	3	90s	1/wk	10 weeks	CON AFAP, ECC 3-s	0	CON AFAP, ECC 3-s	0	0	Minimum of 48h	0
8b	40% 1RM	14	3	90s	2/wk	10 weeks	CON AFAP, ECC 3-s	0	CON AFAP, ECC 3-s	0	0	Minimum of 48h	0
9	Moment inertia of 0.025 kg·m22 for 4 weeks then 0.05 kg·m22 for the following 2 weeks	9	4	3 mins	2/wk (week 1, 3, 5) 3/wk (week 2, 4, 6)	6 weeks	0	0	0	0	0	Minimum of 48h	0
10	Moment inertia of 0.025 kg·m22 for 4 weeks then 0.05 kg·m22 for the following 2 weeks	9	4	2-3 mins	2/wk (week 1, 3, 5) 3/wk (week 2, 4, 6)	6 weeks	0	0	0	0	The knee started at approximately 15° and reached a maximum flexion of approximately 140°	Minimum of 48h	During the squat, subjects stood on the platform with the feet shoulder width apart and knees slightly flexed. From the standing position, after an initial submaximal repetition to initiate the flywheel movement, the performer descended by

													flexing the hip and knee joints simultaneously (i.e., by an eccentric muscle action). When returning to the starting position, subjects extended the hip and knee joints by a concentric muscle action. The subjects were instructed to push with maximal effort through the entire concentric action and to then resist the pull of the flywheel by performing an eccentric muscle action. The knee started at approximately 15° and reached a maximum flexion of approximately 140°

Abbreviations: 1, load magnitude; 2, number of repetitions; 3, number of sets; 4, rest in-between sets ([s] or [min]); 5, number of exercise interventions per ([d]] or week); 6, duration of the experimental period ([d] or week); 7, fractional and temporal distribution of the contraction modes per repetition and duration [s] of one repetition; 8, rest in-between repetitions ([s] or [min]); 9, time under tension ([s] or [min]); 10, volitional muscle failure; 11, range of motion; 12, recovery time in-between exercise sessions ([h] or [d]); 13, anatomical definition of the exercise (exercise form).

Appendix. I - Formal education of practitioners

	Full sample		DID prescribe MIV-RT		DID NOT prescribe MIV-RT	
	Absolute frequency (n=199)	**Relative frequency (% of n)**	*Absolute frequency (n=83)*	**Relative frequency (% of n)**	*Absolute frequency (n=116)*	**Relative frequency (% of n)**
Do you hold (or are working towards) a degree in sports science or a related field?						
Yes	*85*	**43%**	*42*	**51%**	*43*	**37%**
No	*114*	**57%**	*41*	**49%**	*73*	**63%**
Working toward an undergraduate degree in sports science or a related field	*9*	**5%**	*4*	**5%**	*5*	**4%**
Hold an undergraduate degree in sports science or a related field	*51*	**26%**	*20*	**24%**	*31*	**27%**
Working toward a master's degree in sports science or a related field	*8*	**4%**	*5*	**6%**	*3*	**3%**
Hold a master's degree in sports science or a related field	*28*	**14%**	*15*	**18%**	*13*	**11%**
Working toward a PhD in sports science or a related field	*7*	**4%**	*3*	**4%**	*4*	**3%**
Hold a PhD in sports science or a related field	*8*	**4%**	*6*	**7%**	*2*	**2%**

Appendix. J - List of 'other' exercises prescribed by practitioners

Exercise (lower body)	Absolute Frequency	Exercise (upper body)	Absolute Frequency
Landing	4	Kettlebell swings	2
Kettlebell swings	4	Reaches	2
Deadlifts	4	Olympic lifts and derivatives	2
Calf raises	4	Shoulder taps	2
Leg press	4	Woodchop	2
Walking	4	Arm curl	2
Olympic lifts and derivatives	4	Arm extension / Triceps extension	2
Hip exercises	3	C6	1
Knee flexion/extension	2	Wall Dribble"	1
Burpees	2	Sprinter arms	1
Core exercises	2	Shoulder exercises	1
Pushing and pulling objects e.g., sled	2	Kettlebells	1
Agility work	2	Burpees	1
B65	1	Rhythmic stability	1
Wall drills	1	Arm swings	1
Single leg pounce	1	Resistance band (tennis) forehand and back hand	1
Pushing	1	Person centred approach all appropriate upper body exercises unless contraindicated.	1
Resistance targets touch	1		
Resistance reaches	1		
Repeater legs	1		
Mountain climbers	1		
Stomps	1		
Toe touches	1		
Power stands	1		
Step overs	1		
Bounding	1		
Exercise bike sprints	1		
Jogging	1		
Marching	1		
Stepping	1		
Kicks	1		
Rowing	1		
Punches	1		
Dancing	1		
Person centred approach therefore no lower body power exercises excluded unless contraindicated. Whatever is appropriate	1		

starts basic and is progressed to maximal with or without additional load.			

Appendix. K - List of other jumps listed by practitioners

Type of jump	Absolute Frequency
Assisted jumps	3
Broad/forward jumps	3
CMJ	2
Step-up jumps	2
Jumping on reformer jump boards	2
Skaters/jumping one leg to the other)	2
Jumping over hoops	1
Warm and hot stove jumps	1
Jumping scissors	1
Straight-legged jumps	1
Mini jumps	1
Jumping on unstable surface (e.g., bosu)	1
Sit-to-stand with jump	1
Aquatic jumping	1
Resistance band jumps	1
Bunny hops on step	1

Appendix. L - List of other throws/slams listed by practitioners

Type of throw/slam	Absolute Frequency
Ball throws	4
Overhead throws	2
Wall balls	1
Resistance band throws	1
Throwing motion	1

Appendix. M - Other push/press listed by practitioners

Type of push/press	Absolute Frequency
Push press	3
Medicine ball shotput	1
Dumbbell press	1
Single arm press	1
Just "presses"	1
Band presses	1
Landmine presses	1

Appendix. N - List of adverse events reported by practitioners

Adverse event	Absolute frequency
Muscle soreness	10
Aggravation of existing condition	4
Pain	4
- Specified knee pain	2
Hip arthritis	1
Overworked wrist	1
Aggravated posture deficits	1
Rotator cuff	1
Prefer not to disclose	1
Tendonitis	1
Falling	1
Fear of pain or injury	1
Calf muscle strain	1
Rotator cuff tear	1
Breathlessness outdoors in cold weather	1
Exercise induced asthma	1
Dizziness	1
Incontinence	1
Client believed they had seriously injured themselves	1

Appendix. O - Raw data responses for situations or conditions where practitioners who do prescribe maximal-intentional velocity resistance training would not prescribe maximal-intentional velocity resistance training for older adults.

	Practitioners were asked "Are there any specific situations or conditions where you would not programme, prescribe or recommend EXPLOSIVE resistance training for older adults?" **If practitioners said 'Yes' then they were asked Q81:**
P number	**Q81 Please provide details of the situations or conditions below.**
P7	Very poor strength. Clients who have a very low starting point whos time is better spent focusing on their strength first
P9	Fracture. Severe osteoporosis. RA. Tendinopathy. Lack of confidence.
P12	where adult had limitations cause by eg joint replacement or medical conditions eg severe osteoporosis
P14	Heart rehab, cancer rehab, oestopenia, osteoporosis
P15	People who are not enough to cope or are too weak. Would start them off on much more gentle work and build up over time.
P16	Sorry, too many to add
P32	High falls risk Initial strength training
P33	Underlying injury. Joint diseases. Balance impairments. But these restrictions would only affect specific exercises, and others that can be implemented would. E.g. if could not perform lower body explosive training then I would prescribe explosive upper body training for transfer of gains.
P40	Chronic issues with back, knees , hips etc.
P41	Serious chronic conditions. severe osteoporosis or spinal shifting from severe kyphosis or scoliosis
P44	If the athlete has knee issues, I would modify the depth of the jump in the scissors jumps or eliminate that altogether. The safety of the athlete always comes first.
P45	Injury, osteoporosis, joint issues
P46	In the case of injury or limited mobility
P50	In patients who are too frail or lack balance and coordination
P54	Frail older adult, chronic muscular skeletal conditions, etc
P56	lack of experience - exercises need to be properly introduced (and progressions built) before they can be performed explosively. management of fear lack of safety (equipment or medical conditions that need to be considered)
P64	If they are extremely limited in movement or having existing health conditions that may prevent them from doing activities that require a high neural drive and lots of movement.
P67	Heart conditions, underlying disabilities, previous health history, osteoporosis, osteopaenia, imbalance (virtigo), arthritis, stenosis and other objective criteria depending upon the subject's previous fitness and activity history.

P73	Medical conditions subject to tissue injury (neuromuscular diseases for example), or if the patient is on pharma meds where this kind of exercise could be harmful or recovery processes could potentially be delayed (ie blood thinning agents). Those with designated osteopenia or osteoporosis should not be started on a plan like this. Those just starting with exercise should build up to explosive power work, and not be started immediately on a plan like this.
P74	I work in oncology and often times will not use power training for patients with low platelets. Power training is usually not indicated for my patients with impaired balance.
P80	Individual circumstances Severe oesteoperosis Severe fatigue, severe RA
P82	If three are any redflags Acute heart failure etc.
P89	any joint issues such as shoulder problems hip problems...
P91	If it was contraindicated by non-modifiable circumstance, psychological, medication, illness/disease or MSK injury.
P93	Weaker clients have a hard enough time moving. I don't thnk I would feel they could handle explosive moves
P94	If client has not slept well or reacting to any medication or treatment. Blood pressure too high or too low. Blood sugars not controlled. Joint inflammation or due surgery in near future. How the person is feeling physically and mentally.
P96	Where arthritis, neurologic, proprioceptive deficits abound, and where fear of injury especially falling mitigates compliance. I am also reluctant to engage in ERT if I can't safely spot them.
P97	Careful considerations and precautions would need to be in place for frailer older adults at risk of falls and injuries. Obviously need to take into considerations other health conditions such as MSK, cardiovascular etc
P98	serious balance issues, clients using walkers, injuries, clients coming straight out of rehab, doctor's instructions, client doesn't require these, but some other type of training
P99	When I have some one new to training and or doesn't have suitable balance.
P103	blood pressure, previous injuries, heart conditions
P105	Specific MSK issues relating to a joint which may be sore
P106	Contraindicated e.g. impaired shoulder stability that requires greater strength and control before introducing explosive force production .
P107	If the older adult had any injuries or concerns which prohibited the use of explosive training, I would not prescribe it Pre-existing injury or current conditions
P109	To Dependent, Frail, Pre-Frail, and Lower Independent Seniors
P110	if the clients body is not ready for the explosive training or his/hers goals and nothing to do with explosivity.
P118	Where I am unable to spot them adequately, if they come to class with a particular issue we need to address in class
P120	When I have concerns about safety/injury
P135	Chronic joint and muscle problems in lower extremity, pre-existing pain. I find that if done right, with appropriate supervision, and progressing velocity of movement slowly over time, these exercises could be done safely for the majority of the older population.
P141	I establish balance conditioning first, leg / hip / core stability and progress to explosive; Not suitable for certain individuals at certain times eg awaiting surgery (eg abdominal hernias, Parkinsons, recent emotional trauma, poor vision, poor hearing, muscular atrophy, etc etc)
P146	New clients until fully assessed to have completed a variety of sessions without agrivating condition without any explosive moves. Then gradual introduction if they feel comfortable with the exercises. Some Clients have numerous co-morbidities/pain and will do all moves in a steady controlled manner as the water is used to ease thier discomfort whilst increasing thier general mobility.
P151	Severe osteoporosis

P168	With my poorly COPD and heart failure patients
P170	I work in a social setting, I would not include it if it was not suitable
P175	Dependent on goals, ability any other comorbidities and the stage in the patients rehabilitation
P179	Injury, Health conditions.
P190	There is insufficient energy, agility, range, propulsion or desire to do so available. And of course any other limiting injury factors or other health contraindications.
P193	Post some cancer treatments, recent surgical procedures whether general or orthopaedic surgery, and sudden illness. I would want to be clear the person had sufficient fitness to undertake such high energy exercise
P196	Recent fractures, cognitive decline, low motor competency, reluctant patients
P198	Medical conditions Issues brought about by GP guidance. Previous injury/recurring injury They simply do not want to do them.

Appendix. P - Raw data responses for reasons why practitioners do not prescribe maximal-intentional velocity resistance training for older adults.

	Practitioners were asked "Are there any specific situations or conditions where you would not programme, prescribe or recommend EXPLOSIVE resistance training for older adults?" **If practitioners said 'No' then they were asked Q31:**
P number	**Q31. Please describe why you do NOT programme, prescribe or recommend any form of EXPLOSIVE resistance training for older adults.** **Please provide as much detail as possible about your reasons.**
P2	Potential for injury,
P7	Don't programme as most patients have insufficient muscle strength or balance - would use throwing activities
P9	Has not been part of any Level 4 courses to date
P10	Due to the nature of injuries and illnesses/disease
P12	Because I don't feel it is appropriate for the clientele that I have in my classes, it would be of little or no interest to them. And I have no qualification in such work and am not interested. FLexercise classes give people the benefit from exercise to lead a life of physical and mental wellness rather than an intense work out. Enjoyment and physical and mental benefits are more important to us.
P16	We work on a functional basis for exercoses and work mainly with older adults who have long term conditions which affect their ability to exercise in an explosive manner. We do include marching, they can jog of they have ability too, step ups which again they work at own pace, side stepping, grapevine. The majority of people entering our session are coming from a sedentary starting point so we are introducing them from that level to fitness
P17	Safety. I would be concerned over technique, particularly in group settings. I find it challenging encouraging individuals to select sufficient resistance for strength training, so this would be an even greater challenge.
P18	Many have underlined issues Hips Knees Shoulder Are the common issues we deal with on a daily basis
P19	Some is incorporated into cardio element Most don't like the impact
P20	It does not fit my clients goals. Injuries prevent.
P21	Risk of falls and general de conditioning.
P22	Only because they individuals I train are not at that stage to be able to do this and over a certain age it is not recommended unless in sports
P23	We teach groups not 121s. We air on the side of safety as ours is not a medical or sports specific setting. We don't want to cause injury. We have no specific training for explosive training with older adults and would, therefore, be uninsured

P24	Not what I'm trained in
P25	Don't use explosive moves in pilates or biomechanics
P26	I am not educated or qualified in explosive exercises.
P27	It all comes down to the individual, if they have long term conditions, new joints exercise history and what they enjoy.
P28	My client base are usually frail, deconditioned or have underlying health conditions, so these exercises would be contraindicated according to every qualification I have and according to basic risk assessments that are based on this and on individual ability.
P33	Clients I see have underlying medical conditions and most struggle with their mobility and have lower levels of fitness
P36	Because I work with referrals and most have co-morbilities and medication to consider.
P37	I have a physical disability so never prescribe wha5 I cannot physically demonstrate
P41	Risk of over compliance or poor following of institution
P46	The type of adults I work with are generally not able to complete this type of exercise safety or without pain. I work with a lot of people who fall often or who are very weak.
P47	I teach a chair based class, most of my participants are over 80. Our focus is ADL's pliometrics would be too tricky for them - sit stand walk around the chair is hard enough..
P48	I feel explosive training needs supervision and proper training, that can't be done in a heterogeneous group setting where some participants have trouble with simple calf raises and others are hesitant and others would be willing to try. For one on one training I focus on every day tasks like getting up and down stairs and building strength for that. I do eccentric calf raises at the stair but not sure if that counts....
P50	I teach Pilates
P51	The individual cannot cope with any type of explosive movement by the time we start training
P52	In my setting I only see very frail patients or those reluctant to engage in physical activity. Not against explosive training but it needs to be suitable geared up to do to reduce risk of injury in this group. Engagement often difficult with the average group being 80 plus so beginning with functional movements and strength alongside balance. I would (if seeing long enough) include power and explosive movements. I am attached, as apart of an MDT, clinic. The patients I see often frail and falling. Their primarily expectation is to see a doctor (I do call prior to their arrival). I get max on average 1/2 hour and no follow up from me (programming goes with engagement and how to progress with details on how to access groups or help to complete activity they enjoy and will more likely be consistent with). For those accepting or who need 1:1 support an onward community referral made - many don't accept. Patients preconceived notions and expectations of those in their age group leads to resistance to comply. Psychological fears of failure or to not start to avoid risk of failing. Family wanting to 'keep safe' and avoid 'risk'
P54	Lack of experience with same lack of suitable facilities eg gym spaces to work in Safety issues when working in groups trying to supervise these exercises (when running groups, we are expected to have larger numbers to warrant running the class)
P57	Working with a frail osteoporotic population
P59	Patient group usually too low level with regards falls risk and osteoporosis diagnosis
P60	Customer preference
P61	Against bacpr protocols

P62	I follow a program for older adults developed by Washington State University called Stay Active & Independent for Life (S.A.I.L.). To teach this program I have to follow their evidence-based format which does not include explosive exercises. For my personal training clients, I do not teach explosive because each client seems to have some health issue which may be effective negatively with explosive exercises. Additionally, there is not enough studies done in this type of exercise for older adults that I feel comfortable with adapting.
P65	Because they have never shown any interest in exercising at more than a moderate level
P68	No appropriate for the patient group following an acute illness. Initial focus is on regaining function and then progressing strength and challenging proprioception as an outpatient
P70	I teach a dance exercise programme that is performed standing up for 45 minutes. The focus is on mobility, balance and jy of dance. We do perform strengthening exercises without explosive resistance training, using bodyweight such as squats and lunges.
P71	To reduce the risk of injury. Also sessions are currently online so its harder to make sure technique is proper.
P74	A lot of my strength work is for falls risk adults and I do not think this is appropriate
P75	Many cardiac patients suffer from blood pressure conditions which is greatly affected during strength training activities. Those with hypotension we will need to make sure we do not raise their blood pressure too high. Others may suffer from postural hypotension so want to avoid large postural changes. We will vary the advice depending on the patient and their condition.
P76	Cardiac risk associated with explosive, high intensity movements without prior cardiopulmonary exercise testing.
P77	My population are frail older adults with multiple co-morbidities and more often than not balance impairments and strength deficits that I believe would prevent them from completing explosive resistance training. Most of them use walking aids and have a history of previous falls. As I work in the acute setting, I lack the ability to follow up patients on discharge so am unable to supervise exercises moving forward, so I choose exercises I believe will be safe for them to complete independently.
P78	As most of my class members are over 80 years of age. I don't think any "explosive" type of resistance exercise would be advisable. Risk of of muscle injury. Raised b.p. etc.
P80	Postural Stability - (FAME) - explosive moves are not part of evidence based programme. General exercise - Group exercise, difficult to manage in a group, risk of falls/injury
P82	Most of the patients I see have poor balance and require use of walking aids to mobilise. Some of them are only able to stand up with standing standing aids. So, they lack the balance for the explosive resistance exercises. Because we prescribe exercises and ask patients to do them between therapy visits, we have to ensure that patients are going to be safe to do these exercises independently, so if they do not meet this criteria, then they do not get prescribed. It is possible to have modified exercises, but most of the time, by the time patients get to a level where they could do certain exercises, they are already discharged. We are unable to keep them on our caseload to see them through a lot of the progression
P83	We have found that some clients did bit like this form of physical activity. As they felt it was too hard, we did have some that enjoyed do throwing and hitting while in a seated position.
P84	Mostly bc I am training online and I don't feel comfortable doing so with the population I work with. Most of my clients would not be able to perform these activities anyways but I do have a couple that I do these types of exercises with, just not overall
P87	The method of training that seems to work the best for my over 60 clients consists of controlled and slower strength training exercises. This allows them to focus on their form. When I have added jumping, I hear complaints about pain in their knees and incontinence. I would like to add explosive moves to their workouts, but need guidance on how to proceed. About 10 yrs ago I taught group exercises classes and we always added power and explosive moves for those who want to ramp it up.
P89	Lack of evidence of benefit.

P91	Majority of my clientele, have some sort of injury or overweight. Absolutely no need for explosive training in their programs.
P99	1) Do not feel it is appropriate for the type of population in which I am supporting whereby the focus is simply to reduce sedentary lifestyles and increase engagement in physical activity 2) Do not have the equipment to do so
P100	Parkinsons population are not conditioned enough yet but am working to that goal
P103	My client group tend to be too frail/ have insufficient power for explosive training
P107	It's quite challenging and there has been a range of other choices for people which are more enjoyable and provide progression.
P126	Italian standard population usually don't like any tipe of active exercise. It's difficult to get them work on resistance training and its quite impossible to work on explosive resistenze training with them.
P128	Frail older adults find progressive RT difficult, including an explosive RT would be overwhelming for them.
P141	Have classes of 10 or more participants. Would prefer to have smaller numbers with that type of exercise
P142	In almost all cases, the patients I work with need to build base muscle strength and correct, safe technique prior to building power based exercises.
P143	Only because my clients are not capable/ready to do those things yet, especially with the minimal equipment we have. For example, we are still working on engaging and strengthening the core and other stabilizers. Once they are structurally sound and have enough strength to support doing explosive work without falling apart and compensating then I will incorporate. I would probably give them explosive sprint intervals on the air assault bike.
P146	The impact force of ballistic training risks damage to the skeleton due to their age-related osteoporosis, as well as the potential impacts from falls, which are likely to increase in likelihood performing explosive movements, whether that be fractures in long bones or the inflammation of joints due to their reduced articular cartilage.
P152	Most of the Older Adults I have work with need building of confidence specifically to do with knee joints. I take a softer approach of trying to build stability to help increase confidence. I think alot of them would be too uncomfortable to try explosive techniques. While I ll try to push them outside of their comfort zone just not too far.
P153	Typically find they are less confident in these movements (depending on previous experience, current strength level and current mobility level). Would not be against it if they were capable of performing exercises safely, but would always build a foundation of strength through less explosive/plyometric training first. Each client is very individual in their abilities, so when asked for a general answer I would say overall it's more common that I do not programme this type of exercise for this age group. Risks would usually out-weigh benefits.
P154	There is simply not enough evidence to support such a prescription in within the clinical populations (cardiac, respiratory and stroke) I work with and it is not part of current evidence-based guidelines
P155	Movement impairments don't allow for this type of movement
P156	Most of my class members are over 85. Really don't think anything "explosive" is appropriate for this age group. Risk of damage to muscles, tendons, joints, etc.
P157	Looking at maintenance of existing strength and mobility in a gentle form as most of my participants are over 70 years of age
P158	Balance Fatigue General vulnerability
P159	Not part of My teaching programme
P160	most of my clients are frailer older adults, who might have osteoporosis however, I do have some Parkinsons clients, and they do throwing exercises to improve strength

P161	My only currant clients are a lovely married couple in their 90s, previously I worked with mixed ability groups of clients aged between 70 and 90 - explosive training would obviously be highly inappropriate for these people.
P162	I don't feel qualified to do so
P163	The Extend programme tends towards gentle exercise for safety reasons.at least 20% is chair based. As we are not qualified physios we take care not to damage joints that might be fragile. Sometimes we run a class called Active Extend which follows more of an aerobic programme with active stepping, marching, grapevines, etc.
P164	I do not feel qualified to do more explosive resistance training than the work I have been trained to give.
P165	Not been trained in this form of exercise. I am an EXTEND teacher which although this can be active, is described as gentle exercise
P166	Frail elderly and additional needs
P168	As there is a mixture of ability within these groups due to either age or health condition, I encourage to work safely within their own ability/range. Self development is grown with encouragement which in turn improves confidence and success/improvement on many levels.
P170	In my current setting I work with elderly patients who have specififc commodities. Explosive resistance training is not suitable for the types of goals they have.
P171	Generally the population are frail or have an acute injury therefore typically we use the 10 repetitions of 3 sets principle, no more than 7-8/10 RPE
P173	The population I am working in is specialised learning disability, where the clients ability would not allow explosive exercise to be prescribed as this would be unsafe and put patients at risk of falls or injury, many exercises in this population are supported by nursing staff who also may be uncomfortable helping clients with explosive exercise
P176	The reasoning is that some of the adults I coach, currently have injury background that limits there explosive moment. Therefore, I work mostly around flexibility and mobility recommending yoga for example.
P177	Unless they need it for sport specific training I do not programme it. Most clients wish to do gentler training as they have a fear of injuring themselves or underlaying health conditions.
P179	Too many other co-morbidities eg knee pain. Worried if they don't currently have joint pain, that they have done activity modification to avoid these sorts of exercises so far in their life.
P184	Risks out way the benefits
P185	Not done any training in this type of resistance training so don't feel confident teaching it, and work with special populations so its not appropriate most of the time.
P190	The exercises I give out are based on individual clients needs. I feel that explosive movements have not been with in a clients capabilities. If I had a client that was capable enough to add this type of training I would give it a go.
P191	Most of my patients have neurological impairment and recruitment of a rapid burst of activity can be very challenging or impossible. However, I think this is an under-explored area and I would be willing to focus on building skills in this area.
P194	a lot of clients have osteoarthritis, osteoporosis, osteopenia, hip and knee issues
P196	Regular strength exercises seem good enough. In a group Setting explosive training seems difficult to monitor, lots of clients are afraid and I want to know their underlying conditions.

Appendix. Q - Inter-day reliability for the force plate variables in all conditions assessed by Spearman correlations (R_S). Low and high 95% confidence intervals are also shown along with significance (p). Shaded rows represent Strong correlations (> 0.7); * = (p < 0.05); ** = (p < 0.01).

Force Plate		R_S	95% Confidence	
			Low	High
Total Mean Velocity	TFEO_NDom	0.657	0.115	0.898
	TFEO_Dom	0.692	0.178	0.910
	TFEC_NDom	0.783	0.364	0.939
	TFEC_Dom	0.469	-0.163	0.828
	OFEO_NDom	0.741	0.273	0.925
	OFEO_Dom	0.706	0.204	0.914
	OFEC_NDom	0.769	0.333	0.934
	OFEC_Dom	0.622	0.056	0.886
	ST_Rear	0.791	0.346	0.945
	ST_Front	0.236	-0.440	0.742
	FT_Rear	0.709	0.170	0.921
	FT_Front	0.482	-0.186	0.845
AP Mean Velocity	TFEO_NDom	0.706	0.204	0.914
	TFEO_Dom	0.434	-0.205	0.813
	TFEC_NDom	0.797	0.395	0.943
	TFEC_Dom	0.343	-0.305	0.774
	OFEO_NDom	0.657	0.115	0.898
	OFEO_Dom	0.385	-0.261	0.792
	OFEC_NDom	0.832	0.480	0.953
	OFEC_Dom	0.580	-0.010	0.871
	ST_Rear	0.418	-0.262	0.821
	ST_Front	0.236	-0.440	0.742
	FT_Rear	0.955	0.823	0.989
	FT_Front	0.591	-0.034	0.884
ML Mean Velocity	TFEO_NDom	0.713	0.218	0.916
	TFEO_Dom	0.608	0.034	0.881
	TFEC_NDom	0.832	0.480	0.953
	TFEC_Dom	0.406	-0.238	0.802
	OFEO_NDom	0.797	0.395	0.943
	OFEO_Dom	0.517	-0.099	0.847
	OFEC_NDom	0.713	0.218	0.916
	OFEC_Dom	0.594	0.012	0.876
	ST_Rear	0.891	0.612	0.973
	ST_Front	0.345	-0.339	0.791
	FT_Rear	0.500	-0.163	0.852
	FT_Front	0.291	-0.392	0.767

Appendix. R - Inter-day reliability for the insole variables in all conditions assessed by Spearman correlations (R_S). Low and high 95% confidence intervals are also shown along with significance (p). Shaded rows represent Strong correlations (> 0.7); * = (p < 0.05); ** = (p < 0.01).

Insoles		R_s	95% Confidence Low	95% Confidence High
Total Mean Velocity	TFEO_NDom	0.699	0.191	0.912
	TFEO_Dom	0.476	-0.154	0.831
	TFEC_NDom	0.797	0.395	0.943
	TFEC_Dom	0.608	0.034	0.881
	OFEO_NDom	0.811	0.428	0.947
	OFEO_Dom	0.231	-0.412	0.720
	OFEC_NDom	0.797	0.395	0.943
	OFEC_Dom	0.615	0.045	0.883
	ST_Rear	0.745	0.244	0.932
	ST_Front	0.555	-0.088	0.871
	FT_Rear	0.555	-0.088	0.871
	FT_Front	0.782	0.324	0.943
AP Mean Velocity	TFEO_NDom	0.699	0.191	0.912
	TFEO_Dom	0.378	-0.269	0.789
	TFEC_NDom	0.797	0.395	0.943
	TFEC_Dom	0.699	0.191	0.912
	OFEO_NDom	0.776	0.348	0.936
	OFEO_Dom	0.315	-0.334	0.761
	OFEC_NDom	0.811	0.428	0.947
	OFEC_Dom	0.594	0.012	0.876
	ST_Rear	0.682	0.119	0.913
	ST_Front	0.609	-0.006	0.890
	FT_Rear	0.418	-0.262	0.821
	FT_Front	0.782	0.324	0.943
ML Mean Velocity	TFEO_NDom	0.371	-0.276	0.786
	TFEO_Dom	0.517	-0.099	0.847
	TFEC_NDom	0.741	0.273	0.925
	TFEC_Dom	0.587	0.001	0.873
	OFEO_NDom	0.748	0.288	0.928
	OFEO_Dom	0.336	-0.313	0.771
	OFEC_NDom	0.608	0.034	0.881
	OFEC_Dom	0.462	-0.172	0.825
	ST_Rear	0.618	0.009	0.893
	ST_Front	0.500	-0.163	0.852
	FT_Rear	0.800	0.367	0.948
	FT_Front	0.827	0.435	0.956

Appendix. S - Inter-day reliability for inertial measurement unit variables in all conditions assessed by Spearman correlations (R_S). Low and high 95% confidence intervals are also shown along with significance (p). Shaded rows represent Strong correlations (> 0.7); * = (p < 0.05); ** = (p < 0.01).

Runscribe		R_S	95% Confidence Low	95% Confidence High	p
AP Mean Acceleration	TFEO_NDom	0.692	0.178	0.910	< 0.05 *
	TFEO_Dom	0.476	-0.154	0.831	0.12
	TFEC_NDom	0.797	0.395	0.943	< 0.01 **
	TFEC_Dom	0.483	-0.145	0.833	0.11
	OFEO_NDom	0.748	0.288	0.928	< 0.01 **
	OFEO_Dom	0.867	0.571	0.964	< 0.01 **
	OFEC_NDom	0.734	0.259	0.923	< 0.01 **
	OFEC_Dom	0.713	0.218	0.916	< 0.01 **
	ST_Rear	0.764	0.283	0.938	< 0.01 **
	ST_Front	-0.191	-0.720	0.478	0.57
	FT_Rear	0.736	0.225	0.930	< 0.01 **
	FT_Front	0.355	-0.330	0.795	0.28
ML Mean Acceleration	TFEO_NDom	0.853	0.533	0.960	< 0.01 **
	TFEO_Dom	0.175	-0.459	0.691	0.59
	TFEC_NDom	0.825	0.462	0.951	< 0.01 **
	TFEC_Dom	0.273	-0.374	0.741	0.39
	OFEO_NDom	0.776	0.348	0.936	< 0.01 **
	OFEO_Dom	0.867	0.571	0.964	< 0.01 **
	OFEC_NDom	0.685	0.165	0.907	< 0.05 *
	OFEC_Dom	0.748	0.288	0.928	< 0.01 **
	ST_Rear	0.609	-0.006	0.890	< 0.05 *
	ST_Front	0.836	0.459	0.958	< 0.01 **
	FT_Rear	0.600	-0.020	0.887	0.05
	FT_Front	0.791	0.346	0.945	< 0.01 **
AP RMS Acceleration	TFEO_NDom	0.538	-0.071	0.855	0.07
	TFEO_Dom	0.392	-0.253	0.796	0.21
	TFEC_NDom	0.664	0.127	0.900	< 0.05 *
	TFEC_Dom	0.399	-0.246	0.799	0.20
	OFEO_NDom	0.713	0.218	0.916	< 0.01 **
	OFEO_Dom	0.685	0.165	0.907	< 0.05 *
	OFEC_NDom	0.650	0.103	0.895	< 0.05 *
	OFEC_Dom	0.503	-0.118	0.842	0.10
	ST_Rear	0.827	0.435	0.956	< 0.01 **
	ST_Front	-0.173	-0.710	0.492	0.61
	FT_Rear	0.700	0.153	0.919	< 0.05 *
	FT_Front	0.482	-0.186	0.845	0.13
ML RMS Acceleration	TFEO_NDom	0.783	0.364	0.939	< 0.01 **
	TFEO_Dom	0.245	-0.399	0.727	0.44
	TFEC_NDom	0.860	0.552	0.962	< 0.01 **
	TFEC_Dom	0.322	-0.327	0.764	0.31
	OFEO_NDom	0.804	0.412	0.945	< 0.01 **
	OFEO_Dom	0.769	0.333	0.934	< 0.01 **
	OFEC_NDom	0.685	0.165	0.907	< 0.05 *
	OFEC_Dom	0.678	0.152	0.905	< 0.05 *
	ST_Rear	0.645	0.054	0.902	< 0.05 *
	ST_Front	0.718	0.188	0.924	< 0.05 *
	FT_Rear	0.500	-0.163	0.852	0.12
	FT_Front	0.764	0.283	0.938	< 0.01 **

Appendix. T - Concurrent validity of insoles for all variables in all conditions assessed by Spearman correlations (R_S). Low and high 95% confidence intervals are shown along with significance (p). Shaded rows represent strong correlations (> 0.7/< -0.7); * = (p < 0.05); ** = (p < 0.01).

Force Plate vs Insoles		Total Mean Velocity R_s	95% Confidence Low	95% Confidence High	*p*	AP Mean Velocity R_s	95% Confidence Low	95% Confidence High	*p*	ML Mean Velocity R_s	95% Confidence Low	95% Confidence High	*p*
Day 1	TFEO_NDom	0.245	-0.399	0.727	0.44	0.203	-0.436	0.706	0.53	-0.427	-0.810	0.214	0.17
	TFEO_Dom	0.483	-0.145	0.833	0.11	0.357	-0.291	0.780	0.26	0.406	-0.238	0.802	0.19
	TFEC_NDom	0.545	-0.061	0.858	0.07	0.497	-0.127	0.839	0.10	0.203	-0.436	0.706	0.53
	TFEC_Dom	0.378	-0.269	0.789	0.23	0.406	-0.238	0.802	0.19	0.049	-0.554	0.618	0.88
	OFEO_NDom	0.860	0.552	0.962	< 0.01 **	0.818	0.445	0.949	< 0.01 **	0.916	0.712	0.977	< 0.01 **
	OFEO_Dom	0.846	0.515	0.958	< 0.01 **	0.811	0.428	0.947	< 0.01 **	0.650	0.103	0.895	< 0.05 *
	OFEC_NDom	0.902	0.670	0.974	< 0.01 **	0.818	0.445	0.949	< 0.01 **	0.874	0.590	0.966	< 0.01 **
	OFEC_Dom	0.769	0.333	0.934	< 0.01 **	0.783	0.364	0.939	< 0.01 **	0.839	0.497	0.955	< 0.01 **
	ST_Rear	0.266	-0.380	0.737	0.40	0.196	-0.442	0.702	0.54	0.112	-0.508	0.656	0.73
	ST_Front	0.105	-0.513	0.652	0.75	0.070	-0.539	0.631	0.83	0.203	-0.436	0.706	0.53
	FT_Rear	0.678	0.152	0.905	< 0.05 *	0.259	-0.387	0.734	0.42	0.462	-0.172	0.825	0.13
	FT_Front	0.664	0.127	0.900	< 0.05 *	0.217	-0.424	0.713	0.50	0.538	-0.071	0.855	0.07
Day 2	TFEO_NDom	0.678	0.152	0.905	< 0.05 *	0.497	-0.127	0.839	0.10	0.524	-0.090	0.850	0.08
	TFEO_Dom	0.748	0.288	0.928	< 0.01 **	0.825	0.462	0.951	< 0.01 **	0.343	-0.305	0.774	0.28
	TFEC_NDom	0.573	-0.020	0.868	0.05	0.552	-0.051	0.860	0.06	0.524	-0.090	0.850	0.08
	TFEC_Dom	0.580	-0.010	0.871	< 0.05 *	0.517	-0.099	0.847	0.08	-0.021	-0.600	0.573	0.95
	OFEO_NDom	0.755	0.303	0.930	< 0.01 **	0.818	0.445	0.949	< 0.01 **	0.853	0.533	0.960	< 0.01 **
	OFEO_Dom	0.441	-0.197	0.816	0.15	0.622	0.056	0.886	< 0.05 *	0.497	-0.127	0.839	0.10
	OFEC_NDom	0.888	0.629	0.970	< 0.01 **	0.923	0.734	0.979	< 0.01 **	0.909	0.691	0.975	< 0.01 **
	OFEC_Dom	0.881	0.609	0.968	< 0.01 **	0.867	0.571	0.964	< 0.01 **	0.930	0.756	0.981	< 0.01 **
	ST_Rear	0.691	0.135	0.916	< 0.05 *	0.691	0.135	0.916	< 0.05 *	0.427	-0.251	0.824	0.19
	ST_Front	0.691	0.135	0.916	< 0.05 *	0.291	-0.392	0.767	0.39	0.927	0.728	0.982	< 0.01 **
	FT_Rear	0.691	0.135	0.916	< 0.05 *	0.700	0.153	0.919	< 0.05 *	0.355	-0.330	0.795	0.28
	FT_Front	0.618	0.009	0.893	< 0.05 *	0.409	-0.272	0.817	0.21	0.573	-0.062	0.878	0.07

Appendix. U - Concurrent validity of inertial measurement units for mean acceleration variables in all conditions assessed by Spearman correlations (R_S). Low and high 95% confidence intervals are shown along with significance (p). Shaded rows represent strong correlations (> 0.7/< -0.7); * = (p < 0.05); ** = (p < 0.01).

Force Plate vs Runscribe			AP Mean Velocity / AP Mean Acceleration R_s	95% Confidence Low	95% Confidence High	*p*	ML Mean Velocity / ML Mean Acceleration R_s	95% Confidence Low	95% Confidence High	*p*
	Day 1	TFEO_NDom	-0.671	-0.903	-0.140	< 0.05 *	0.000	-0.587	0.587	1.00
		TFEO_Dom	-0.161	-0.683	0.470	0.62	-0.196	-0.702	0.442	0.54
		TFEC_NDom	0.273	-0.374	0.741	0.39	0.140	-0.487	0.671	0.66
		TFEC_Dom	0.643	0.091	0.893	< 0.05 *	-0.119	-0.660	0.503	0.71
		OFEO_NDom	-0.329	-0.767	0.320	0.30	0.084	-0.529	0.639	0.80
		OFEO_Dom	-0.056	-0.622	0.549	0.86	0.238	-0.406	0.724	0.46
		OFEC_NDom	0.168	-0.465	0.687	0.60	0.028	-0.568	0.605	0.93
		OFEC_Dom	0.322	-0.327	0.764	0.31	0.357	-0.291	0.780	0.26
		ST_Rear	-0.028	-0.605	0.568	0.93	0.385	-0.261	0.792	0.22
		ST_Front	0.056	-0.549	0.622	0.86	0.049	-0.554	0.618	0.88
		FT_Rear	0.364	-0.284	0.783	0.25	-0.133	-0.668	0.492	0.68
		FT_Front	0.441	-0.197	0.816	0.15	0.049	-0.554	0.618	0.88
	Day 2	TFEO_NDom	-0.315	-0.761	0.334	0.32	-0.434	-0.813	0.205	0.16
		TFEO_Dom	-0.266	-0.737	0.380	0.40	-0.210	-0.709	0.430	0.51
		TFEC_NDom	0.056	-0.549	0.622	0.86	-0.014	-0.596	0.577	0.97
		TFEC_Dom	-0.035	-0.609	0.563	0.91	0.357	-0.291	0.780	0.26
		OFEO_NDom	0.014	-0.577	0.596	0.97	0.210	-0.430	0.709	0.51
		OFEO_Dom	-0.091	-0.643	0.524	0.78	0.322	-0.327	0.764	0.31
		OFEC_NDom	0.308	-0.340	0.758	0.33	0.413	-0.230	0.805	0.18
		OFEC_Dom	0.343	-0.305	0.774	0.28	0.427	-0.214	0.810	0.17
		ST_Rear	0.273	-0.408	0.759	0.42	0.073	-0.565	0.656	0.83
		ST_Front	0.373	-0.311	0.802	0.26	0.182	-0.485	0.715	0.59
		FT_Rear	0.245	-0.432	0.746	0.47	-0.045	-0.640	0.584	0.89
		FT_Front	0.400	-0.282	0.813	0.22	-0.009	-0.618	0.607	0.98

Appendix. V - Concurrent validity of inertial measurement units for root mean squared acceleration variables in all conditions assessed by Spearman correlations (R_S). Low and high 95% confidence intervals are shown along with significance (p). Shaded rows represent strong correlations (> 0.7/< -0.7); * = (p < 0.05); ** = (p < 0.01).

Force Plate vs Runscribe		AP Mean Velocity / AP RMS Acceleration				ML Mean Velocity / ML RMS Acceleration			
		R_s	95% Confidence		*p*	R_s	95% Confidence		*p*
			Low	High			Low	High	
Day 1	TFEO_NDom	-0.664	-0.900	-0.127	< 0.05 *	0.070	-0.539	0.631	0.83
	TFEO_Dom	-0.140	-0.671	0.487	0.66	-0.196	-0.702	0.442	0.54
	TFEC_NDom	0.322	-0.327	0.764	0.31	0.182	-0.453	0.694	0.57
	TFEC_Dom	0.755	0.303	0.930	< 0.01 **	-0.021	-0.600	0.573	0.95
	OFEO_NDom	-0.266	-0.737	0.380	0.40	0.014	-0.577	0.596	0.97
	OFEO_Dom	-0.105	-0.652	0.513	0.75	0.217	-0.424	0.713	0.50
	OFEC_NDom	0.364	-0.284	0.783	0.25	0.014	-0.577	0.596	0.97
	OFEC_Dom	0.343	-0.305	0.774	0.28	0.336	-0.313	0.771	0.29
	ST_Rear	-0.042	-0.614	0.559	0.90	0.287	-0.361	0.748	0.37
	ST_Front	0.098	-0.519	0.647	0.76	0.007	-0.582	0.591	0.98
	FT_Rear	0.266	-0.380	0.737	0.40	-0.098	-0.647	0.519	0.76
	FT_Front	0.371	-0.276	0.786	0.24	0.091	-0.524	0.643	0.78
Day 2	TFEO_NDom	-0.196	-0.702	0.442	0.54	-0.462	-0.825	0.172	0.13
	TFEO_Dom	-0.280	-0.744	0.367	0.38	-0.329	-0.767	0.320	0.30
	TFEC_NDom	0.224	-0.418	0.716	0.48	0.133	-0.492	0.668	0.68
	TFEC_Dom	0.280	-0.367	0.744	0.38	0.490	-0.136	0.836	0.11
	OFEO_NDom	0.049	-0.554	0.618	0.88	0.189	-0.447	0.698	0.56
	OFEO_Dom	0.098	-0.519	0.647	0.76	0.392	-0.253	0.796	0.21
	OFEC_NDom	0.329	-0.320	0.767	0.30	0.371	-0.276	0.786	0.24
	OFEC_Dom	0.399	-0.246	0.799	0.20	0.413	-0.230	0.805	0.18
	ST_Rear	0.273	-0.408	0.759	0.42	0.027	-0.596	0.630	0.94
	ST_Front	0.355	-0.330	0.795	0.28	0.218	-0.456	0.733	0.52
	FT_Rear	0.309	-0.375	0.775	0.36	0.009	-0.607	0.618	0.98
	FT_Front	0.191	-0.478	0.720	0.57	-0.036	-0.635	0.590	0.92