Exploring the Effectiveness and Implementation of Power Training to Improve Independence and Performance of Activities of Daily Life in Older Adults



Mohamed el Hadouchi

Empower Older Adults

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Empower Older Adults

Exploring the Effectiveness and Implementation of Power Training to Improve Independence and Performance of Activities of Daily Life in Older Adults

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copromotoren:	dr. H. Kiers
promotiecommissie:	prof.dr. M. Pijnappels prof.dr. C. Delecluse prof.dr. J. Zwerver dr. J.S.M. Hobbelen dr. J.A. Barten

you dont stop because you become older, you become older because you stop

(Life's) First Gear: The Power to Move

"Back in my younger days, I could spring into action like a well-tuned engine," recalls a spirited eighty-year-old. "But now," he sighs, my muscles feel like an engine that won't turn on properly. That vital spark of power – the one that gets everything moving – seems to have faded away. It's as if someone has removed my body's first gear."

"Imagine starting a car in third or fourth gear," he explains, leaning forward intently. "The engine strains, shudders, and might even stall. That's how my body feels now. My coordination stumbles, my balance wavers, and that split-second ability to react has vanished. Every movement demands more energy, creates more strain.."

His voice grows more determined, "The goal I have for myself is clear: I want to stay active and maintain my independence, to keep my engine running smoothly. Being able to move well isn't only about comfort – it's about freedom. It's about maintaining my quality of life and not having to rely on others for daily tasks."

This fundamental challenge – regaining and maintaining strength, speed, and power – lies at the heart of this thesis. Just as a car cannot efficiently move without its first gear, older adults cannot thrive without the power that initiates movement. This muscular power is their 'first gear' – the crucial starting point for all physical activities."

Table of Contents

Chapter 1	General Introduction	11
Part 1	**"Harmonizing Outcomes: How to Measure the Impact of Power Training in Older Adults"**	29
Chapter 2	Therapeutic Validity and Replicability of Power Training Interventions in Older Adults: a Review using the TIDieR Checklist and CONTENT Scale	31
Chapter 3	The Reliability, Validity, and Responsiveness of Tests used to Assess the Effects of Power Training in Older Adults: A Systematic Review	53
Chapter 4	Establishing a Core Outcome Set to Evaluate the Effects of Power Training in Older Adults: a Delphi Study	99
Part 2	**"From Theory to Practice: Evaluation of the Effects and Clinical Applicability of Power Training in Older Adults"**	129
Chapter 5	Effectiveness of Power Training Compared to Strength Training in Older Adults: a Systematic Review and Meta-Analysis	131
Chapter 6	Power Training in Older Adults: a Pilot and Feasibility Study	161
Chapter 7	The Impact of Power Training on Muscle Power, Physical Performance, and Physical Functioning in Older Adults: a Descriptive Case Series	179
Chapter 8	General Discussion	199
Appendix	Summary	217
	Samenvatting	223
	Dankwoord	227
	Publications	233
	About the Author	235

1

General Introduction

Mohamed el Hadouchi

General Introduction

The Ageing Population: Challenges and Opportunities for Physical Functioning

As the global population continues to age, maintaining the physical performance and independence of older adults has become a critical public health concern. Population ageing describes a simultaneous increase in the number of older adults and the growth of the oldest-old demographic, which poses substantial societal, economic, and health-related challenges.[1–3] Worldwide, it has been estimated that by 2050, one in six people will be over the age of 65.[3] In the Netherlands, the number of individuals aged 65 years and older has been predicted to increase from 19.2% in 2020 to 26.5% in 2050, with the number of individuals aged 80 years and older doubling.[4] As a consequence, a growing number of individuals will experience a decline in physical function, which is a critical determinant of maintaining independence, autonomy, and active participation.[5–7] Muscle strength and power, fundamental components of physical functioning, progressively deteriorate with advancing age, increasing the demand of healthcare systems and contributing to rising health care costs. However, engaging in regular physical activity can attenuate both the individual and societal impacts of ageing by preserving functional capacity, enhancing overall well-being, and promoting social participation.[8] To improve physical functioning in older adults, targeted interventions should incorporate physical activity and emphasize physical functioning as a key determinant of maintaining independence.

The Ageing of Skeletal Muscles

Throughout the ageing process, the human body undergoes various, interconnected transformations that impact physical functioning. As a general rule, metabolic efficiency declines with advancing age. More specifically, the ageing of human musculature is characterized by a complex cascade of physiological alterations significantly impacting muscle structure, function, and performance. This multifaceted phenomenon encompasses quantitative and qualitative changes at the cellular, molecular, and systemic levels, collectively contributing to a decline in muscular capacity and functional independence in older adults. Previous research has shown that muscle mass decreases between 3-8% per decade after age 30, doubling after age 60.[9,10] The decline in muscle strength occurs 2-3 times faster, with approximately 8-10% loss per decade between ages 40-70, further accelerating to 3-4% per year after age 70.[11,12]

The age-related progressive and widespread loss of skeletal muscle mass is called sarcopenia. Factors influencing sarcopenia are complex and multifactorial, involving hormonal changes,

reduced protein production, increased inflammation, and most importantly, decreased physical activity.[9,13] At the cellular level, sarcopenia is characterized by a reduction in the size and number of muscle fibers and by the loss of Type II muscle fibers, which are crucial for rapid muscle force production and strength.[14–16] Sarcopenia is known to raise the risk of musculoskeletal disorders affecting physical mobility and functional capacity.[17,18]

The Critical Role of Muscle Power in Ageing and Physical Functioning

Age-related physiological changes also have a significant impact on muscle power, which is defined as the product of muscle force and contraction velocity.[19–21] Muscle power reflects to what extent muscles can produce a forceful, rapid movement, and combines both strength (the force muscles can exert) and speed (how fast muscles can contract). Throughout our lives, muscle power is a crucial component of skill-related physical fitness and plays a significant role in enhancing athletic performance.

The ability of the muscles to produce force rapidly deteriorates more rapidly and at an earlier age than muscle mass and muscle strength, namely 10-30% per decade after age 40.[22,23] By age 80, the average person may have lost up to 40% of their peak muscle strength and as much as 70% of their peak muscle power.[15,24] Research shows that the loss of muscle power is more closely associated with functional decline in activities in daily life than the loss of muscle strength alone.[25] As we age, activities that require quick movements with force, such as climbing a flight of stairs, rising from a chair, or catching oneself to prevent a fall, become more difficult to perform. Decreased muscle power is also strongly associated with fall risk, highlighting its importance for maintaining balance and preventing falls.[26,27]

Changes in Muscle Fiber Composition and Power Decline

Ageing causes a shift in muscle fiber type composition, directly influencing the ability to produce muscle power. Muscle fibers can be broadly classified into two main types: type I (slow-twitch) and type II (fast-twitch) fibers. Type I or slow-twitch muscle fibers are characterized by a slower contraction speed, high endurance, aerobic energy production, the presence of myoglobin, resistance to fatigue, and a smaller cross-sectional area **(Figure 1)**.[28] These properties make type I fibers well-suited for endurance-based activities that require prolonged, steady exertion. In contrast, fast-twitch or type II muscle fibers are known for their rapid contraction speed, high force production, quick fatigue, anaerobic energy production, and lower endurance.[29] These fast-twitch fibers are optimally adapted for short, intensive efforts that require rapid and forceful contractions such as sprinting and explosive movements, where a quick and powerful contraction is necessary, as seen in Olympic weightlifting.

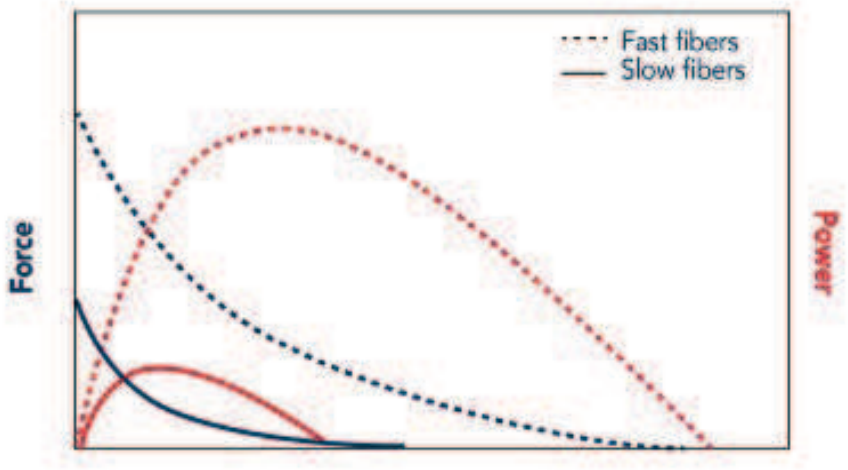


Figure 1: Force-velocity (blue lines) and power (red lines) curves for fast (dashed line) and slow (solid line) muscle fibers. Faster muscle fibers generate higher forces and produce more power than slow muscle fibers.[20,30]

Fast-twitch fibers can be further divided into two main subtypes: type IIa and type IIb/x. Type IIa muscle fibers can generate a reasonable amount of force at a certain speed, while type IIb/x fibers are specialized in producing force in the shortest possible time, making them suitable for explosive movements. Type IIb/x fibers can contract very quickly and powerfully but become fatigued very rapidly. As individuals age, the fast-twitch type II muscle fibers are lost more rapidly than type I fibers. This selective atrophy results in a relative increase in the proportion of type I fibers, which are more fatigue-resistant but less powerful. The preferential loss of type II fibers primarily results in a loss of movement speed and is a primary contributor to the pronounced decrease in muscle power observed with ageing.

Additional physiological factors contributing to the loss of muscle power include changes in muscle pinnation angle and fascicle length, which affect the force-velocity relationship of muscles, leading to reduced power output.[31] Furthermore, age-related alterations in tendon stiffness and elasticity impair the effective transfer of muscle force to bones, consequently impacting power generation.[31] At the molecular level, changes in the expression and function of contractile proteins, such as myosin heavy chain isoforms, contribute to reduced contractile speed and force generation capacity.[32] Additionally, a decline in the efficiency of sarcoplasmic reticulum calcium release and reuptake leads to prolonged relaxation times and decreased force production. This alteration in calcium handling contributes to the overall slowing of muscle contraction and relaxation kinetics observed in older adults, directly impacting the velocity component of power.[33]

Changes in Neuromuscular Junction and Motor Units

A decline in the number and size of motor units, which are comprised of motor neurons and skeletal muscle fibers, leads to decreased neural and consequenty muscular activation.[34] This reduction in motor unit firing rates contributes to a diminished generation of force in older adults. There is evidence of motor neuron loss and subsequent denervation of muscle fibers, particularly affecting fast motor units.[35,36] This process leads to a remodeling of motor units, where surviving motor neurons reinnervate some of the denervated muscle fibers, resulting in larger motor units with reduced precision of control and diminished fine motor coordination.[36] The neuromuscular junction itself undergoes structural and functional changes with age, which include a reduction in the number of synaptic vesicles, alterations in acetylcholine receptor density, and changes in the morphology of the post-synaptic membrane. These changes contribute to reduced neuromuscular transmission efficiency and impaired motor control,[35] which have a direct impact on power production. The less efficient neural activation of muscle fibers particularly affect the high-threshold motor units associated with type II fibers, contributes significantly to the loss of rapid force production capabilities.

Physical Activity, Physical Fitness, and Ageing

One of the most widely accepted definitions of physical activity was proposed by Caspersen et al.[37] and reinforced by the World Health Organization, which defines physical activity as any bodily movement produced by skeletal muscles that results in energy expenditure, often measured as habitual patterns of energy expenditure during daily activities.[37,38] In contrast, the definition of physical fitness refers to a set of attributes that individuals possess or achieve, which relate to the ability to perform physical activity.[37] Physical fitness is typically measured in terms of capacity to perform or sustain physical work, as well as performance-based measures such as time to complete an activity. Additionally, physiological variables like maximal oxygen uptake or heart rate response can be used to assess physical fitness.

Physical fitness can be divided into two categories: health-related physical fitness and performance-related physical fitness. While there is some overlap, health-related physical fitness primarily focuses on general well-being, biomedical aspects of health, and overall capacity—aspects that are important for older adults, but often do not constitute the limiting factor in their physical functioning. In contrast, performance-related physical fitness concentrates on the ability to perform daily tasks. Components of performance-related physical fitness include explosive muscle power, speed, agility, balance, and coordination, all which are factors crucial for initiating, reacting, or accelerating during movement. Research has demonstrated that a vital, healthy, and high-quality life is fundamentally rooted in physical fitness, health status, and an active lifestyle.[38,39]

Physical activity has been shown to mediate some of the physical effects on physical fitness associated with ageing, while inactivity often accelerates the negative impact of ageing.[3,40] The potential benefits of physical activity in older adults are well-studied, but the optimal exercise and training regimen for older adults to maintain their physical performance and function remains an active area of research. Traditional views assume that ageing inevitably led to decreased fitness, trainability, and recovery capacity, with little room for improvement. However, recent research challenges this perspective, and studies now show that older adults can achieve significant improvements in muscle strength, power, and functional capacity through resistance training and multicomponent exercise programs.[41–43] While absolute performance levels may not match those of younger individuals, relative improvements in physical capacity are achievable, even at advanced ages, and contribute significantly to successful ageing and an enhanced quality of life.[44]

Power training: A Promising but Underutilized Approach

An intervention that holds significant promise for enhancing physical fitness and functional capacity in older adults is power training, a high-velocity resistance training that emphasizes rapid and explosive force production.[45,46] This approach is distinct from traditional strength training, as it prioritizes movement speed and neuromuscular efficiency in addition to maximal power output. Power training has demonstrated superior effects in improving postural control, reaction time, stair climbing ability, and fall prevention, all of which are critical for maintaining independence in ageing populations.[47] Despite its well-documented physiological benefits, power training remains underutilized in rehabilitation and fitness programs for older adults. One of the primary barriers to its widespread adoption is the lack of consensus regarding its definition, as numerous interventions are classified as power training despite not adhering to its core principles of high-velocity, explosive force production. Additionally, the absence standard implementation strategies, concerns regarding its feasibility and safety in frail individuals, and inconsistent assessment methodologies impede its integration into practice. These challenges highlight the need for further research to not only evaluate the efficacy of power training but also establish clear criteria's that distinguish it from other training modalities. Bridging these gaps is essential for enhancing the effectiveness of power training in supporting functional independence in older adults.

Optimizing Muscle Power in Ageing: The Role of Targeted Power Training

Power training uses (modified) plyometric exercises involving rapid stretching and contracting of muscles.[48] The core principle of power training lies in its aim to target and stimulate fast-twitch muscle fibers (Type II fibers), which are particularly susceptible to age-related atrophy and dysfunction. Neuromuscular adaptations induced by power training include en-

hanced motor unit recruitment, improved firing frequency, and better synchronization of motor units, leading to more efficient muscle activation and improved coordination between agonist and antagonist muscles.[49,50] Furthermore, while targeting Type II fibers, power training can stimulate hypertrophy in both Type I and Type II fibers, contributing to the preservation or increase of overall muscle mass.

Physiological adaptations resulting from power training can translate into significant functional improvements for older adults.[51] Training muscle power increases the capacity to generate force rapidly, improving postural control and reactive balance, both of which are crucial for fall prevention.[52] Improvements in physical capabilities can *potentially* enhance self-confidence in performing daily tasks for some older adults, which may also facilitate greater social engagement and independence.[53] It is plausible that the combined effects of improved physical function, increased independence, and greater social participation *could contribute to* improved quality of life.[54] However, it is important to acknowledge that individual responses may vary due to differences in neuromuscular adaptation, baseline physical capacity and adherence. Power training research faces several key gaps, including the lack of standardized assessment tools and inconsistent study designs, which limit its replicability and validity of power training. A core outcome set is needed to ensure consistent evaluation across studies. Additionally, its feasibility, adherence, and safety in real-world settings require further investigation, as well as its impact on muscle power, physical performance, and functional independence. Addressing these gaps through a harmonized and integrated approach is essential for optimizing power training in ageing populations.

Parameters of Power Training: Key Factors and Considerations

Power training can be approached from two perspectives: the force-based approach and the velocity-based approach. The difference between these approaches is determined by the level of resistance or load, expressed as a percentage of the one-repetition maximum (1-RM), which is the maximum load an individual can move during a specific exercise.[55] In force-based power training, the focus lies on generating a maximum amount of force as quickly as possible, resulting in relatively low movement velocity. The load typically ranges between 80-90% of the 1-RM, leading to high resistance and a low number of repetitions (often between 1-5).[55] This approach may be less suitable for most older adults given the high loads involved, as it may carry a higher risk of injury and can be intimidating for those new to resistance training. According to the National Strength and Conditioning Association (NSCA), muscle fatigue may pose safety risks and is not necessary for strength and power adaptive responses,[55] suggesting that approach is not necessary to improve physical functioning in older adults.

On the other hand, velocity-based power training focuses on maximizing movement speed with a given resistance, utilizing lighter loads compared to force-based training. The load typically ranges between 5-60% of the 1-RM, depending on whether the specific focus is strength-speed or speed-strength.[20,56] Strength-speed refers to the capacity to generate force rapidly while moving a submaximal load at high velocity. This modality typically involves lifting moderately heavy loads, approximately 80-90% of 1-RM, with maximal intended speed to optimize neuromuscular power output.[57,58] Speed-strength focuses on moving a relatively light load at high velocity, typically employing loads between 30-60% of 1-RM.[21,59] In older adults, selecting relatively light resistance during training allows for higher movement velocities and an increased number of repetitions, typically ranging between 6 and 10. This approach is considered more appropriate for older adults, as it reduces the risk of injury and joint stress, while still providing significant neuromuscular benefits. Research indicates that low-load, high-velocity resistance training can enhance muscle strength and functional capacity in older populations without imposing excessive stress on the joints.[60] Additionally, research indicates that resistance training with lighter loads and faster movements can enhance technique and boost confidence in performing daily activities requiring quick movements.[61,62]

Velocity-based power training offers a systematic and progressive approach to attaining the theoretical balance between strength and speed, thereby maximizing power output. This training method strategically modulates intensity along the force-velocity continuum to enhance the interaction between force production and movement velocity. The optimal power output is achieved at the equilibrium point, where strength and speed are proportionally balanced, representing the most effective condition for generating maximal power **(Figures 2 and 3)**.

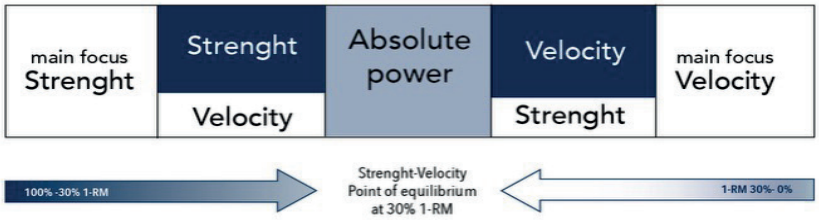


Figure 2: The Force-Velocity Continuum delineates the inverse relationship between force and velocity in the context of power training. Strength and velocity represent complementary yet interdependent components, with maximal power output occurring at approximately 30% of one-repetition maximum (1-RM).

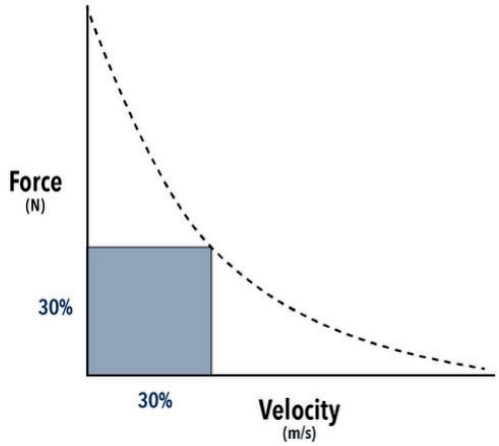


Figure 3: The force-velocity relationship characterizes the inverse association between force production and movement velocity. The optimal point for neuromuscular power development occuring occurs at approximately 30% of maximal force and velocity.

Power Training in the International Classification of Functioning, Disability, and Health

The International Classification of Functioning, Disability, and Health (ICF) is a globally recognized framework developed by the WHO to classify and describe health and health-related domains.[63] It provides a comprehensive structure for understanding and measuring health and disability at both invidual and population levels. This thesis used the ICF to position power training within the function, activities, and participation domains, while drawing upon suggestions from Stewart et al.[40] to make a distinction between health-related and performance-related physical fitness. Making this distinction complements the ICF model by acknowledging that physical fitness encompasses both health components (cardiorespiratory endurance, body composition, flexibility, muscular strength) and performance components (power, balance, coordination, reaction time). Within the activity domain of the ICF, it is crucial to differentiate between capacity and performance, as this becomes particularly relevant for power training in older adults. While capacity refers to an individual's ability in a standardized environment, performance reflects actual execution in real-life settings. For the older adult population, emphasis should be placed on performance-related aspects, with muscle power serving as the crucial component for initiating movement, responding to disturbances, and maintaining functional performance in daily life activities.

Another important framework used to position power training is the Bouchard model, which demonstrates the interrelationship between physical activity, fitness, and health.[64,65] The conceptual integration with the ICF framework connects Bouchard's ideas on these relationships with the ICF domains of functioning, disability, and health. The conceptual model shown in

Figure 4 further integrates Bouchard's ideas with the ICF domains. By aligning Bouchard's model vertically and the ICF model horizontally, physical fitness intersects with functions/anatomical properties, creating a central point that distinguishes between health-related and performance-related physical fitness.[40] This integrated framework provides a comprehensive approach to understanding how power training specifically impacts both the physiological capacities and real-world performance of older adults, acknowledging that improvements in power must translate to enhanced functioning in daily activities to be truly beneficial.

The model serves as an underlying framework and shows how physical activity, fitness, and movement interventions can be approached holistically. By considering both capacity and performance as defined by the ICF, we gain a more nuanced understanding of how power training impacts the functional abilities of older adults. This perspective considers not just the physiological changes, but also the functional outcomes, contextual factors, and broader health implications. It underscores the need for comprehensive assessment strategies and interventions that address both the physiological aspects of power and the contextual factors that influence real-world performance. Together, this integrated theoretical foundation provides a robust basis for both research and practical applications in the field of power training for the ageing population.

Terminology

Academic research on muscle performance has long struggled with consistently interpreting and defining the concept of muscle power. In their comprehensive review, Cronin et al. identified a significant issue in the literature, namely the interchangeable use of terms like explosive strength, rate of force development, and impulse, despite these concepts having distinct definitions and implications.[66] The consequences of this lack of consistency can become significant, and may lead to the misinterpretation of research findings, incorrectly applying study results, or difficulties in comparing outcomes across studies. It is therefore crucial to establish clear and consistent definitions, also to increase the translation of research into practical training programs. This dissertation uses the terminology described in **Table 1** to describe muscle power and other relevant terms.

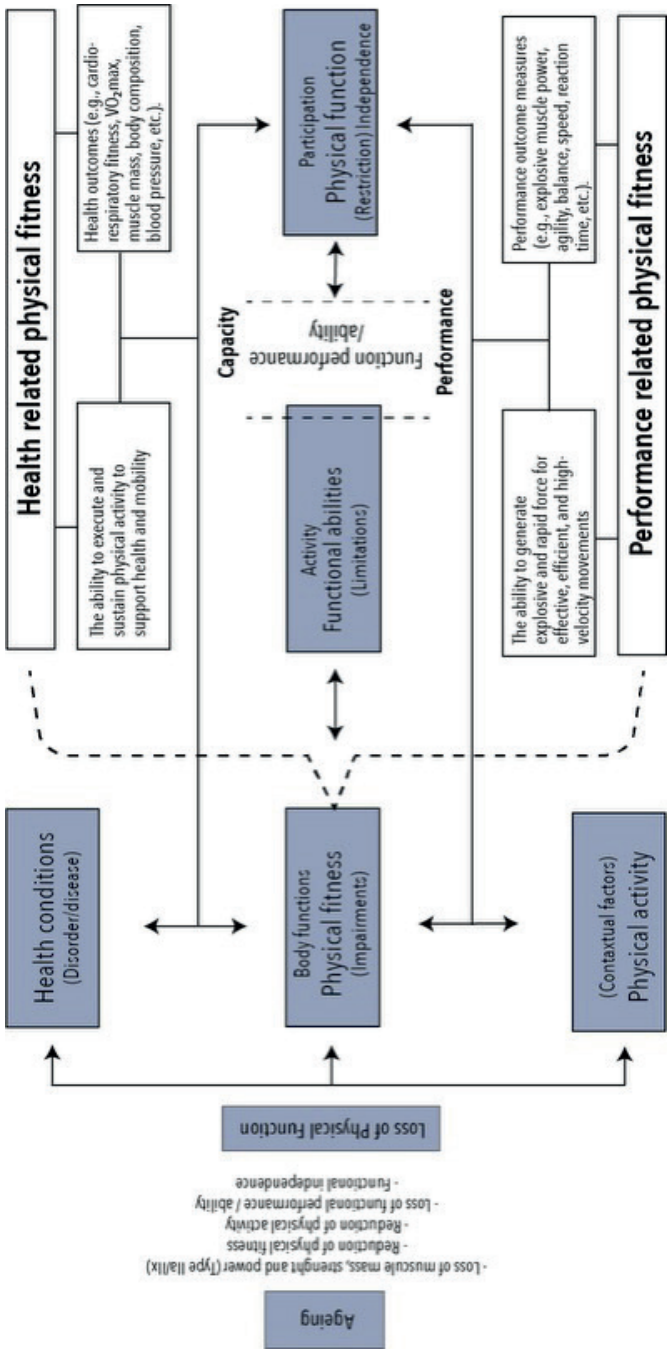


Figure 4: The ICF Framework integrated with Physical Activity, Fitness, and Health to position power training in Ageing population

Table 1: Terminology used throughout this thesis

Concept	Definition
Muscle power	The rate at which mechanical work is performed or energy is transferred, calculated as the product of force and velocity.[19–21]
Muscle strength	The maximum force a muscle or muscle group can generate. It is commonly assessed as the maximum load lifted in a single repetition (1-RM) during a dynamic contraction or as the peak force produced during a isometric contraction. When measured under isometric conditions, it is specifically referred to as maximal isometric strength, indicating the highest force output without changes in muscle length.[19]
Explosive strength	The capacity to exert maximal force in minimal time, encompassing the rate of force development and other measured of rapid force production.[67]
Rate of force development	The rate of increase in contractile force at the onset of muscle contraction, as determined by the slope of force-time or torque-time during rapid, voluntary contractions.[68]
Impulse	The cumulative effect of force applied over a period of time, calculated as: Impulse = Force x Time.[69]
Physical activity	Physical activity is any bodily movement produced by skeletal muscles that requires energy expenditure.[37]
Physical fitness	A set of attributes or characteristics that people have or achieve that relates to the ability to perform physical activity,encompassing cardiorespiratory endurance, muscular strength and endurance, body composition, flexibility, balance, agility, reaction time, and power.[70]
Physical performance	Physical performance is the measurable capacity of underlying physical attributes such as strength, power, balance, and speed in a standardized setting.[38,71]
Physical functioning	Physical functioning, part of the Activities and Participation domain of the ICF, reflects an individual's ability to perform daily tasks and engage in life situations. It determines physical independence, whereas physical performance highlights underlying attributes,functioning specifically refers to the ability to independently carry out activities such as walking or climbing stairs.[63]
Activities of daily life	Activities of Daily Living (ADLs) refer to fundamental tasks necessary for self-care and independent living, including basic functions such as bathing, dressing, toileting, transferring, continence, and feeding.[38]
Independence	Independence in daily life refers to the ability to perform ADLs without assistance, reflecting an individual’s autonomy and functional capacity.[38]

Aim of the Dissertation

This dissertation is built on the premise that power training holds great potential for improving physical function in older adults, but its widespread implementation is hindered by several unresolved issues. There is a gap between theoretical knowledge and practical implementation due to a lack of clear, standardized protocols for power training. This makes it difficult for practitioners to integrate power training into existing rehabilitation and fitness programs. Additionally, there is no standardized assessment protocol to consistently and accurately measure the impact of power training. Inconsistent methodologies complicate the ability to compare results across studies and establish evidence-based guidelines. Lastly, there is limited research on long-term adherence and feasibility of power training in older adults. While some studies have shown that power training can improve functional outcomes, questions regarding its feasibility in both clinical and community settings remain, particularly among older adults with varying physical capacities. Addressing these gaps is crucial to ensure that power training can be effectively utilized to enhance functional independence in ageing populations.

In response to these critical gaps, this dissertation aims to bridge the divide between scientific evidence and real-world application of power training for older adults. Specifically, it seeks to:(1) establish standardized assessment methods within the ICF across its different domains to measure the impact of power training; (2) evaluate the effectiveness of power training in improving physical functioning in older adults; and (3) investigate the feasibility of power training in practical settings. By addressing these aims, this dissertation strives to provide a robust foundation for future research and clinical practice in physical therapy exercise science, offering insights for researchers, clinicians, and policymakers working to promote healthy ageing and maintain functional independence in older populations.

Outline of the Dissertation

This dissertation is structured into two main parts, each addressing related but distinct research objectives. **Chapter 1** provides a general introduction, outlining the theoretical framework and key concepts that underpin the research.

Part One, *Harmonizing Outcomes: How to Measure the Impact of Power Training in Older Adults,* focuses on measurement and methodological foundations. **Chapter 2** examines the therapeutic validity and replicability of power training interventions using the TIDieR checklist and the CONTENT scale. **Chapter 3** presents a systematic review of the reliability, validity, and responsiveness of tests employed to evaluate the effects of power training in older adults. **Chapter 4** reports on a Delphi and Nominal Group Technique study conducted to

establish consensus on a core outcome set for measuring the effects of power training in this population.

Part Two, *From Theory to Practice: Evaluating the Effects and Clinical Applicability of Power Training in Older Adults*, addresses clinical effectiveness and feasibility. **Chapter 5** presents a systematic review and meta-analysis comparing the effectiveness of power training with that of strength training in older adults. **Chapter 6** describes a pilot and feasibility study on the implementation of power training, providing insights into its practical applicability. **Chapter 7** presents a descriptive case series exploring the impact of power training on physical functioning in older adults, thereby illustrating its relevance in clinical practice.

Although the chapters are presented in a thematic structure—**Part One** focusing on measurement and methodology, and **Part Two** on effectiveness and feasibility—the chronological order of the underlying studies differs. The systematic review and meta-analysis in **Chapter 5** served as a foundation for the studies presented in **Chapters 2 and 3**. Specifically, the extracted data on intervention content informed the evaluation of therapeutic validity and replicability **(Chapter 2)**, while the data on outcome measures informed the psychometric assessment of tests used to evaluate the effects of power training **(Chapter 3)**. The deliberate organization of the dissertation, with methodological foundations preceding clinical applicability, was chosen to maintain conceptual clarity and coherence.

Finally, **Chapter 8** provides a General Discussion. This chapter integrates the findings of all preceding chapters, synthesizing methodological and clinical insights. It further discusses theoretical and practical implications and offers recommendations for future research and clinical practice in the field of power training for older adults.

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Part 1

"Harmonizing Outcomes: How to Measure the Impact of Power Training in Older Adults"

2

Therapeutic Validity and Replicability of Power Training Interventions in Older Adults: a Review Using the TIDieR Checklist and CONTENT Scale

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Mohamed el Hadouchi
Henri Kiers
Brittany A. Boerstra
Cindy Veenhof
Jaap van Dieen

Abstract

Background: Randomized controlled trials (RCTs) indicate that power training has the ability to improve muscle power and physical performance in older adults. However, power training definitions are broad and previously-established criteria are vague, making the validity and replicability of power training interventions used in RCTs uncertain.

Objective: The aim of this review was to assess whether the power training interventions identified in a previous systematic review (el Hadouchi 2022) are fully described, therapeutically valid, and meet our proposed criteria for power training.

Design: Review

Methods: Power training interventions used in older adults, previously-identified in a systematic review, were assessed. The completeness of intervention descriptions was evaluated using the Template for Intervention Description and Replication (TIDieR), and therapeutic validity was evaluated using the CONTENT scale in combination with a set of criteria specific for power training.

Results: None of the power training interventions were fully described or met the CONTENT scale's criteria for therapeutic validity. Five out of 14 interventions (35.7%) met all specific power training criteria.

Conclusions: Power training interventions used in RCTs comparing power training to strength training are poor to moderately described, may not be therapeutically valid, and may not reflect the construct of power training. This makes it difficult for clinicians or reseachers to apply or replicate power training interventions reported in RCTs, and begs the question whether the true effects of power training have been estimated.

Keywords: power training, replicability, validity, older adults

Introduction

Research suggests that power training offers more potential for improving physical performance and functioning in older adults compared to strength training alone. [1–5] Power training is a dynamic exercise training that requires a higher velocity of muscular contractions compared to traditional strength training and emphasizes the development of type 2 muscle fibers responsible for shorter bursts of explosive movement. [6,7] These type 2 muscle fibers, also known as fast twitch fibers, deteriorate at a faster rate with older age, thereby reducing one's ability to generate muscle strength rapidly. [7]

The age-related decline in muscular condition has been expressed in terms of loss of muscle strength (the ability to produce large muscle force) and muscle power (the ability to produce a large muscle force at high contraction velocity). [4,8,9] Several studies revealed that in older adults, the annual decline in muscle power is larger than the annual decline in muscle strength, [2,10–15] making the ability to move with sufficient velocity (emphasizing muscle power) more often the limiting factor than the ability to produce sufficient muscle force (emphasizing muscle strength).[3,10] As a result, aging is often accompanied by functional limitations, increased risk of falls, reduced movability, and a decreased quality of life.[16]

Power training has been shown to increase muscle power even in older adults. [3,17] However, the descriptions of power training interventions used in randomized controlled trials (RCTs) are often incomplete and lack clarity, hindering replicability. Additionally, power training definitions used in RCTs are vague and there is a lack of consensus regarding the elements that need to be fulfilled for an exercise intervention to constitute as power training. As a result, there are large differences in applied power training interventions. [5] The heterogeneity between power training interventions raises the question whether the interventions used in RCTs adequately target muscle power and are therapeutically valid.

Therapeutic validity has been defined as the potential effectiveness of a specific intervention given the target group. [18] Only with a clear description of the intervention is available, it is possible to determine whether the intervention is potentially effective, in this case whether the intervention meets the definition of power training and is suitable for older adults. At this moment, there is no clear and comprehensive framework that specifies the essential components of power training, contributing to the frequently encountered confusion between power training and strength training. Therefore, we developed a set of power training criteria based on biomechanical principles and exercise physiology theories proposed by Kraemer et al.[6] and Haff et al.[19] to assess to which extent the interventions used in RCTs reflected power

training principles. These power training criteria evaluate: (1) type of exercises; (2) movement pace; (3) rate of force development; (4) training load; and (5) duration of the intervention.

In this review, we aimed to assess whether the power training interventions identified in a previous systematic review by el Hadouchi et al.[5] are fully described, therapeutically valid, and meet our proposed criteria for power training. Answering these questions will provide insight into whether the conclusions drawn from the included RCTs evaluating the effects of power training interventions in older adults were warranted. Furthermore, addressing these gaps in the literature will provide a framework for the necessary improvements for future research reporting on power training interventions or other exercise interventions.

Methods

Power training interventions were rated on whether they were described in sufficient detail, to what extent they showed therapeutic validity, and whether they met our proposed criteria for power training. The scope of this review is limited to RCTs included in an existing systematic review comparing the effectiveness of power training to strength training in older adults,[5] but the search was updated for the present review. This review was registered in the International Prospective Register of Systematic Reviews (PROSPERO 2021: CRD42021273832).

Search Strategy and Study Selection

The original systematic search was performed in PubMed, Embase, Ebsco/CINAHL, Ebsco/SPORTDiscus, Wiley/Cochrane Library and Scopus up until 18 September 2020 in collaboration with a medical librarian. The search string **(Appendix 1)** was applied once more to all abovementioned databases on 7 August 2023 to search for any more recently-published literature. Study selection was performed independently by two coauthors (MeH and HK) by first selecting relevant titles and abstracts using the online software Rayyan, [20] followed by a full-text screening. RCTs that compared a power training intervention to a strength training intervention in older adults were included if: (a) the mean age of the study population was >65 years and participants were recruited from a 'healthy'population. Healthy was defined using the WHO definition for health, in which individuals can be considered healthy despite the presence of (chronic) health conditions; (b) the intervention was defined as power training by the authors or the intervention met the definition of power training proposed by Haff et al.: [19] "an intervention primarily aimed at muscle power, movement speed or rate of force development"; (c) the study included outcome measures for muscle power, activity-based tests, or physical functioning in daily life; (d) the strength training control group was age-matched and received at least partially supervised strength training; and (e) studies were

written in English, Dutch, or German. Studies were excluded if the study population consisted of solely of participants with specific (medical) conditions on the basis on non-generalizability. Furthermore, studies were excluded if the interventions were home- or internet-base in view of concerns regarding adherence. A detailed explanation of the search strategy, study selection, and risk of bias assessment can be found in the primary study. [5] **Figure 1** summarizes the literature search and study selection in a PRISMA flow diagram. [21]

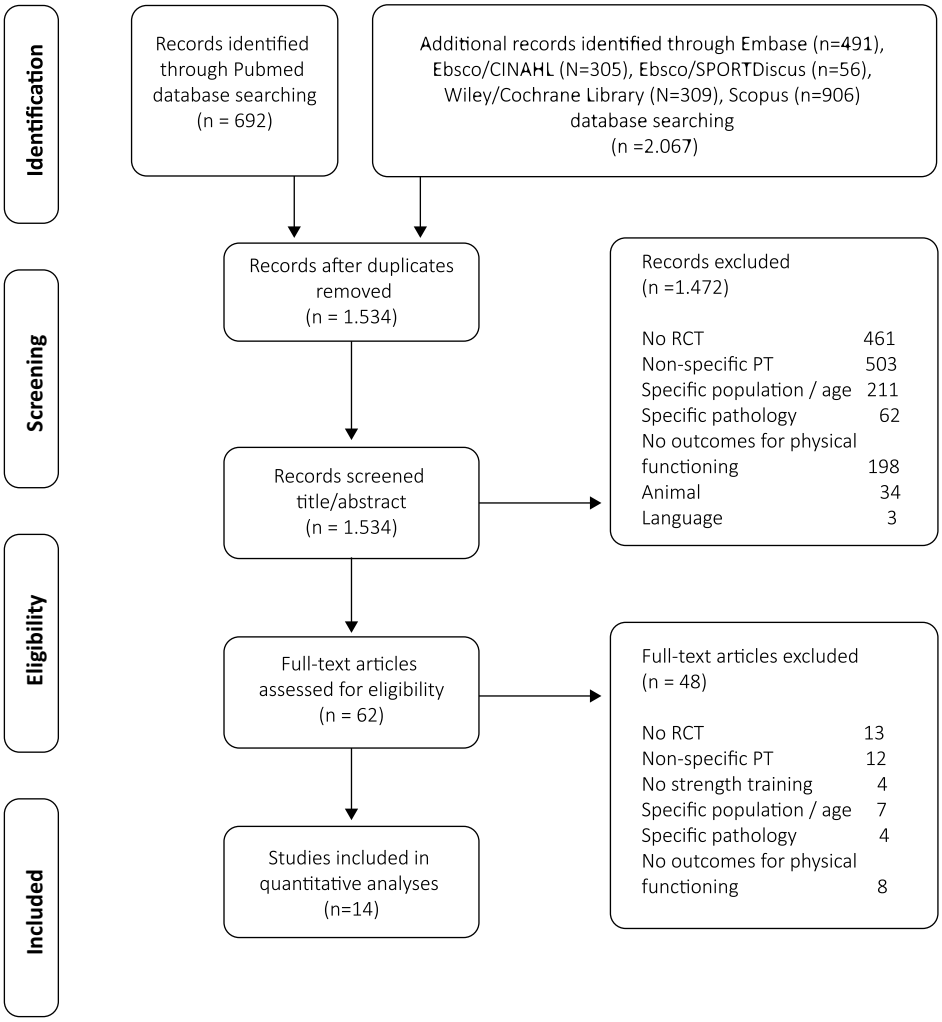


Figure 1

Completeness of Descriptions

The completeness of interventions descriptions was assessed using the Template for Intervention Description and Replication Checklist (TIDieR) checklist, [22] which consists of 12 items that assess whether interventions are described in sufficient detail. The goal of the TIDieR checklist is to assess whether interventions are described in sufficient detail to allow their replication or translation into clinical practice. The TIDieR checklist was applied independently by two researchers (MeH and BB) with regular meetings to form consensus. If no consensus was reached, a third researcher was consulted and a consensus was reached through discussion between all three.

Within the TIDieR checklist, criterion 8 aims to identify the number of training sessions, their schedule, duration, intensity, and dose. We felt that additional information was needed to further specify relevant details. Therefore, we expanded criterion 8 to include the following training parameters: a) total number of sessions, b) frequency (trainings/week), c) duration of a session, d) intensity, e) type of exercises, f) level of exercise (the degree of difficulty of the exercises), and g) combination with other exercises or interventions. The expansion of this criterion was done in consultation with professionals (researchers, sports and geriatric physiotherapists, and strength and conditioning trainers) by asking them which training parameters are of importance when evaluating and reproducing an exercise intervention. Each item on the TIDieR checklist was scored with no (0) or yes (1). For criterion 8, a point was only awarded if all training parameters were described. In the absence of a scoring guideline, we used the following interpretation of the scores: 0–4 points were considered poor, 5–9 points were considered moderate, and 10–12 points was considered good. The scoring system emphasizes the completeness and transparency of what has been reported rather than a qualitative ranking of interventions.

Therapeutic Validity

Therapeutic validity was defined as “the potential effectiveness of a specific intervention given the target group” and was assessed using the validated CONTENT scale for the therapeutic validity of therapeutic exercise programs. [18] The CONTENT scale was completed independently by two researchers (MeH and BB), after which consensus was formed. If no consensus was reached, a third researcher was consulted and a consensus was reached through discussion between the three. The checklist consists of 9 criteria that, if described and met, are worth 1 point each. An intervention was considered therapeutically valid if the total score was >6 points.

Power Training Criteria

Item 5 of the CONTENT scale includes the question:"Was the rationale for the content and intensity of the therapeutic practice described and plausible?". Due to the importance of this item in determining whether the exercises used are consistent with the principles of power training, we developed a specific set of criteria to assess to what extent the interventions used in RCTs reflect power training principles. These power training criteria are based on biomechanical principles and exercise physiology theories proposed by Kraemer et al.[6] and Haff et al.[19] and are listed in **Table 1.** The results of item 5 are interpreted separate from the CONTENT scale.

Table 1: Power training criteria

	Concept	Criteria
1	Type of exercises	The training consists of exercises that emphasize the speed of the performance (e.g. Olympic weightlifting or strength exercises that have been adapted into power exercises).
2	Movement pace	The instruction and execution of the power exercises is "as fast as possible".
3	Rate of force development	Each exercise should be characterized by a fast and powerful concentric phase, followed by a slow and steady eccentric phase.
4	Training load	The resistance of the exercises is low. The intervention uses a training load of 20-30% of the 1-repetition maximum (1-RM) OR, a build-up range is used between 0-60% 1-RM (0-60% 1-RM for lower extremity exercises and 30-60% 1-RM for upper extremity exercises).
5	Duration	The minimum duration of the intervention is 8 weeks with a training frequency of at least twice a week.

Results

Study Characteristics

The updated search yielded 21 additional recently-published studies, none of which met eligibility criteria. Therefore, a total of 14 power training interventions from previously-identified RCTs were included. **Table 2** provides an overview of the study characteristics and training parameters. The RCTs varied greatly with regard to the setting, the supervision, the length of follow-up, and the training parameters. A majority of power training interventions utilized exercise machines (53%), while the remaing interventions used own body weight exercises, task-specific exercises such as step up and step down to simulate stair climbing (7%), or a combination of both (40%). The power training interventions were supervised by exercise trainers (60%) or student physicians (20%). In the remaining 20% of studies, the level of su-

Table 2: Study characteristics and training parameters

Study (year)	Type of training	Total sessions	Frequency (sessions/ week)	Duration (min)	Intensity	Type of exercises	# sets	# reps	Rest in between sets (min)	Movement speed	Supervision	Tailoring
Balachandran (2014)[16]	PT	30	2	40-45	50-80% 1-RM	Machines	3	10-12	2	CON: HS; ECC: LS	Exercise trainer	5% increase in load once particpant could perform 3x12 reps
Bean (2009)[4]	PT	48	3	40-60	11-16 RPE	Body and task-specific exercises	2	10	1	CON: HS; ECC: LS	Exercise trainer	Decrease in load at RPE >17; decrease in load at RPE <11
Bottaro (2007)[23]	PT	20	2	NR	40-60% 1-RM	Machines	3	8-10	NR	CON: HS; ECC: NS	NR	NR
Fielding (2002)[24]	PT	48	3	NR	70% 1-RM	Machines	3	8-10	NR	CON: HS; ECC: NS	Exercise trainer	Biweekly 1RM measurement to ensure that exercise intensity remained at 70% 1RM
Henwood (2006)[25]	HVT	16	2	60	45-70% 1-RM	Combination of machines and body- and task-specific exercises	3	10	1	CON: HS; ECC: NS	Exercise trainer	5-10% increase in load at >10 reps
Henwood (2008)[26]	PT	48	2	60	45-75% 1-RM	Machines	3	8	1	CON: HS; ECC: LS	Exercise trainer	5-10% increase in load at >10 reps
Lopes (2014)[27]	PT	36	3	NR	30-50% 1-RM	Machines and free weights	3	2-7	NR	CON: HS; ECC: NS	NR	Biweekly 1RM measurement to ensure exercsise intensity remained between 30-50% 1-RM

Table 2: *Continued*

Marsh (2009)[28]	PT	36	3	40	70% 1-RM	Machines	3	8-10	NR	CON: HS; ECC: LS	ACSM-certified interventionists	Biweekly 1-RM measurement to ensure that exercise intensity remained at 70% 1-RM
Miszko (2003)[17]	PT	48	3	NR	40% 1-RM	Combination of machines and body- and task-specific exercises	3	6-8	NR	CON: HS; ECC: LS	NR	NR
Orr (2006)[29]	PT	20	2	NR	20%, 50%, and 80% 1-RM	Machines	3	8	NR	CON: HS; ECC: LS	Exercise trainer	Weekly 1-RM measurement to ensure that exercise intensity remained at target intensity
Ramirez-Campillo (2014)[30]	HVT	36	3	70	45-75% 1-RM	Machines and free weights	3	8	1	CON: HS; ECC: LS	Exercise trainer	Increase in load at >8 reps
Reid (2015)[31]	PT	32	2	NR	40, 70% 1-RM	Machines	3	8-10	NR	CON: HS; ECC: NS	Other	NR
Tiggeman (2016)[32]	PT	24	2	NR	13-18 RPE/45-65% 1-RM	Machines	2	8-10	2	CON: HS; ECC: LS	Other	Decrease in load at RPE >18; increase in load at RPE <13
Zech (2012)[33]	PT	24	2	NR	10-16 RPE	Conation of machines, body- and task-specific exercises, and balance	2	NR	2	CON: HS; ECC: LS	Other	Biweekly increase to 16 RPE

Caption: PT: power training; HVT: high velocity training;1-RM: 1-repetition maximum; RPE: rate of perceived exertion; CON: concentric: ECC: eccentric; HS: high-speed; NS: normal-speed; LS: low-speed.

Table 3: Overview of findings

Tool	Criteria	Balachandran (2014)	Bean (2009)	Bottaro (2007)	Fielding (2002)	Henwood (2006)	Henwood (2008)	Lopes (2014)	Marsch (2009)	Miszko (2003)	Orr (2006)	Ramirez-Campillo (2014)	Reid (2013)	Tiggeman (2016)	Zech (2012)	Frequency of reporting
TIDieR	Total score	7	6	3	7	7	8	4	7	4	7	5	4	8	8	
CONTENT scale	Total score	5	5	4	5	5	5	5	5	4	5	5	5	5	4	
Power training criteria	Type of exercises	√	-	√	√	√	√	√	√	√	√	√	√	√	√	93%
	Movement pace	√	√	√	√	√	√	√	√	√	√	√	√	√	√	100%
	Rate of force development	√	√	√	√	√	√	√	√	√	√	√	√	√	√	100%
	Training load	-	-	√	-	-	-	√	-	√	√	-	√	-	-	36%
	Duration	√	√	√	√	√	√	√	√	√	√	√	√	√	√	100%

Caption: PT: power training; NR: not reported. The following score system was used to determine replicability of studies as determined through the TIDieR checklist: 0–4 poor; 5–9 moderate; 10–12 points good. Interventions with a CONTENT score >6 points are considered therapeutically valid.

pervision was unclear. Twenty percent of training sessions were performed in a gym, 20% in an exercise room of a clinical setting, and 13% at a rehabilitation center. The age of the participants ranged from 66 to 93 years (median 72 years), with a large majority of participants considered "community-dwellers" who lived independently or in a nursing home.

Completeness of Descriptions

None of the RCTs described all the items on the TIDieR checklist. The quality of reporting the featured power training interventions was scored poor to moderate **(Table 3)**. Twelve of the RCTs described the procedures, activities, and/or processes used in the power training intervention (criterion 4), but only 7 of RCTs described a rationale for the intervention (criterion 2). Wth respect to criterion 8, all RCT's described at least one training parameter (criteria 8a-g), but none of the RCTs described all parameters (mean: 5, range: 3-6). Most notably, criterion 10 for 'modification', criterion 11 for 'adherence'; and criterion 12 for 'deliverance' were not reported in any of the RCTs. A complete overview of findings related to the TIDieR checklist can be found in **Appendix 2**.

Therapeutic Validity

None of the power training interventions were considered therapeutically valid (>6 points), as all of the power training intervention scored between 4–5 points on the CONTENT scale. Criteria 1 and 2 regarding patient selection, criterion 4 evaluating whether the intervention was 'based on a priori aims and intentions', and criterion 6 evaluating whether 'the intensity of the intervention was described' were met by all studies. Criterion 7 for 'monitoring and adjustment of intervention' was met by 11 of the 14 studies. There were also several criteria that were met by only a few of the selected studies. Criterion 3 for 'eligibility criteria for therapist and setting', criterion 5 for 'rationale for content and intensity of intervention'; criterion 8 for whether the intervention was 'personalized and contexualized for individual participants', and criterion 9 for 'adherence determined and acceptable' were scored as insufficient for all of the studies. In applying criterion 5 for 'rationale for content and intensity of therapeutic exercise' it became clear that most studies did not indicate the rationale for the chosen intensity or content of the intervention. The training intensity varied widely between studies. Two studies used the Borg-scale rate of perceived exertion (RPE) to describe training intensity, while the remaining studies used a range of 1RM percentages to describe the training intensity. The rationale for the content and intensity of therapeutic exercise was lacking in all of the studies. A complete list of therapeutic validity scores can be found in **Appendix 3**.

Power Training Criteria

Power training criteria were applied to each of the 14 interventions. The criterion for type of exercises was met by 13 out of 14 interventions, 1 study did not specify the exercises used. The criterion for movement pace and rate of force development were met by all interventions. The criterion for training load was met by only 5 interventions, because a majority of interventions used higher training loads, or determined training load through a rating of perceived exertion (RPE). Lastly, the criterion for duration was also met by all interventions. A total of 5 interventions (36%) met all power training criteria.

Discussion

Our results show that the power training interventions used in older adults were poor to moderately described, as they did not meet the criteria for replicability established by the TIDieR checklist. Most notably, information regarding the modification, adherence, and deliverance of the power training intervention was not provided in any of the included RCTs. Furthermore, none of the power training interventions were considered therapeutically valid and only a third of interventions met the proposed power training criteria.

To our best knowledge, this is the first study to evaluate power training interventions featured in RCTs using the TIDieR checklist and CONTENT scale. There are several systematic reviews evaluating the effects of power training in older adults, [34-36] even comparing power training to strength training, [37-39] but the content of power training interventions was not evaluated in these studies. Previous reviews also noted the heterogeneity in findings between RCTs evaluating the effects of power training in older adults, which could be the result of differences in power training protocols.

Differences in training protocols, in addition to differences in outcome measurement, can greatly increase the heterogeneity of findings across studies even if these have a similar methodology. This heterogeneity increases uncertainty about the effectiveness of power training. Additionally, there is a lack of consensus with regard to the ideal training load for power training interventions, which hampers the implementation of power training interventions in clinical practice. The relationship between muscle force and contraction velocity is such that as the magnitude of force required to move an external object increases, the velocity at which a muscle is capable of moving the external object decreases. This inverse relationship gives rise to two distinct approaches for training muscle power: (1) the high force and low velocity approach (~70% 1RM) and, (2) the low force and high velocity approach (~30% 1RM). Direct comparisons indicate that interventions using a training load between

20-30% 1RM were most effective at improving muscle power in older adults, [6,7,16,19,40,41] but there are still studies that use power training interventions with a higher load. However, more generally, the lack of clarity in the description of training interventions investigated precludes determination of which intervention characteristics contribute most to effectiveness of power training. This not only hinders the understanding of the effectiveness of power training in older adults, but also hampers the implementation of power training interventions.

Standardizing the way in which RCTs report on power training interventions and other exercise interventions could improve the assessment of therapeutic validity, increase replication of results, and promote implementation. From the RCTs included in the present review that did not describe the intervention fully, it could not be determined whether the criteria from the CONTENT scale for therapeutic validity were considered but not reported, or not considered at all. More specifically, missing information with regards to the reporting of modification, adherence, and deliverance of power training interventions indicate a lack of quality in these areas.

We propose that future research should use the TIDieR checklist in combination with the CONSORT checklists and CONTENT scale to ensure that a complete description of the intervention is reported and that the content of the intervention reflects the construct of power training. While this may increase the word counts of papers reporting RCTs, we believe that adherence to these checklists on an a priori basis can improve the interpretations, assessment, and understanding of the effects of power training in older adults.

Certain criteria within the TIDieR checklist and CONTENT scale were considered to be more relevant to the construct of power training than others. Specifically, criterion 8 of the TIDieR checklist was expanded to include power training parameters not fully covered by the original checklist. Yet, this criterion was not fully met by any of the included RCTs. Furthermore, criterion 2 of the CONTENT scale, which evaluates the presence of a rationale, was met by only half of the included studies. Although a rationale is not necessary to replicate the intervention, a hypothesis about the mechanism by which the intervention has an effect should be established prior to testing the effectiveness of the intervention to increase therapeutic validity and justify the use of appropriate measurement tools.

There are several limitations to this review. Because this review is a secondary analysis and used the same search strategy as el Hadouchi et al.[5], the scope of the review is limited to evaluating interventions used in RCTs comparing the effects of power training to strength training in older adults with muscle power, activity-based tests, and physical activity level in daily life as outcomes. Additionally, because the CONTENT scale assess the therapeutic valid-

ity of power training interventions based on how well and complete the interventions were described, it is possible that the intervention was indeed power training and performed well, but was not adequately described in the article. Lastly, the dichotomous response options in the TIDieR checklist limit the interpretation of these criteria and an ordinal or qualitative response would likely have been more informative. To compensate for this, we provided a thorough description of these criteria in **Table 2.** Further strengths of this review include the incorporation of power training criteria to expand the CONTENT scale's ability to evaluate the intensity and type of exercises used in the power training interventions. While these proposed power training criteria were developed by experts, it would be advisable to get broader consensus whether these criteria accurately represent the construct of power training.

Conclusions

Power training interventions used in RCTs comparing power training to strength training are poor to moderately described, may not be therapeutically valid, and may not reflect the construct of power training. These factors make it difficult for clinicians or researchers to interpret, translate or replicate power training interventions reported in RCTs, and beg the question whether the true effects of power training have been estimated. Future RCTs evaluating the effects of power training in older adults should guarantee therapeutic validity, and provide clearer and more complete descriptions of the intervention.

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Appendix 1: PubMed search string used in literature search.

(("Aged"[Mesh] OR "Aging"[Mesh] OR "Homes for the Aged"[Mesh] OR "Housing for the Elderly"[Mesh] OR "Geriatrics"[Mesh] OR "Geriatric Nursing"[Mesh] OR "Health Services for the Aged"[Mesh] OR (elder*[tw] OR eldest[tw] OR frail*[tw] OR geriatri*[tw] OR old age*[tw] OR oldest old*[tw] OR senior*[tw] OR senium[tw] OR very old*[tw] OR septuagenarian*[tw] OR octagenarian*[tw] OR octogenarian*[tw] OR nonagenarian*[tw] OR centarian*[tw] OR centenarian*[tw] OR supercentenarian*[tw] OR older people[tw] OR older subject*[tw] OR older patient*[tw] OR older age*[tw] OR older adult*[tw] OR older man[tw] OR older men[tw] OR older male*[tw] OR older woman[tw] OR older women[tw] OR older female*[tw] OR older population*[tw] OR older person*[tw]) OR aging[tiab] OR ageing[tiab] OR community-dwell*[tiab]) AND ("Self Efficacy"[Mesh] OR "Activities of Daily Living"[Mesh] OR "Quality of Life"[Mesh] OR self efficac*[tiab] OR "activities of daily living"[tiab] OR "activity of daily living"[tiab] OR "activities of daily life"[tiab] OR "activity of daily life"[tiab] OR daily living activit*[tiab] OR daily life activit*[tiab] OR adl[tiab] OR iadl[tiab] OR "quality of life"[tiab] OR life qualit*[tiab] OR living qualit*[tiab] OR "quality of living"[tiab] OR "qol"[tiab] OR "hrql"[tiab] OR "hrqol"[tiab] OR functional abilit*[tiab] OR physical abilit*[tiab] OR functional perform*[tiab] OR physical perform*[tiab] OR functional independen*[tiab] OR physical independen*[tiab] OR "Personal Autonomy"[Mesh] OR functional autonom*[tiab] OR physical autonom*[tiab] OR "Physical Fitness"[Mesh] OR Independent living[tiab] OR Living independent*[tiab] OR high function*[tiab] OR higher function*[tiab] OR physical function*[tiab]) AND ((power[tiab] OR plyometric*[tiab] OR high velocit*[tiab] OR high intens*[tiab] OR explosive strength[tiab]) AND ("Exercise"[Mesh] OR "Sports"[Mesh] OR "Exercise Therapy"[Mesh] OR training[tiab] OR physical activity[tiab] OR exercise[tiab]))) AND (randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized[tiab] OR randomised[tiab] OR placebo[tiab] OR randomly[tiab] OR trial[tiab] OR groups[tiab])

Appendix 2: TIDier checklist for replicability

		Balachandran (2014)	Bean (2009)	Bottaro (2007)	Fielding (2002)	Henwood (2006)	Henwood (2008)	Lopes (2014)	Marsch (2009)	Miszko (2003)	Orr (2006)	Ramirez-Campillo (2014)	Reid (2013)	Tiggeman (2016)	Zech (2012)	Frequency of reporting
1	Intervention	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %
2	Rationale	0	1	1	0	1	1	0	0	0	1	0	0	1	1	50.0%
3	Materials	1	1	0	1	1	1	1	1	1	1	0	0	1	1	80.0%
4	Procedure	1	1	1	1	1	1	1	1	1	1	0	0	1	1	85.7%
5	Person	1	1	0	1	1	1	0	1	0	1	1	1	1	1	78.6%
6	Modes	1	1	0	1	1	1	0	1	1	1	1	1	1	1	85.7%
7	Location	1	0	0	1	1	1	0	1	0	0	0	0	1	1	50%
8	Training parameters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	a) Total number of sessions	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100%
	b) Frequency (sessions/week)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100%
	c) Duration of a session (min)	Y	Y	N	N	Y	Y	N	Y	N	N	Y	N	N	N	42.8%
	d) Intensity	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	85.7%
	e) Type	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100%
	f) Level	N	Y	N	N	N	N	N	N	Y	N	N	Y	N	N	21.4%
	g) Combination	Y	N	N	Y	Y	N	N	N	N	N	N	N	N	Y	28.6%
9	Tailoring	1	0	0	1	0	1	1	1	0	1	1	1	1	1	71.4%
10	Modification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
11	Adherence	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
12	Delivered	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Total score	7	6	3	7	7	8	4	7	4	7	5	4	8	8	

Caption: Each met criteria is 1 point (1: yes; 0: no): 0–4 poor; 5–9 moderate; 10–12 points good. For sub-questions within criteria 8:
Y: reported; N: not reported.

Appendix 3: CONTENT scale for therapeutic validity

		Balachandran (2014)	Bean (2009)	Bottaro (2007)	Fielding (2002)	Henwood (2006)	Henwood (2008)	Lopes (2014)	Marsch (2009)	Miszko (2003)	Orr (2006)	Ramirez-Campillo (2014)	Reid (2013)	Tiggeman (2016)	Zech (2012)	Frequency of reporting
1	The patient selection is described.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
2	The patient selection is adequate.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
3	Eligibility criteria for therapist and setting determined and adequate.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
4	The therapeutic exercise is based on a-priori aims and intentions.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
5	The rationale for the content and intensity of therapeutic exercise is described and plausible.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
6	The intensity of the therapeutic exercise described.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100%
7	The therapeutic exercise was monitored and adjusted when considered necessary.	1	1	0	1	1	1	1	1	0	1	1	1	1	0	78.6%
8	The therapeutic exercise was personalized and contextualized to the individual participant.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
9	Adherence to the therapeutic exercise was determined and acceptable.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
	Total score	5	5	4	5	5	5	5	5	4	5	5	5	5	4	

Caption: Each met criteria is 1 point (1=yes; 0=no). Interventions with a total score >6 are considered therapeutically valid.

3

The Reliability, Validity, and Responsiveness of Tests Used to Assess the Effects of Power Training in Older Adults: a Systematic Review

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Mohamed el Hadouchi
Henri Kiers
Brittany A. Boerstra
Ralf Berends
Emma Schreurder
Cindy Veenhof
Jaap van Dieen

Abstract

Background: Research shows that power training offers more potential for improving muscle power and physical performance in older adults than strength training. However, the measurement properties of the tests used to assess the effects of power training are unclear.

Objective: to review the reliability, validity, and responsiveness of tests used to measure the effects of power training in older adults.

Methods: A comprehensive literature search was conducted on 24 previously-identified tests in PubMed, Embase, CINAHL, PsycInfo, and SPORTDiscus until April 29, 2024. The methodological quality of the studies was assessed using COSMIN Risk of Bias checklist. Tests were categorized according to the International Classification of Functioning, Disability, and Health (ICF) and evaluated using Terwee's Modified Quality Criteria for Rating the Results of Measurement Properties.

Results: The search yielded a total of 74 articles, of which a majority had 'doubtful' or 'inadequate' methodological quality. Research on reliability was abundant and was considered high for a majority of tests, while validity and responsiveness were studied less. None of the included tests satisfied all criteria for Terwee's Checklist.

Conclusions: Aiming to cover each of the ICF domains, this review suggests the 1RM bench press, 1RM leg press, and CMJ for the function domain; and the 6-MWT, 10-MWT, timed stair climb, 5-STS, 30-seconds Sit to Stand, and TUG for the activities domain. No recommendations can be made for the participation domain at this time.

Keywords: power training; older adults; reliability, validity, responsiveness

Introduction

Muscle power is the product of muscle force and contraction velocity, and determines whether movements, like rising from a chair, can be performed. [1–3] Research shows that muscle power is a determinant of physical performance, and a critical variable in predicting mobility and physical functioning in older adults.[4–7] Ageing is characterized by a loss of muscle power, which can make activities of daily life, such as rising from a chair or climbing a flight of stairs, more difficult to perform. Muscle power is best increased through power training,[7] a form of exercise that involves moving resistance at a higher velocity than traditional strength training. [5,6,8,9] A recent systematic review suggests that power training offers more potential to improve muscle power and physical performance in older adults than strength training.[10]

The effects of power training are commonly evaluated using performance-based tests administered by physical therapists or trainers, as these provide more accurate measures of performance than patient-reported outcome measures (PROMs).[11] Tests can be categorized within the International Classification of Functioning, Disability, and Health (ICF).[12] muscle power can be considered a function, while physical performance belongs to the activity domain where a distinction can be made between generic tests and tests with an emphasis on movement speed. Lastly, physical functioning in daily life belongs to the participation domain. [10] A recent systematic review reported that while no reports on the effects of power training in the participation domain of the ICF were found, a wide variety of tests were used to evaluate the effects of power training in the function and activity domains of the ICF.[10] Overall, the results indicated a benefit of power training over strength training. However, the measurement properties of the tests used were unclear, making a comprehensive assessment of these tests warranted.

Therefore, the objective of this study was to review the reliability, validity, and responsiveness of tests used to measure the effects of power training in older adults. We specifically investigated the tests identified in a previous systematic review and meta-analysis of randomized controlled trials comparing the effectiveness of power training to strength training in older adults. [10] This research will support the development of a standardized testing protocol to assess the effects of power training in older adults, based on a set of reliable, valid, and responsive measurement tools.

Methods

This systematic review was developed in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [13] and adhered to the Consensus-based Standards for the selection of health Measurement Instruments (COSMIN) [14] and the COSMIN methodology for systematic reviews of Patient-Reported Outcome Measures (PROMs). [15–17] This review was also registered in the International Prospective Register of Systematic Reviews (PROSPERO 2021: CRD42021273812).

Data Sources and Searches

A previous systematic review identified 24 tests that were used to evaluate the effects of power training in older adults **(Figure 1)**. [10] Our aim was to assess the measurement properties of the tests used to measure the effects of power training in older adults in the above-mentioned review. Therefore, a comprehensive literature search was conducted in the bibliographic databases PubMed, Embase, CINAHL Plus (Ebsco), APA PsycInfo, and SPORTDiscus (Ebsco) from inception to April 29, 2024 in collaboration with a medical information specialist. The following terms were used (including synonyms and closely related words) as index terms of free-text words: "functional strength measurements", "muscular strength measurements", "aged", "tests", "reliability", "validity", "responsiveness". The search strategy for PubMed **(Appendix 1)** was developed first and then translated for the remaining databases. Duplicate articles were excluded by a medical information specialist using Endnote X21.0.1 (Clarivatetm), following the Amsterdam EfficientDeduplication (AED)-method [18] and the Bramer-method. [19] The references of the identified articles were also searched for relevant publications.

Study Selection

Study selection was independently performed by four researchers (MeH, BB, ES, RB). First, all potentially relevant titles and abstracts were screened using the online software Rayyan. [20] Second, the remaining articles were read in entirety to ensure eligibility criteria were met. Differences in judgement were resolved through a consensus procedure.

Studies that contained data on the reliability, validity, or responsiveness of a measurement of instrument of interest were included if: (1) the study population consisted of older adults (mean age >65 years) recruited from a healthy population, regardless of their level of disability, physical functioning, or fitness. We defined healthy using the World Health Organization's (WHO) definition for health, in which individuals can be considered healthy despite the presence of (chronic) disease; [21] (2) studies evaluated the performance test or measurement

tool itself, and not the equipment used to support the measurement (e.g. stopwatch or force plate); (3) data on measurement properties were available in the form of a statistical summary; (4) the article was written in English; and (5) a full-text version of the article was available.

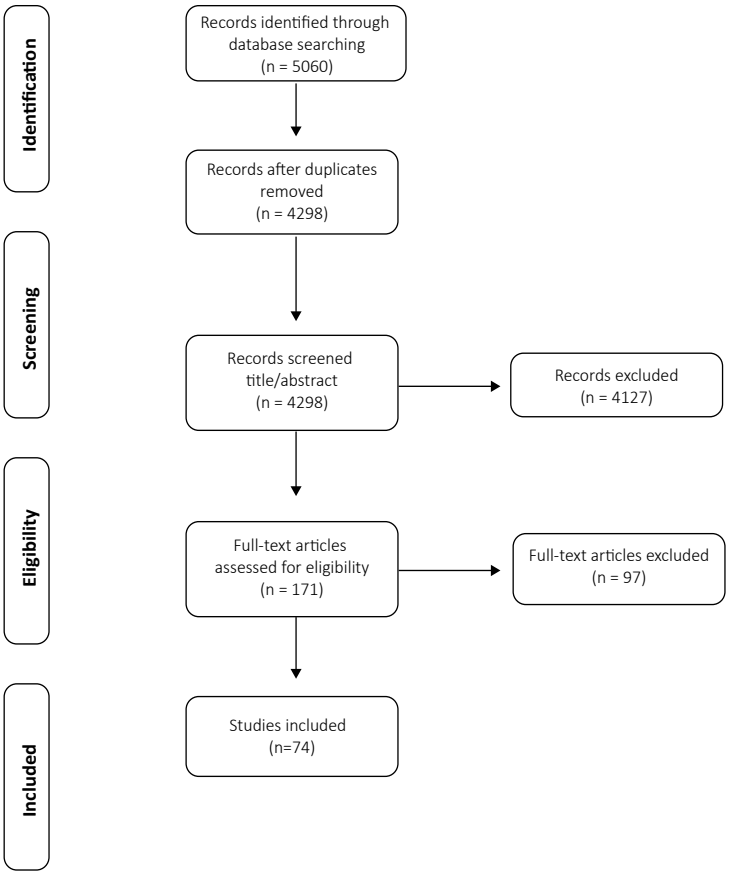


Figure 1: PRISMA flowchart of search and selection process.

Methodological Quality of Selected Studies

The methodological quality of studies evaluating structural validity, internal constency, construct validity, or responsiveness were assessed via the COSMIN RoB checklist.[15–17] Box 3 was used for structural validity, box 4 for internal consistency, box 9a for construct validity, and box 10 for responsiveness. Although the COSMIN RoB checklist was primarily developed for patient-reported outcome measures (PROMs), it can also be used to evaluate performance-based outcome measurement instruments (PerFOMs).[14]

The methodological quality of studies evaluating reliability and measurement error was assessed via the extended COSMIN RoB designed for performance-based measurement isntruments (PerfOMs). [14] In this extended COSMIN RoB Tool, both Part A: Elements of a comprehensive research question and Part B: Assessing risk of bias were applied independently by 3 researchers (BB, ES, RB). If a consensus could not be reached, a fourth researcher (MeH) was consulted whom made the final decision.

The assessment procedure for the COSMIN Risk of Bias checklist involves a 4-point scale scoring each item as very good, adequate, doubtful, or inadequate. The 'worst score counts' method was applied, meaning that the overall rating of the quality of each study is determined by the lowest rating on any standard in the box. [15–17]

Measurement Properties Definitions

In the COSMIN taxonomy,[22] reliability refers to the proportion of the total variance in the measurements which is due to true differences between individuals, and measurement error refers to the systematic and random error of an individual's score that is not attributed to true changes in the construct to be measured. Internal consistency evaluates the degree of interrelatedness among items for tests composed of several subscales. Within the validity domain, structural validity and construct validity were considered. Structural validity is the degree to which the test results are an adequate reflection of the construct to be measured, while construct validity, reflects how well a test compares with another test measuring the same construct. Construct validity was used instead of criterion validity, the degree to which the score on a test is an adequate reflection of a gold standard, since there is no generally accepted standard for evaluating power training in older adults. Finally, responsiveness is the ability of a measurement instrument to detect a change over time in the construct to be measured.

Data Extraction

Data and study characteristics were extracted from each of the included studies and manually entered into Microsoft Excel by three reviewers (BB, ES, RB). Data for reliability and responsiveness are summarized in **Appendix 2** and validity results are summarized in **Appendix 3.** Results of the studies were then classified as evidence for reliability, validity, and responsiveness in **Table 1.** For the sake of clarity and consistency, measurement properties were recategorized to what was factually measured according to the COSMIN Taxonomy of Measurement Properties. Measurement properties that did not fit any of the COSMIN definitions for measurement properties were excluded.

Table 1: Characteristics of the included studies

Study	Author and year	COSMIN domain	Measurement property	COSMIN RoB rating
1	Adell et al. (2013) [23]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
2	Alfonso-Rosa et al. (2014) [24]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
3	Amarante do Nascimento et al. (2013) [25]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
4	Barbalho et al. (2018) [26]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
5	Batting et al. (2019) [27]	Reliability	Measurement error	Inadequate
		Validity	Construct validity: comparison with another instrument	Inadequate
6	Beauchamp (2012) [28]	Reliability	Reliability	Adequate
			Measurement error	Adequate
7	Beninato et al. (2016) [29]	Validity	Structural validity	Adequate
8	Bergamin et al. (2017) [30]	Reliability	Reliability	Doubtful
9	Bodilsen et al. (2015) [31]	Reliability	Reliability	Adequate
			Measurement error	Adequate
10	Brooks et al. (2006) [32]	Validity	Construct validity: comparison with another instrument	Inadequate
		Responsiveness	Responsiveness	Doubtful
11	Chan et al. (2020) [33]	Reliability	Reliability	Doubtful
		Validity	Construct validity: comparison with another instrument	Inadequate
12	Choi et al. (2014) [34]	Reliability	Reliability	Very good
			Measurement error	Very good
13	Connelly et al. (1996) [35]	Reliability	Reliability	Inadequate
14	Cress et al. (1996) [36]	Reliability	Reliability	Inadequate
			Internal consistency	Very good
		Validity	Construct validity: comparison with another instrument	Doubtful
15	Ditroilo et al. (2011) [37]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful

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Table 1: *Continued*

Study	Author and year	COSMIN domain	Measurement property	COSMIN RoB rating
16	Ellis et al. (2019) [38]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
17	Fonseca et al. (2014) [39]	Reliability	Reliability	Very good
			Measurement error	Adequate
18	Freire et al. (2012) [40]	Reliability	Reliability	Doubtful
19	Frykholm et al. (2019) [41]	Reliability	Reliability	Very good
			Measurement error	Very good
20	Galhardas et al. (2020) [42]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
21	Germanou et al. (2007) [43]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
22	Goldberg et al. (2012) [44]	Reliability	Reliability	Inadequate
			Measurement error	Inadequate
		Validity	Construct validity: comparison with another instrument	Very good
23	Gómez et al. (2013) [45]	Reliability	Reliability	Doubtful
		Validity	Structural validity	Doubtful
24	Hansen et al. (2018) [46]	Reliability	Reliability	Very good
			Measurement error	Very good
25	Hernandes et al. (2011) [47]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
26	Hoeymans et al. (1997) [48]	Reliability	Reliability	Doubtful
27	Hwang et al. (2016) [49]	Reliability	Reliability	Inadequate
			Measurement error	Inadequate
		Validity	Construct validity: comparison with another instrument	Inadequate
28	Işik et al. (2015) [50]	Reliability	Reliability	Inadequate
		Validity	Construct validity: comparison with another instrument	Inadequate

29	Jenkins et al. (2017) [51]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
30	Kristensen et al. (2019) [52]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
31	Labadessa et al. (2016) [53]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
32	LeBrasseur et al. (2008) [54]	Reliability	Reliability	Inadequate
			Measurement error	Inadequate
33	Lin et al. (2004) [55]	Reliability	Reliability	Inadequate
			Construct validity: comparison with another instrument	Adequate
		Responsiveness	Responsiveness	Doubtful
34	Madsen et al. (1996) [56]	Reliability	Measurement error	Inadequate
35	Marques et al. (2016) [57]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
36	Marques et al. (2021) [58]	Validity	Structural validity	Adequate
			Construct validity: comparison with another instrument	Doubtful
37	McLay et al. (2020) [59]	Validity	Construct validity: comparison with another instrument	Adequate
38	Medina-Mirapeix et al. (2016) [60]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
39	Medina-Mirapeix et al. (2018) [61]	Reliability	Reliability	Inadequate
			Measurement error	Inadequate
		Validity	Construct validity: comparison with another instrument	Inadequate
40	Mkacher et al. (2017) [62]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
41	Morris-Chatta et al. (1994) [63]	Reliability	Reliability	Inadequate
42	Nunes et al. (2020) [64]	Reliability	Reliability	Inadequate
			Measurement error	Inadequate
		Validity	Construct validity: comparison with another instrument	Very good
43	Ordway et al. (2006) [65]	Reliability	Measurement error	Doubtful
44	Ostchega et al. (2000) [66]	Reliability	Reliability	Inadequate

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Table 1: *Continued*

Study	Author and year	COSMIN domain	Measurement property	COSMIN RoB rating
45	Özden et al. (2020) [67]	Reliability	Reliability	Inadequate
			Measurement error	Inadequate
		Validity	Construct validity: comparison with another instrument	Inadequate
46	Parraca (2022) [68]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
47	Peel et al. (2001) [69]	Reliability	Reliability	Doubtful
48	Phillips et al. (2004) [70]	Reliability	Measurement error	Doubtful
49	Rikli et al. (1998) [71]	Reliability	Reliability	Doubtful
		Validity	Construct validity: comparison with another instrument	Very good
50	Rockwood et al. (2000) [72]	Reliability	Reliability	Inadequate
		Validity	Construct validity: comparison with another instrument	Inadequate
51	Rodrigues (2023) [73]	Reliability	Reliability	Inadequate
52	Rolenz et al. (2016) [74]	Validity	Construct validity: comparison with another instrument	Adequate
53	Rydwik et al. (2007) [75]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
54	Saint-Maurice et al. (2020) [76]	Reliability	Reliability	Doubtful
55	Schaubert et al. (2005) [77]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
56	Schaubert et al. (2005) [78]	Reliability	Reliability	Doubtful
		Validity	Construct validity: comparison with another instrument	Adequate
57	Schroeder et al. (2007) [79]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
58	Schwenk et al. (2012) [80]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
59	Sherwood et al. (2019) [81]	Validity	Construct validity: comparison with another instrument	Inadequate
		Reliability	Reliability	Very good
60	Suwit et al. (2020) [82]		Measurement error	Very good
		Reliability	Reliability	Doubtful

61	Suzuki et al. (2019) [83]	Reliability	Reliability	Doubtful
			Measurement error	Inadequate
62	Symons et al. (2004) [84]	Reliability	Reliability	Inadequate
			Measurement error	Inadequate
63	Symons et al. (2005) [85]	Reliability	Reliability	Inadequate
			Measurement error	Inadequate
64	Tolk et al. (2019) [86]	Reliability	Reliability	Doubtful
		Validity	Construct validity: comparison with another instrument	very good
		Responsiveness	Responsiveness	Very good
65	Tolk et al. (2019) [87]	Reliability	Reliability	Doubtful
		Validity	Construct validity: comparison with another instrument	Inadequate
		Responsiveness	Responsiveness	Inadequate
66	Topp et al. (1994) [88]	Reliability	Reliability	Doubtful
67	Uszko-Lencer et al. (2017) [89]	Reliability	Reliability	Doubtful
		Validity	Construct validity: comparison with another instrument	Inadequate
68	Van Driessche et al. (2018) [90]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
69	van Iersel et al. (2008) [91]	Reponsiveness	Responsiveness	Doubtful
70	Verdijk et al. (2009) [92]	Validity	Construct validity: comparison with another instrument	Adequate
71	Wallmann et al. (2013) [93]	Reliability	Reliability	Doubtful
72	Webber et al. (2010) [94]	Reliability	Reliability	Doubtful
			Measurement error	Doubtful
73	Whitney et al. (2005) [95]	Validity	Construct validity: comparison with another instrument	Adequate
74	Wrisley et al. (2010) [96]	Validity	Construct validity: comparison with another instrument	Very good

Table 2: Rating of measurement properties using Terwee's criteria

		Reliability			Validity					Responsiveness
Measurement instrument		Reliability	Measurement error	Internal consistency	Content validity	Structural validity	Construct validity*	Cross-cultural validity	Criterion validity	Responsiveness
1a	1-RM bench/chest press	+ + +	?	N/A	N/A	?	+	N/A	N/A	?
1b	1-RM Leg/knee flexion	+ + +	?	N/A	N/A	?	?	N/A	N/A	?
1c	1-RM Leg/knee extension	+	?	N/A	N/A	?	+ +	N/A	N/A	?
1d	1-RM leg press	+ + +	?	N/A	N/A	?	+	N/A	N/A	?
1e	1-RM arm curl	+	?	N/A	N/A	?	?	N/A	N/A	?
1f	1-RM preacher curl	+	?	N/A	N/A	?	+	N/A	N/A	?
1g	1-RM lat pull	+	?	N/A	N/A	?	?	N/A	N/A	?
1h	1-RM pull down machine	?	?	N/A	N/A	?	?	N/A	N/A	?
2a	Isometric ankle flexion	+	?	N/A	N/A	?	?	N/A	N/A	?
2b	Isometric ankle extension	?	?	N/A	N/A	?	?	N/A	N/A	?
2c	Isometric knee flexion	?	?	N/A	N/A	?	?	N/A	N/A	?
2d	Isometric knee extension	+ + +	?	N/A	N/A	?	?	N/A	N/A	?
2e	Isotonic ankle flexion	+	?	N/A	N/A	?	?	N/A	N/A	?
2f	Isokinetic ankle flexion	+ + -	?	N/A	N/A	?	?	N/A	N/A	?
2g	Isokinetic ankle extension	?	?	N/A	N/A	?	?	N/A	N/A	?
2h	Isokinetic leg/knee flexion	+ + +	?	N/A	N/A	?	?	N/A	N/A	?
2i	Isokinetic leg/knee extension	+ + +	?	N/A	N/A	?	+	N/A	N/A	?
3	Short Physical Performance Battery	+ + +	?	N/A	N/A	?	?	N/A	N/A	?
4	Continuous Scale Physical Functional Performance	+	?	+	N/A	?	?	N/A	N/A	?
5	5-times Sit to Stand	+ + +	?	N/A	N/A	?	?	N/A	N/A	?
6	30-sec Sit to Stand	+ + +	?	N/A	N/A	?	?	N/A	N/A	-
7	Countermovement jump	+ + +	?	N/A	N/A	?	?	N/A	N/A	?
8	6-minute Walk Test	+ + +	?	N/A	N/A	?	+	N/A	N/A	?

9	10-meter Walk Test	+ + +	?	N/A	N/A	?	+	N/A	N/A	?
10	Timed Up and Go	+ + +	?	N/A	N/A	?	+ +-	N/A	N/A	?
11	8-foot Up and Go	+	?	N/A	N/A	?	?	N/A	N/A	?
12	Functional Gait Assessment	?	?	N/A	N/A	+	+ +	N/A	N/A	?
13	Four Square Step Test	+	?	N/A	N/A	?	+-	N/A	N/A	?
14	Stair Climb Test	+ + +	?	N/A	N/A	?	?	N/A	N/A	-
15	Gymaware power tool	?	?	N/A	N/A	?	+	N/A	N/A	?

Caption: The level of evidence was rated as 'strong' when a performance test or tool scored three positives (+++) or three negatives (---), as 'moderate' with 2 positives (++) or 2 negatives (--), as 'limited' with one positive (+) or negative (-), as 'conflicting' with a mixture of positives (+) and negatives (-), and as 'unknown' when no studies were available. Abbreviations used: 1-RM: 1-repetition maximum.

Rating of Measurement Properties

Each test was given a quality rating based on number and methodological quality of included studies using Terwee et al.'s Modified Quality Criteria for Rating the Results of Measurement Properties checklist. [23] This checklist was modified from its original purpose of evaluating health status questionnaires in collaboration with its authors, to provide explicit criteria to critically appraise and score measurement properties of performance tests and tools. This tool rates criteria related to the validity, reliability, and responsiveness as positive (+), negative (-), or undetermined (?), which are then used to determine the overall level of evidence for the quality of measurement properties. The level of evidence was rated as 'strong' when a performance test or tool scored three positives (+++) or three negatives (---), as 'moderate' with 2 positives (++) or 2 negatives (--), as 'limited' with one positive (+) or negative (-), as 'conflicting' with a mixture of positives (+) and negatives (-), and as 'unknown' when no studies were available.

Within the validity domain of Terwee's checklist, columns for content validity and cross-cultural validity were deemed irrelevant as these forms of validity do not apply to performance-based outcome measurements, and thus scored as 'not applicable'. Criterion validity was also scored as 'not applicable', because there is no accepted 'golden standard' to which the tests can be compared.

Results

Search and Study Selection

The literature search generated a total of 5060 references: 1266 in PubMed, 1393 in Embase, 1903 in CINAHL, 295 in APA PsycInfo and 203 in SPORTDiscus. Reference checking did not lead to any further unique articles. Following the removal of duplicates, 4298 references were screened based on title and abstract, of which 171 references continued to full-text screening. During this phase, 97 articles were excluded on the basis of eligibility criteria, leaving a total of 74 articles included in the present review. **Figure 1** summarizes the search and selection process in a PRISMA flow diagram.

The 74 included studies evaluated measurement properties for 15 of the pre-identified 24 tests, as shown in **Figure 2.** Nine of the 15 tests showed promising results and are covered in this review in greater detail. Within the reliability domain, 60 of the included studies evaluated reliability, 42 studies evaluated measurement error, and only one study evaluated the internal consistency of tests. Within the validity domain, 24 studies evaluated construct validity and five studies evaluated structural validity. The responsiveness of tests was evaluated in five studies.



Figure 2: Previously-identified tests used to evaluate power training and tests included in the present study

Methodological Quality of Selected Studies

An overview of the methodological quality of the included studies according to the COSMIN Risk of Bias checklist is given in **Table 1.** Of the 60 studies that reported reliability, five studies had very good methodological quality, two studies were adequate, 38 studies were doubtful, and 15 studies were inadequate. Of the 42 studies that reported on measurement error, four studies had very good methodological quality, three studies were adequate, 24 studies were doubtful, and 11 studies were inadequate. The high number of 'doubtful' ratings was mainly

due to a lack of reporting on whether the individuals administering and scoring the performance test were blinded to previous results (standards 4 and 5 in the extended COSMIN RoB tool to assess the quality of studies on reliability and measurement error). The single study that evaluated internal consistency had very good methodological quality. [24]

Within the validity domain, five studies evaluated structural validity, of which two studies had adequate methodological quality and three studies were rated as doubtful as a result of unclear rotation methods in the factor analysis. Of the 24 studies that evaluated construct validity, five studies had very good methodological quality, six studies were adequate, two studies were doubtful, and 11 studies were inadequate. All of the studies that were declared inadequate lacked information on measurement properties of the comparative test. Of the five studies that reported responsiveness, one study had good methodological quality, three studies were doubtful, and one study was inadequate.

Rating of Measurement Properties

The overall rating of each test according to the Terwee criteria 23 is summarized in **Table 2.** On the basis of these findings, the 1-RM bench press, 1-RM leg press, 5-times Sit to Stand (5-STS), 30-seconds Sit to Stand, countermovement jump, 6-minute Walk Test (6-MWT), 10-meter walk test (10-MWT), Timed Up and Go (TUG) test, and Stair Climb Test are recommended for use in the evaluation of power training effects in older adults. The transfer to activities of daily life may be more problematic for isolated movements than for functional movements as the latter more closely mimic real-life movements. Even so, isolated movement testing, such as muscle strength testing for specific muscle groups, had relatively high reliability and validity. In contrast, functional testing can be more difficult to design and may have more varied results. For example, a simple functional test like a chair stand test can be limited by lower body strength or power, but it does predict physical performance in older adults. The Short Physical Performance Battery (SPPB) is excluded from the recommendation despite its positive rating because this test has a ceiling effect.

Reliability

All of the tests recommended to evaluate the effects of power training in older adults met Terwee's criteria for strong positive reliability (3 or more studies with ICC/weighted kappa >0.70 or Pearson's r >0.80). Despite this, three studies were found in which several recommended tests showed moderate reliability. In Ostchega et al.,[66] the 5-STS had a test-retest ICC of 0.64, and in Rockwood et al.,[72] the TUG had a test-retest ICC of 0.56. Moreover, the peak power/body mass (W/Kg) estimated from a countermovement jump showed moderate reliability between sessions (ICC: 0.62) for men.[37]

None of the recommended tests met Terwee's criteria for measurement error (MIC > SDC or MIC outside of LOA) as the minimal important important change (MIC) was not reported in any of the studies. The studies quantified measurement error using the standard error of measurement (SEM), smallest detectable change (SDC), limits of agreement (LoA), and the coefficient of variation (CV). Note that we also used the term SDC where original studies used minimal detectable change (MDC), minimal detectable difference (MDD), and smallest real difference (SRD), as these are calculated in the same way. As a result, the rating for measurement error was 'unknown' for all tests, but in an effort to be more forthcoming in the findings, these statistical results will be discussed below. The TUG had consistently low measurement errors for both test-retest (SEM: 0.04 to 1.20 seconds; SDC: 0.37 to 3.01; LoA: 0.02 to 0.05) and inter-rater measurement error (LoA: 0.06). Measurement errors were also small but less consistent for the 10-MWT (SEM: 0.14 seconds, SDC95: 0.13 to 0.40 seconds), timed stair climb (SEM: 1.06 to 1.98 seconds), and 5STS (SEM: 0.76 to 1.98; SDC95: 2.10 to 2.91). Values were slightly higher for the CMJ (SDC: 3.2 to 444.7; SDC%: 14.9% to 19.3%) and the 30-sec STS for both test-retest (SEM: 0.85 to 1.32; SEM%: 18%; SDC: 2.68 to 3.67; SDC%: 27.0% to 49.0%) and inter-rater measurement error (SDC: 567; SDC%: 16%). The 6-MWT had conflicting results, with some studies reporting small measurement errors (SEM: 9.88 to 14.84 seconds, 2.5% to 5%), while other studies reported large measurement errors (SEM: 31.0 to 34.0 seconds; LoA:-67.0 to 120.0). Measurement errors were also conflicting for 1RM strength tests, ranging from small errors for the bench press (SEM: 1.71; LoA: −48.34 to 36.45; %CV: 4.9 to 7.9), to relatively large errors for the leg press (LoA: −371.42 to 236.10; %CV: 4.2 to 6.3).

Internal consistency was not assessed in any of the recommended tests, only in the CS-PFP which had a limited positive rating for internal consistency (Cronbach's alpha: 0.96 to 0.97).

Validity

Structural validity was not assessed in any of the recommended tests, only in the Functional Gait Assessment (FGA) test and the SPPB. The FGA had limited positive rating for structural validity because a single study explained 53.3% of variance through a factor analysis[58], while the rating for SPPB was unknown because the explained variance was not reported.

Construct validity was assessed more frequently. Of the recommended tests, the 1-RM bench press, 1-RM leg press, 6-MWT, and 10-MWT had a limited positive rating for construct validity (1 study in which correlation with an instrument measuring the same construct was >0.5). The TUG had a conflicting rating for construct validity, meaning that some studies found correlations >0.5 and some did not.

Responsiveness

The Terwee criterion for responsiveness was: a) correlation with an instrument measuring the same construct is >0.5; or b) at least 75% of the results are in accordance with the hypotheses; or c) AUC >0.7 and correlation with related constructs is higher than with unrelated constructs. None of the recommended tests met this criterion. In fact, responsiveness was only assessed in the 30-seconds Sit to Stand, the Stair Climb Test, and the TUG. The 30-seconds Sit to Stand fulfilled 44% of a priori hypotheses, while the Stair Climb Test fulfilled 36% of a priori hypotheses. With regard to the TUG, responsiveness was quantified using a standardized response mean (SRM) and responsiveness index (RI): Brooks et al.[32] reported an SRM of 1.1 while van Iersel et al.[91] found an SRM of 0.9 (1.1%), and RI of 1.9 (2.6%), and an effect size of 0.1. As a result, the 30-seconds Sit to Stand, the Stair Climb Test, and the TUG all received a limited negative rating for responsiveness.

Discussion

A previous systematic review showed that a wide variety of different tests and outcome measures have been used interchangeably without distinguishing between various domains.[10] This review categorized 24 previously-identified tests using the ICF framework to provide a structured and in-depth analysis of the tests used to measure the effects of power training. Of the 24 previously identified tests, literature on measurement properties was available for only 15 tests. Our findings suggest that while a majority of tests exhibited good reliability (ICC or correlation >0.7), the validity and responsiveness of each of the tests were poorly described or not investigated. Thus, it remains unclear whether the tests truly measure the construct or outcome they are intended to measure and whether the tests are able to pick up a change in performance over time. The methodological quality of the majority of the studies reporting on measurement properties was doubtful or insufficient as well, possibly because several studies had been conducted prior to publication of the guidelines on conducting and reporting such studies. Based on these findings, a recommendation of tests used to measure the effects of power training in older adults can be made for the time being. Aiming to cover each of the ICF domains, this review suggests 1-RM bench press, 1-RM leg press, and the CMJ for function domain; and the 6-MWT, 10-MWT, the Stair Climb Test, 5-STS, 30-seconds Sit to Stand, and the TUG for the activity domain. No recommendations can be provided for the participation domain based on this review. Several of these tests have been recommended in other populations as well. In patients with hip and knee arthritis, the 30-seconds Sit to Stand and TUG were the best rated Sit to Stand tests[98] and the 6-MWT was recommended to assess the functional status of patients with chronic obstructive pulmonary disorder (COPD).[99] Overall, further research is needed to provide information on the tests used to measure the effects of power training in older adults.

Measurement properties are not the sole factor that determine which tests are appropriate when evaluating effects of power training in older adults. Specific to measuring muscle power, it is crucial to critically assess whether the tests reflects the construct of muscle power. Muscle power is the product of muscle force and contraction velocity, and thus, tests challenging the force and velocity component of the movement simultaneously should be utilized. Commonly used strength tests, such as isometric or 1RM strength tests, capture muscle force but do not take velocity of movement into account. While force or velocity alone can be used as a proxy for power, proxies are rarely as accurate as actual measurements and effect estimates based on proxies may limit our understanding of improvements in power and resulting effects on performance with training.

Additionally, in tests that utilize a scoring system, it is important to be aware of a ceiling effect that may prohibit an accurate effect estimation. The SPPB, for example, is a generic measurement instrument with scores ranging from 0 to 12 or 16 points, and has been used to make an inference about physical performance or functional status in previous research. However, it is difficult to measure an effect of the intervention if a participant already scores a 9 at baseline. For this reason, the SPPB was not included in the list of recommended tests.

To the best of our knowledge, this is the first systematic review to summarize the measurement properties of tests used to evaluate the effects of power training in older adults. We included a wide range of studies while rigorous assessment criteria in the COSMIN RoB ensured that a high methodological quality was pursued throughout this review. This review evaluated tests that were categorized within the function and activities domain of the ICF, which provided a more complete picture of the tests and a more in-depth understanding of how these tests were used. However, for results to be most relevant to older adults, it is important that changes also occur within the participation domain. As such, the effects of power training have been measured by performance tests that evaluate an individual's ability to perform an activity or movement within a clinical or research setting. Yet, researchers are often actually interested whether the effect of power training translates into increased participation and increased independence. In short, there is a discrepancy between the outcome that is currently being measured by tests (function and activity) and the outcome that we are actually interested in (participation). Future research into the effects of power training should employ methods for outcome assessment within a participant's home environment to see how improved capacity translate to increased participation in daily tasks and activities. Tests or devices that are able to measure the change of velocity, such as accelerometers, can provide a solution for measuring within the participation domain. Accelerometers were not included in the present review because these devices have not yet been used to evaluate the effects of power training in older adults. Covering each of the ICF domains will make it

possible to more accurately determine whether power training is effective and to which ICF domain this effect relates. Further research is needed to gain expert consensus on the categorization of tests within ICF domains and evaluate whether there are other or additional tests that should be use to measure the effects of power training in older adults.

Limitations

This review encountered several limitations. While the use of the ICF framework facilitated specific insights into the effects of power training on various domains of the ICF, categorizing tests into ICF domains can be considered artificial as some tests may cover multiple domains. Additionally, some tests that are relevant for evaluating the effects of power training may not fully be covered by the ICF categories. These limitations may infleunce the interpretation and generalization of study findings. With regard to the availability of relevant literature, tests that performed best were studied most often while tests that performed poorly were studies less often. This may not necessarily reflect the measurement properties of the test, but could also be the result of publication bias. It is important to differentiate between tests that scored low as a result of inadequate measurement properties and tests that scored low as a result of insufficient research. In the data extraction process, the type and amount of data on measurement properties varied largely between studies, making comparibility between studies more difficult. For example, SEM estimates were not providedly consistently in each study, and if they were reported, confidence intervals were often omitted. Furthermore, the present study focused on the tests used to evaluate power training in older adults and only included literature in which measurement properties were evaluated in older adults as well. This may have contributed to a lack of research for some tests. It is likely that more literature is available on measurement properties of the included tests applied to younger populations, but the question remains how transferable these results are to older populations. Lastly, we acknowledge that the PROSPERO registration of this study occurred after the first systematic search, which ideally, would have taken place before the systematic search.

Conclusions

Aiming to cover each of the ICF domains, this review suggest the 1-RM bench press, 1-RM leg press, and CMJ for the function domain; and the 6-MWT, 10-MWT, timed stair climb, 5-STS, 30-seconds Sit to Stand, and TUG for the activities domain. No recommendations can be made for the participation domain at this time.

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Appendix 1: Search string used in PubMed

Search **Query**

#7 **#5 AND #6**

#6 "Validation study"[pt] OR "Reproducibility of results"[Majr] OR "Sensitivity and Specificity"[-Majr] OR valid*[ti] OR reliab*[ti] OR reproduc*[ti] OR sensitivity[ti] OR specificity[ti] OR responsiv*[ti] OR valid*[ot] OR reliab*[ot] OR reproduc*[ot] OR sensitivity[ot] OR specificity[ot] OR responsiv*[ot]

#5 **#3 AND #4**

#4 "Aged"[Mesh] OR elder*[tw] OR eldest[tw] OR frail*[tw] OR geriatri*[tw] OR "old age*"[-tiab] OR "oldest old*"[tiab] OR senior*[tiab] OR senium[tiab] OR "very old*"[tiab] OR septuagenarian*[tiab] OR octagenarian*[tiab] OR octogenarian*[tiab] OR nonagenarian*[tiab] OR centarian*[tiab] OR centenarian*[tiab] OR supercentenarian*[tiab] OR "older people"[tiab] OR "older subject*"[tiab] OR "older patient*"[tiab] OR "older age*"[tiab] OR "older adult*"[tiab] OR "older man"[tiab] OR "older men"[tiab] OR "older male*"[tiab] OR "older woman"[tiab] OR "older women"[tiab] OR "older female*"[tiab] OR "older population*"[tiab] OR "older person*"[tiab] OR "older individual*"[tiab] OR "Middle Aged"[Mesh] OR "middle age*"[tiab] OR "aged 50"[tiab] OR "aged 60"[tiab] OR "aged 70"[tiab] OR "aged 80"[tiab] OR "aged 90"[tiab] OR "aged 100"[tiab] OR "over 50"[tiab] OR "over 60"[tiab] OR "over 70"[tiab] OR "over 80"[tiab] OR "over 90"[tiab] OR "over 100"[tiab] OR "50 years and older"[tiab] OR "60 years and older"[tiab] OR "70 years and older"[tiab] OR "80 years and older"[-tiab] OR "90 years and older"[tiab] OR "100 years and older"[tiab] OR "50 years and over"[tiab] OR "60 years and over"[tiab] OR "70 years and over"[tiab] OR "80 years and over"[tiab] OR "90 years and over"[tiab] OR "100 years and over"[tiab] OR "50 year and older"[tiab] OR "60 year and older"[tiab] OR "70 year and older"[tiab] OR "80 year and older"[tiab] OR "90 year and older"[tiab] OR "100 year and older"[tiab] OR "50 years or older"[tiab] OR "60 years or older"[tiab] OR "70 years or older"[tiab] OR "80 years or older"[tiab] OR "90 years or older"[tiab] OR "100 years or older"[tiab] OR "50 years or over"[tiab] OR "60 years or over"[tiab] OR "70 years or over"[tiab] OR "80 years or over"[tiab] OR "90 years or over"[tiab] OR "100 years or over"[tiab] OR "50 year or older"[tiab] OR "60 year or older"[-tiab] OR "70 year or older"[tiab] OR "80 year or older"[tiab] OR "90 year or older"[tiab] OR "100 year or older"[tiab] OR "older than 50"[tiab] OR "older than 60"[tiab] OR "older than 70"[tiab] OR "older than 80"[tiab] OR "older than 90"[tiab] OR "older than 100"[tiab]

#3 **#2** NOT ("questionnaire*"[tw] OR "address"[PT] OR "biography"[PT] OR "case reports"[PT] OR "comment"[PT] OR "directory"[PT] OR "editorial"[PT] OR "festschrift"[PT] OR "interview"[PT] OR "lecture"[PT] OR "legal case"[PT] OR "legislation"[PT] OR "letter"[PT] OR "news"[PT] OR "newspaper article"[PT] OR "patient education handout"[PT] OR "popular work"[PT] OR "congress"[PT] OR "con-

sensus development conference"[PT] OR "consensus development conference, nih"[PT] OR "practice guideline"[PT]) NOT ("Animals"[MeSH] NOT "Humans"[MeSH])

#2 **#1** NOT (("Adolescent"[Mesh] OR "Child"[Mesh] OR "Infant"[Mesh] OR adolescen*[tiab] OR child*[tiab] OR schoolchild*[tiab] OR infant*[tiab] OR girl*[tiab] OR boy[tiab] OR boys[tiab] OR teen[tiab] OR teens[tiab] OR teenager*[tiab] OR youth*[tiab] OR pediatr*[tiab] OR paediatr*[tiab] OR puber*[tiab] OR minors[tiab]) NOT ("Adult"[Mesh] OR adult*[tiab] OR man[tiab] OR men[tiab] OR woman[tiab] OR women[tiab]))

#1 "Walk Test"[Mesh] OR "Muscle Strength Dynamometer"[Mesh] OR "muscle dynamomet*"[tiab] OR "muscular dynamomet*"[tiab] OR "isokinetic dynamomet*"[tiab] OR "Biodex*"[tiab] OR "IKD"[tiab] OR "Dynaport*"[tiab] OR "MoveMonitor*"[tiab] OR "McRoberts*"[tiab] OR "GymAware"[tiab] OR "Short Physical Performance Battery"[tiab] OR "SPPB"[tiab] OR "Short Performance Physical Battery"[tiab] OR "1RM"[tiab] OR "1-RM"[tiab] OR "One Repetition"[tiab] OR "Chair Stand"[tiab] OR "Five Times Sit to Stand"[tiab] OR "5 Times Sit to Stand"[tiab] OR "FTSST"[tiab] OR "30 Seconds Sit to Stand"[tiab] OR "30 Second Sit to Stand "[tiab] OR "Thirty Seconds Sit to Stand"[tiab] OR "Thirty Second Sit to Stand"[tiab] OR "30-s Sit to Stand"[tiab] OR "Counter Movement Jump*"[tiab] OR "Countermovement Jump*"[tiab] OR "CMJ"[tiab] OR "Medicine Ball"[tiab] OR "walk test*"[tiab] OR "6 minute walk"[tiab] OR "6 minutes walk"[tiab] OR "6minute walk"[tiab] OR "6 min walk"[tiab] OR "6min walk"[tiab] OR "six min walk"[tiab] OR "six minute walk"[tiab] OR "six minutes walk"[tiab] OR "sixminute walk"[tiab] OR "6 meter timed walk"[tiab] OR "6 meter walk"[tiab] OR "six meter walk"[tiab] OR "6 m walk"[tiab] OR "6m walk"[tiab] OR "6MWT"[tiab] OR "6-MWT"[tiab] OR "10 meter timed walk"[tiab] OR "10 meter walk"[tiab] OR "ten meter walk"[tiab] OR "10 m walk"[tiab] OR "10m walk"[tiab] OR "10MWT"[tiab] OR "10-MWT"[tiab] OR "400 meter walk"[tiab] OR "400 m walk"[tiab] OR "400m walk"[tiab] OR "Up and Go Test*"[tiab] OR "Up & Go Test*"[tiab] OR "Time Up and Go"[tiab] OR "Timed Up and Go"[tiab] OR "Timed Up & Go"[tiab] OR "Get Up and Go"[tiab] OR "TGUG"[tiab] OR "TGUGT"[tiab] OR "8 Foot Up-and-Go"[tiab] OR "8 Ft Up-and-Go"[tiab] OR "Squat Jump*"[tiab] OR "Jump Squat*"[tiab] OR "Timed Balance"[tiab] OR "Wingate"[tiab] OR "Sitting-Rising"[tiab] OR "Rising-Sitting"[tiab] OR "Stair Climb*"[tiab] OR "Four Square Step"[tiab] OR "Four Step Square"[tiab] OR "4 Square Step"[tiab] OR "4 Step Square"[tiab] OR "FSST"[tiab] OR "Square Step Test*"[tiab] OR (("30-s"[tiab] OR "30 second*"[tiab]) AND test*[tiab]) OR "10 m walking"[tiab] OR "10m walking"[tiab] OR "10 meter walking"[tiab] OR "ten meter walking"[tiab] OR "maximal walking speed"[tiab] OR "Continuous Scale Physical Function*"[tiab] OR "CS-PFP"[tiab] OR "Functional Gait Assessment"[tiab] OR "functional strength measurement*"[tiab] OR "wearable inertial sensor*"[tiab]

Appendix (supplementary information) 2: Reliability and responsiveness of tests

			Reliability			**Responsiveness**
Measurement instrument	Article/year	Subgroup or specific analyses	Reliability	Measurement error	Internal consistency	Responsiveness
1RM bench/chest press	Amarante do Nascimento (2013)		ICC: 0.99	LoA: 0.00 (0.00 to 0.00)		
	LeBrasseur (2008)	Older men	ICC: 0.98 (0.96 to 0.99)	LoA: (−48.34 to 36.45)		
		Older men with mobility limitations	ICC: 0.984 (0.96 to 0.99)	LoA: (−47.08 to 54.49)		
	Nunes (2020)		ICC 0.98	SEM: 1.71		
	Phillips (2004)	Men		% CV: 4.9 (3.9 to 6.5)		
		Women		% CV: 6.2 (5.3 to 7.6)		
	Barbalho (2018)	Women	ICC: 0.99	SEM test 1: 0.2; SEM test 2: 0.3; SDC% test 1: 3.1; SDC% test 2: 1.8		
	Schroeder (2007)	Keiser A-300 pneumatic equipment	Pearson's r: 0.94	% CV: 5.3		
		Cybex VR2	Pearson's r: 0.91	% CV: 7.9		
1RM leg press	Ellis (2019)		ICC: 0.96 (0.81 to 1.00); *ICC: 0.93 (0.83 to 0.97)	LoA: 4.5 (-8.11 to 17.11); *LoA: -3.81 (-23.39 to 15.77)		
	LeBrasseur (2008)	Older men	ICC: 0.95 (0.88 to 0.98)	LoA: (−371.42 to 236.10)		
		Older men with mobility limitations	ICC: 0.98 (0.96 to 0.99)	LoA: (−231.42 to 181.33)		
	Phillips (2004)	Men		% CV: 4.3 (3.2 to 6.8)		
		Women		% CV: 6.2 (5.3 to 7.6)		
	Barbalho (2018)	Women	ICC: 0.99	SEM test 1: 0.2; SEM test 2: 0.3; SDC% test 1: 2.3; SDC% test 2:		
	Schroeder (2007)	Keiser A-300 pneumatic equipment	Pearson's r: 0.90	% CV: 6.3		
		Cybex VR2	Pearson's r: 0.96	% CV: 4.2		
1RM leg/knee flexion	Schroeder (2007)	Keiser A-300 pneumatic equipment	Pearson's r: 0.84	% CV: 7.8		
		Cybex VR2	Pearson's r: 0.93	% CV: 7.0		
1RM leg/knee extension	Amarante do Nascimento (2013)		ICC: 0.99	LoA: 2.21 (-1.26 to 0.95)		

	Nunes (2020)		ICC: 0.97	SEM: 2.03		
	Schroeder (2007)	Keiser A-300 pneumatic equipment	Pearson's r: 0.88	% CV: 9.0		
		Cybex VR2	Pearson's r: 0.98	% CV: 4.7		
1RM arm curl	Amarante do Nascimento (2013)		ICC: 0.96	LoA: 1.72 (-0.97 to 0.75)		
1RM preacher curl	Nunes (2020)		ICC: 0.99	SEM: 0.36		
1RM lat pull	Schroeder (2007)	Keiser A-300 pneumatic equipment	Pearson's r: 0.91	% CV: 5.9		
		Cybex VR2	Pearson's r: 0.92	% CV: 4.4		
1RM pull down machine	Rydwik (2007)		Pearson's r: 0.97	LoA: (-2.6 to 5.6)		
Isometric ankle flexion	Bergamin (2017)	Dorsi flexion R (highest)	ICC: 0.93 (0.86 to 0.97)			
		Dorsi flexion R (average)	ICC: 0.92 (0.84 to 0.96)			
		Dorsi flexion L (highest)	ICC: 0.96 (0.91 to 0.98)			
		Dorsi flexion L (average)	ICC: 0.96 (0.91 to 0.98)			
	Webber (2010)	Dorsi flexion peak torque	ICC: 0.97 (0.94 to 0.99)	SEM: 1.3 (+/- 2.4); SDC95: 3.5; CV of typical error: 6; Ratio LoA: 16		
	Bergamin (2017)	Plantair flexion R (highest)	ICC: 0.71 (0.48 to 0.85)			
		Plantair flexion R (average)	ICC: 0.71 (0.47 to 0.85)			
		Plantair flexion L (highest)	ICC: 0.80 (0.62 to 0.90)			
		Plantair flexion L (average)	ICC: 0.78 (0.58 to 0.89)			
	Webber (2010)	Plantair flexion peak torque	ICC: 0.90 (0.74 to 0.95)	SEM: 9.2 (+/- 18.0); SDC95: 25.4; CV of typical error: 12; Ratio LoA: 34		
Isometric knee flexion	Madsen (1996)	Peak torque		% CV intra-session: 0.0 to 21.8; inter-session: 2.3 to 31.5		
Isometric knee extension	Bergamin (2017)	Highest	ICC: 0.88 (0.77 to 0.94)			
		Average	ICC: 0.87 (0.75 to 0.94)			
	Madsen (1996)	Peak torque		% CV Intra-session: 0.0 to 8.7; inter-session: 1.9 to 50.2		
	Van Driessche (2018)	Peak velocity at 0% maximal isometric strength	ICC: 0.96 (0.93 to 0.97)	SEM: 11.3 (3%); Ratio LoA: 0 ± 9		
		Peak velocity at 25% maximal isometric strength	ICC: 0.90 (0.84 to 0.94)	SEM: 13.5 (5%); Ratio LoA: 0 ± 14		

Measurement instrument	Article/year	Subgroup or specific analyses	Reliability	Measurement error	Internal consistency	Responsiveness
		Peak velocity at 50% maximal isometric strength	ICC: 0.85 (0.76 to 0.91)	SEM: 15.5 (9%); Ratio LoA: -2 ± 29		
		Peak power at 0% maximal isometric strength	ICC: 0.97 (0.95 to 0.98)	SEM: 16.4 (7%); Ratio LoA: 1 ± 20		
		Peak power at 25% maximal isometric strength	ICC: 0.98 (0.97 to 0.99)	SEM: 16.4 (6%); Ratio LoA: -2 ± 20		
		Peak power at 50% maximal isometric strength	ICC: 0.96 (0.94 to 0.98)	SEM: 23.4 (9%); Ratio LoA: -4 ± 37		
Isotonic ankle flexion	Webber (2010)	Dorsi flexion peak power (1-Nm load, W)	ICC: 0.90 (0.79 to 0.95)	SEM: 2.5 (+/- 4.9); SDC95: 6.9; CV of typical error: 17; Ratio LoA: 48		
		Dorsi flexion peak power (50%, W)	ICC: 0.95 (0.90 to 0.98)	SEM: 1.9 (+/- 3.7); SDC95: 5.3; CV of typical error: 12; Ratio LoA: 34		
		Plantair flexion peak power (1-Nm load, W)	ICC: 0.92 90.83 to 0.96)	SEM: 27.6 (+/- 54.1); SDC95: 76.5; CV of typical error: 16; Ratio LoA: 44		
		Plantair flexion peak power (50%, W)	ICC: 0.92 (0.68 to 0.93)	SEM: 22.2 (+/- 43.5); SDC95: 61.5; CV of typical error: 14; Ratio LoA: 40		
Isokinetic ankle flexion	Ordway (2006)	Peak torque at 30°/s		Ratio LoA: 26		
	Ordway (2006)	Peak torque at 120°/s		Ratio LoA: 28		
	Ordway (2006)	Total work at 30°/s		Ratio LoA: 35		
	Ordway (2006)	Total work at 120°/s		Ratio LoA: 33		
	Topp (1994)	Concentric dorsi flexion (peak)	ICC: 0.85			
		Concentric dorsi flexion (average)	ICC: 0.74			
		Eccentric dorsi flexion (peak)	ICC: 0.86			
		Eccentric dorsi flexion (average)	ICC: 0.85			
	Webber (2010)	Dorsi flexion peak torque at 30°/s	ICC: 0.95 (0.89 to 0.98)	SEM: 1.5 (+/- 3.0); SDC95: 4.2; CV of typical error: 11; Ratio LoA: 30		
	Webber (2010)	Dorsi flexion peak torque at 90°/s	ICC: 0.96 (0.92 to 0.98)	SEM: 1.2 (+/- 2.3); SDC95: 3.2; CV of typical error: 11; Ratio LoA: 31		
	Webber (2010)	Dorsi flexion peak power at 30°/s	ICC: 0.94 (0.88 to 0.97)	SEM: 0.8 (+/- 1.6); SDC95: 2.3; CV of typical error: 11; Ratio LoA: 32		
	Webber (2010)	Dorsi flexion peak power at 90°/s	ICC: 0.97 (0.94 to 0.99)	SEM: 1.0 (+/- 2.0); SDC95: 2.9; CV of typical error: 9; Ratio LoA: 26		

	Morris-Chatta (1994)	Dorsi flexion at 30°/s	Pearson's r: 0.89; Spearman's r: 0.91			
		Dorsi flexion at 60°/s	Pearson's r: 0.90; Spearman's r: 0.88			
	Bergamin (2017)	Dorsi flexion at 90°/s R	ICC: 0.77 (0.58 to 0.89)			
		Dorsi flexion at 90°/s L	ICC: 0.36 (0.01 to 0.63)			
	Morris-Chatta (1994)	Dorsi flexion at 120°/s	Pearson's r: 0.67; Spearman's r: 0.68			
		Dorsi flexion at 180°/s	Pearson's r: 0.76; Spearman's r: 0.72			
	Topp (1994)	Concentric plantair flexion (peak)	ICC: 0.93			
		Concentric plantair flexion (average)	ICC: 0.90			
		Eccentric plantair flexion (peak)	ICC: 0.89			
		Eccentric plantair flexion (average)	ICC: 0.87			
	Webber (2010)	Plantair flexion peak torque at 30°/s	ICC: 0.89 (0.77 to 0.95)	SEM: 8.7 (+/- 17.1); SDC95: 2.9; CV of typical error: 13; Ratio LoA: 36		
	Webber (2010)	Plantair flexion peak torque at 90°/s	ICC: 0.85 (0.68 to 0.93)	SEM: 8.9 (+/- 17.5); SDC95: 24.7; CV of typical error: 14; Ratio LoA: 40		
	Webber (2010)	Plantair flexion peak power at 30°/s	ICC: 0.88 (0.75 to 0.95)	SEM: 4.6 (+/- 9.0); SDC95: 12.8; CV of typical error: 13; Ratio LoA: 35		
	Webber (2010)	Plantair flexion peak power at 90°/s	ICC: 0.86 (0.71 to 0.93)	SEM: 9.8 (+/- 19.2); SDC95: 27.1; CV of typical error: 13; Ratio LoA: 35		
	Morris-Chatta (1994)	Plantair flexion at 30°/s	Pearson's r: 0.86; Spearman's r: 0.91			
		Plantair flexion at 60°/s	Pearson's r: 0.90; Spearman's r: 0.88			
	Bergamin (2017)	Plantair flexion at 90°/s R	ICC: 0.90 (0.80 to 0.95)			
		Plantair flexion at 90°/s L	ICC: 0.60 (0.31 to 0.79)			
	Morris-Chatta (1994)	Plantair flexion at 120°/s	Pearson's r: 0.92; Spearman's r: 0.87			
		Plantair flexion at 180°/s	Pearson's r: 0.80; Spearman's r: 0.77			
Isokinetic ankle extension	Ordway (2006)	Peak torque at 30°/s		Ratio LoA: 43		
		Total work at 30°/s		Ratio LoA: 36		

Measurement instrument	Article/year	Subgroup or specific analyses	Reliability	Measurement error	Internal consistency	Responsiveness
Isokinetic leg/knee flexion	Madsen (1996)	Peak torque at 30°/s		% CV intra-session: 0.0 to 44.5; inter-session: 5.1 to 45.7		
	Parraca (2022)	Peak Torque at 60°/s R	ICC men: 0.96 (0.91 to 0.98); women: 0.94 (0.88 to 0.97)	SEM men:3.24 (5.9%); women: 1.83 (5.6%); SDC men: 8.99 (16.4%); women: 5.08 (15.6%)		
		Peak Torque at 60°/s L	ICC men: 0.97 (0.94 to 0.99); women: 0.88 (0.75 to 0.94)	SEM men:3.36 (5.9%); women: 2.55 (7.6%); SDC men: 9.33 (16.5%); women: 7.08 (21.1%)		
	Ordway (2006)	Peak torque at 60°/s		Ratio LoA: 33		
	Madsen (1996)	Peak torque at 120°/s		% CV intra-session: 0.0 to 47.1; inter-session: 4.8 to 69.4		
	Jenkins (2017)	Peak torque at 1.05 rad/s: familiarization 1 to 2	ICC men: 0.84 (0.75 to 0.89); women: 0.78 (0.71 to 0.84)	SEM men: 8.96; women: 5.18; SDC men: 24.83; women: 14.36; % CV men: 20.22; women: 18.32		
		Peak torque at 1.05 rad/s: familiarization 2 to baseline	ICC men: 0.90 (0.84 to 0.93); women: 0.74 (0.66 to 0.81)	SEM men: 7.19; women: 5.59; SDC men: 19.94; women: 15.50; % CV men: 14.94; women: 18.65		
		Peak torque at 1.05 rad/s: familiarization 3-12 weeks	ICC men: 0.93 (0.90 to 0.95); women: 0.78 (0.71 to 0.83)	SEM men: 5.45; women: 5.29; SDC men: 15.10; women: 14.68; % CV men: 10.62; women: 16.70		
		Peak torque at 1.05 rad/s: familiarization 4-24 weeks	ICC men: 0.90 (0.86 to 0.94); women: 0.85 (0.80 to 0.89)	SEM men: 6.80; women: 4.29; SDC men: 18.85; women: 11.91; % CV men: 12.90; women: 13.19		
	Jenkins (2017)	Peak torque at 3.14 rad/s: familiarization 1 to 2	ICC men: 0.83 (0.74 to 0.89); women: 0.59 (0.48 to 0.69)	SEM men: 6.59; women: 5.38; SDC men: 18.28; women: 14.90; % CV men: 22.25; women: 30.67		
		Peak torque at 3.14 rad/s: familiarization 2 to baseline	ICC men: 0.87 (0.81 to 0.91); women: 0.74 (0.66 to 0.80)	SEM men: 6.09; women: 4.39; SDC men: 16.88; women: 12.17; % CV men: 19.79; women: 24.25		
		Peak torque at 3.14 rad/s: familiarization 3-12 weeks	ICC men: 0.87 (0.82 to 0.91; women: 0.69 (0.60 to 0.76)	SEM men: 5.94; women: 5.44; SDC men: 16.46; women: 15.09; % CV men: 18.32; women: 27.58		

	Peak torque at 3.14 rad/s: familiarization 4-24 weeks	ICC men: 0.92 (0.88 to 0.95); women: 0.78 (0.71 to 0.84)		SEM men: 5.10; women: 4.47; SDC men: 14.13; women: 12.38; % CV men: 15.71; women: 21.94	
Madsen (1996)	Total work at 30°/s			% CV intra-session: 0.0-54.4; inter-session: 3.3 to 56.6	
Parraca (2022)	Total work at 60°/s R	ICC men:0.96 (0.91 to 0.98); women: 0.94 (0.87 to 0.97)		SEM men: 4.41 (8.1%); women: 2.42 (7.7%); SDC men: 12.22 (22.6%); women: 6.70 (21.4%)	
	Total work at 60°/s L	ICC men:0.97 (0.94 to 0.99); women: 0.85 (0.70 to 0.93)		SEM men: 4.12 (7.6%); women: 3.42 (10.5%); SDC men: 11.43 (21%); women: 9.49 (29.2%)	
Madsen (1996)	Total work at 120°/s			% CV intra-session: 0.0 to 27.2; inter-session: 6.4 to 111.0	
Bergamin (2017)	Flexion at 90°/s	ICC: 0.88 (0.77 to 0.94)			
Germanou (2007)	Flexion at 90°/s	ICC: 0.86 (0.61 to 0.95)		SEM: 6.5 (18.7%); SDC: 51.8 (51.8%); LoA: (17.86 to 14.22)	
Germanou (2007)	Flexion at 120°/s	ICC: 0.93 (0.78 to 0.98)		SEM: 4.4 (14.6%); SDC: 12.2 (40.5%); LoA: (9.02 to 12.87)	
Germanou (2007)	Flexion at 150°/s	ICC: 0.75 (0.24 to 0.92)		SEM: 6.5 (21.8%); SDC: 18.0 (60.4%); LoA: (22.83 to 9.17)	
Isokinetic leg/knee extension	Symons (2004)	Power (peak)	ICC: 0.83 (0.65 to 0.92)		
Symons (2005)	Power (peak)	ICC: 0.84 (0.71 to 0.91)			
Symons (2004)	Power (average)	ICC: 0.84 (0.67 to 0.93)			
Symons (2005)	Power (average)	ICC: 0.89 (0.80 to 0.94)			
Madsen (1996)	Peak torque at 30°/s			% CV intra-session: 0.0 to 28.3; inter-session: 0.0 to 50.2	
Parraca (2022)	Peak torque at 60°/s R	ICC men: 0.97 (0.94 to 0.99); women: 0.97 (0.94 to 0.99)		SEM men: 4.81 (4.3%); women; 3.36 (5%); SRD men: 13.32 (12%); women: 9.31 (13.8%)	

Measurement instrument	Article/year	Subgroup or specific analyses	Reliability	Measurement error	Internal consistency	Responsiveness
		Peak torque at 60°/s L	ICC men: 0.95 (0.88 to 0.98); women: 0.96 (0.91 to 0.98)	SEM men: 7.03 (6.7%); women: 3.63 (5.3%); SRD men: 19.50 (18.5%); women: 10.06 (14.7%)		
	Ordway (2006)	Peak torque at 60°/s		Ratio LoA: 21		
	Madsen (1996)	Peak torque at 120°/s		% CV intra-session: 0.0 to 14.6; inter-session: 1.1 to 31.8		
	Jenkins (2017)	Peak torque at 1.05 rad/s: familiarization 1 to 2	ICC men: 0.90 (0.84 to 0.93); women: 0.90 (0.86 to 0.93)	SEM men: 12.12; women: 6.94; SDC men: 33.59; women: 19.23; % CV men: 14.15; women: 13.19		
		Peak torque at 1.05 rad/s: familiarization 2 to baseline	ICC men: 0.95 (0.93 to 0.97); women: 0.92 (0.89 to 0.94)	SEM men: 8.39; women: 6.14; SDC men: 23.26; women: 17.01; % CV men: 9.59; women: 11.37		
		Peak torque at 1.05 rad/s: familiarization 3-12 weeks	ICC men: 0.95 (0.93 to 0.97); women: 0.80 (0.74 to 0.85)	SEM men: 8.44; women: 9.89; SDC men: 23.39; women: 27.41; % CV men: 9.07; women: 17.50		
		Peak torque at 1.05 rad/s: familiarization 4-24 weeks	ICC men: 0.95 (0.93 to 0.97); women: 0.93 (0.91 to 0.95)	SEM men: 7.74; women: 5.22; SDC men: 21.46; women: 14.48; % CV men: 8.07; women: 9.20		
	Jenkins (2017)	Peak torque at 3.14 rad/s: familiarization 1 to 2	ICC men: 0.90 (0.86 to 0.94); women: 0.91 (0.87 to 0.93)	SEM men: 8.11; women: 4.70; SDC men: 22.47; women: 13.02; % CV men: 15.63; women: 15.04		
		Peak torque at 3.14 rad/s: familiarization 2 to baseline	ICC men: 0.93 (0.90 to 0.95); women: 0.91 (0.79 to 0.93)	SEM men: 7.12; women: 4.70; SDC men: 19.72; women: 13.02; % CV men: 13.45; women: 14.74		
		Peak torque at 3.14 rad/s: familiarization 3-12 weeks	ICC men: 0.96 (0.95 to 0.98); women: 0.89 (0.85 to 0.92)	SEM men: 5.27; women: 5.49; SDC men: 14.61; women: 15.23; % CV men: 9.42; women: 16.15		
		Peak torque at 3.14 rad/s: familiarization 4-24 weeks	ICC men: 0.96 (0.94 to 0.97); women: 0.92 (0.90 to 0.94)	SEM men: 5.42; women: 4.19; SDC men: 15.03; women: 11.61; % CV men: 9.50; women: 12.30		
	Madsen (1996)	Total work at 30°/s		% CV intra-session: 0.0 to 12.9; inter-session: 1.0 to 49.1		

	Symons (2004)	Eccentric at -90°/s (peak)	ICC: 0.88 (0.75 to 0.95)	% CV average: 18.98 (15.97 to 30.21); peak: 20.50 (17.36 to 33.00); Ratio LoA average: 52.37; peak: 56.78		
	Symons (2005)	Eccentric at -90°/s (peak)	ICC: 0.91 (0.83 to 0.95)	% CV average: 13.43 (10.95 to 17.38); peak: 16.93 (13.80 to 21.90); Ratio LoA average: 41.80; peak: 54.29		
	Symons (2004)	Eccentric at -90°/s (average)	ICC: 0.91 (0.81 to 0.96)			
	Symons (2005)	Eccentric at -90°/s (average)	ICC: 0.93 90.87 to 0.96)			
	Symons (2004)	5-s isometric contractions at 90°/s (peak)	ICC: 0.89 (0.77 to 0.95)	% CV average: 7.52 (6.05 to 11.03); peak: 8.23 (6.71 to 12.27); Ratio LoA average: 20.83; peak: 23.04		
	Symons (2005)	5-s isometric contractions at 90°/s (peak)	ICC: 0.90 (0.82 to 0.95)	% CV average: 7.65 (6.24 to 9.90); peak: 8.18 (6.67 to 10.58); Ratio LoA average: 22.68; peak: 24.35		
	Symons (2004)	5-s isometric contractions at 90°/s (average)	ICC: 0.90 (0.79 to 0.96)	% CV average: 10.92 (8.90 to 16.41); peak: 9.24 (7.48 to 13.71); Ratio LoA average: 30.25; peak: 25.58		
	Symons (2005)	5-s isometric contractions at 90°/s (average)	ICC: 0.92 (0.85 to 0.96)	% CV average: 12.88 (10.50 to 16.66); peak: 12.81 (10.44 to 13.80); Ratio LoA average: 39.90; peak: 39.68		
	Frykholm (2019)	Isometric seconds	ICC: 0.88 (0.76 to 0.94)	% CV: 15.8; LoA: 18.5 (43.1%)		
	Frykholm (2019)	Isokinetic joules	ICC: 0.98 (0.94 to 0.99)	% CV: 6.5; LoA: 327 (18.0%)		
	Frykholm (2019)	Isotonic repetitions	ICC: 0.91 (0.85 to 0.94)	% CV: 14.9; LoA: 12 (40.8%)		
5-times Sit to Stand	Beauchamp (2021)		ICC: 0.64 (0.54 to 0.73)	SEM: 0.10; SDC90: 0.23		
	Goldberg (2012)		ICC: 0.95 (0.89 to 0.97)	SEM: 0.9 (6.3%); SDC95: 2.5 (17.5%); LoA: (−2.6 to 2.6)		
	Hoeymans (1997)		Pearson's r: 0.82			
	Medina-Mirapeix (2018)		ICC: 0.982 (0.96 to 0.99); *ICC: 0.99 (0.99 to 0.99)	SEM: 0.76 (0.50 to 1.14); SDC: 2.10 (1.40 to 3.18); LoA: 1.20 (1.76 to 4.16); *SEM: 0.24 (0.16 to 0.38); *LoA: 0.11 (−0.82 to 1.		

Measurement instrument	Article/year	Subgroup or specific analyses	Reliability	Measurement error	Internal consistency	Responsiveness
	Symons (2004)	Eccentric at -90°/s (peak)	ICC: 0.88 (0.75 to 0.95)	% CV average: 18.98 (15.97 to 30.21); peak: 20.50 (17.36 to 33.00); Ratio LoA average: 52.37; peak: 56.78		
	Symons (2005)	Eccentric at -90°/s (peak)	ICC: 0.91 (0.83 to 0.95)	% CV average: 13.43 (10.95 to 17.38); peak: 16.93 (13.80 to 21.90); Ratio LoA average: 41.80; peak: 54.29		
	Symons (2004)	Eccentric at -90°/s (average)	ICC: 0.91 (0.81 to 0.96)			
	Symons (2005)	Eccentric at -90°/s (average)	ICC: 0.93 90.87 to 0.96)			
	Symons (2004)	5-s isometric contractions at 90°/s (peak)	ICC: 0.89 (0.77 to 0.95)	% CV average: 7.52 (6.05 to 11.03); peak: 8.23 (6.71 to 12.27); Ratio LoA average: 20.83; peak: 23.04		
	Symons (2005)	5-s isometric contractions at 90°/s (peak)	ICC: 0.90 (0.82 to 0.95)	% CV average: 7.65 (6.24 to 9.90); peak: 8.18 (6.67 to 10.58); Ratio LoA average: 22.68; peak: 24.35		
	Symons (2004)	5-s isometric contractions at 90°/s (average)	ICC: 0.90 (0.79 to 0.96)	% CV average: 10.92 (8.90 to 16.41); peak: 9.24 (7.48 to 13.71); Ratio LoA average: 30.25; peak: 25.58		
	Symons (2005)	5-s isometric contractions at 90°/s (average)	ICC: 0.92 (0.85 to 0.96)	% CV average: 12.88 (10.50 to 16.66); peak: 12.81 (10.44 to 13.80); Ratio LoA average: 39.90; peak: 39.68		
	Frykholm (2019)	Isometric seconds	ICC: 0.88 (0.76 to 0.94)	% CV: 15.8; LoA: 18.5 (43.1%)		
	Frykholm (2019)	Isokinetic joules	ICC: 0.98 (0.94 to 0.99)	% CV: 6.5; LoA: 327 (18.0%)		
	Frykholm (2019)	Isotonic repetitions	ICC: 0.91 (0.85 to 0.94)	% CV: 14.9; LoA: 12 (40.8%)		
5-times Sit to Stand	Beauchamp (2021)		ICC: 0.64 (0.54 to 0.73)	SEM: 0.10; SDC90: 0.23		
	Goldberg (2012)		ICC: 0.95 (0.89 to 0.97)	SEM: 0.9 (6.3%); SDC95: 2.5 (17.5%); LoA: (−2.6 to 2.6)		
	Hoeymans (1997)		Pearson's r: 0.82			
	Medina-Mirapeix (2018)		ICC: 0.982 (0.96 to 0.99); *ICC: 0.99 (0.99 to 0.99)	SEM: 0.76 (0.50 to 1.14); SDC: 2.10 (1.40 to 3.18); LoA: 1.20 (1.76 to 4.16); *SEM: 0.24 (0.16 to 0.38); *LoA: 0.11 (−0.82 to 1.		

	Ostchega (2000)		ICC: 0.64 (0.53 to 0.73); *ICC: 0.71 (0.52 to 0.77			
	Özden (2020)		ICC: 0.987 (0.97 to 0.99)	SEM95: 1.05; SDC95: 2.91		
	Schaubert (2005)		ICC: 0.82			
	Schaubert (2005)		ICC: 0.81	% CV: 16.85		
	Suzuki (2019)	Total	ICC: 0.77 (0.74 to 0.80)			
		Men	ICC: 0.78 (0.72 to 0.83)			
		Women	ICC: 0.77 (0.73 to 0.80)			
	Wallmann (2013)		*ICC: 1.00 (0.99 to 1.00)			
Stair Climb Test	LeBrasseur (2008)	Older men	ICC: 0.94 (0.87 to 0.97)	LoA: (−0.59 to 1.31)		
		Older men with mobility limitations	ICC: 0.99 (0.98 to 0.99)	LoA: (−0.97 to 1.25)		
	Madsen (1996)			% CV inter-session: 0.0 to 16.0		
	Tolk (2019)		ICC: 0.94 (0.89 to 0.97)	SEM: 1.98; SDC: 5.5		
	Tolk (2019)		ICC: 0.96 (0.91 to 0.98)	SEM: 1.06; SDC: 2.9		
6-minute Walk Test	Alfonso-Rosa (2014)		ICC: 0.99 (0.96 to 1.00)	SEM: 9.88 (2.5%); SDC95: 27.37 (7%); % CV: 5.12; LoA: -7.9 (-47.1 to 31.2)		
	Hansen (2018)		ICC: 0.98 (LL95 0.96); *ICC: 0.96 (LL95 0.94)	SEM: 14.84 (5%); SDC95: 41.13 (13%); LoA: 1.4 (-44.5 to 47.4); *SEM: 20.46 (6%); *SDC95: 56.7 (16%); *LoA: 7.9 (-46.4 to 62.2)		
	Hernandes (2011)		ICC: 0.93	LoA: (-67 to 120)		
	Labadessa (2016)	test 1 and 2	ICC: 0.89 (0.78 to 0.94)	SEM: 31.0; SDC: 72.0; CV: 0.06; LoA: 10.7 (-82 to 103.4)		
		test 1 and 3	ICC: 0.88 (0.76 to 0.94)	SEM: 32.0; SDC: 73.5; CV: 0.07; LoA: 21.7 (-72.2 to 115.4)		
		test 2 and 3	ICC: 0.86 (0.73 to 0.93)	SEM: 34.0; SDC: 78.4; CV: 0.07; LoA: 5.8 (-90.2 to 101.9)		
	Peel (2001)		ICC: 0.94			
	Rikli (1998)	test 1 and 2	ICC men: 0.94; women: 0.88			
		test 2 and 3	ICC men: 0.97; women: 0.91			

Measurement instrument	Article/year	Subgroup or specific analyses	Reliability	Measurement error	Internal consistency	Responsiveness
	Uszko-Lencer (2017)		ICC: 0.90 (0.63 to 0.96)			
8-foot Up and Go	Fonseca (2014)		ICC: 0.98 (0.98 to 0.99)	LoA: 0.05 (-2.25 to 2.35)		
10-meter Walk Test	Adell (2013)		ICC: 0.86	% CV: 11.4; LoA: (-0.33 to 0.27)		
	Chan (2020)		ICC: 0.95 (0.92 to 0.98); *ICC session 1: 0.95 (0.91 to 0.97); *ICC session 2: 0.96 (0.93 to 0.98)	SDC95: 0.13 (18.8%)		
	Marques (2016)		ICC: 0.90 (0.83 to 0.947); *ICC: 0.99 (0.99 to 0.99)	SEM: 0.14 (9.6%); SDC95: 0.4 (26.5%); LoA: 0.02 (-0.35 to 0.39); *LoA: 0.01 (-0.10 to 0.12)		
	Connelly (1996)	Mean	ICC rater 1: 0.92 ; rater 2: 0.88; *ICC day 1: 0.93; *day 2: 0.91			
		First	ICC rater 1: 0.92; rater 2: 0.75; *ICC day 1: 0.83; *day 2: 0.78			
		Best	ICC rater 1: 0.92; rater 2: 0.84; *ICC day 1: 0.88; *day 2: 0.88			
30-seconds Sit to Stand	Alfonso-Rosa (2014)		ICC: 0.92 (0.79 to 0.98)	SEM: 1.21 (9.6%); SDC95: 3.35 (26.7%); % CV: 17.60; LoA: -1.0 (-5.3 to 3.3)		
	Bodilsen (2015)		ICC: 0.82 (LL95 0.67)	SEM: 1.32 (18.0%); SDC95: 3.67 (49%)		
	Hansen (2018)		ICC: 0.94 (LL95 0.90); *ICC: 0.92 (LL95 0.86)	SEM: 0.97 (10.0%); SDC95: 2.68 (27.0%); LoA: 0.2 (-2.9 to 2.5); *SEM: 1.14 (11.0%); *SDC95: 3.15 (30.0%); *LoA: 0.6 (-2.3 to 3.6)		
	Suwit (2020)		ICC: 0.87 (0.74 to 0.93)	SEM: 1.4 (1.2 to 1.7) (9.1%); SDC90: 3.2 (21.1%); % CV: 10.7 (7.45 to 13.2); LoA: −0.9 (-4.7 to 2.9)		
	Tolk (2019)		ICC: 0.90 (0.68 to 0.96)	SEM: 0.85; SDC: 2.4		
	Tolk (2019)		ICC: 0.86 (0.66 to 0.94)	SEM: 0.99; SDC: 2.7		
Continuous Scale Physical Functional Performance	Cress (1996)		Pearson's r: 0.97; *Pearson's r: 0.98		0.97	
Countermovement jump	Ditroilo (2011)	Intra-session peak power	ICC men: 0.89 (0.77 to 0.95); women: 0.96 (0.91 to 0.98)	% CV intrasession men: 4.2 (2.5 to 5.9); women: 3.4 (2.6 to 4.2)		

		Inter-session peak power	ICC men: 0.84 (0.64 to 0.93); women: 0.92 (0.82 to 0.96)	SDC men: 444.7 (19.3%); women: 197.7 (13.9%)		
		Intra-session (peak power/body mass) W/Kg	ICC men: 0.85 (0.70 to 0.93); women: 0.94 (0.89 to 0.97)	% CV intra-session men: 4.3 (2.7 to 6.0); women: 3.4 (2.6 to 4.2)		
		Inter-session (peak power/body mass) W/Kg	ICC men: 0.62 (0.26 to 0.82); women: 0.90 (0.79 to 0.95)	SDC men: 5.7 (20.1%); women: 3.2 (14.9%)		
Four Square Step Test	Batting (2019)			LoA: 0.14 (-3.2 to 3.5)		
	Choi (2014)		ICC: 0.83 (0.57 to 0.93); *ICC: 0.86 (0.72 to 0.93)	SEM: 0.86 (0.68 to 1.17) (9.9%); SDC90: 2.0 (1.58 to 2.72) (23.0%); *SEM: 0.77 (0.65 to 1.04) (8.8%); *SDC90: 1.80 (1.43 to 2.42) (20.5%)		
	Işik (2015)		Cronbach's alpha: 0.96			
Short Physical Performance Battery	Freire (2012)	Group 1: Santa Cruz	ICC: 0.83 (0.73 to 0.89)			
		Group 2: St. Bruno	ICC: 0.89 (0.83 to 0.93)			
	Gomez (2013)		ICC: 0.87 (0.76 to 0.93)			
	Jenkins (2017)	Familiarization 1 to 2	ICC men: 0.84 (0.77 to 0.89); women: 0.88 (0.83 to 0.91)	SEM men: 0.80; women: 0.82; SDC men: 2.22; women: 2.28; % CV men: 9.28; women: 10.37		
		Familiarization 2 to baseline	ICC men: 0.85 (0.79 to 0.90); women: 0.87 (0.83 to 0.90)	SEM men: 0.84; women: 0.86; SDC men: 2.32; women: 2.38; % CV men: 9.39; women: 10.49		
		Familiarization 3-12 weeks	ICC men: 0.93 (0.89 to 0.95); women: 0.89 (0.85 to 0.92)	SEM men: 0.57; women: 0.76; SDC men: 1.57; women: 2.11; % CV men: 5.97; women: 9.01		
		Familiarization 4-24 weeks	ICC men: 0.92 (0.88 to 0.94); women: 0.87 (0.82 to 0.91)	SEM men: 0.63; women: 0.80; SDC men: 1.73; women: 2.21; % CV men 6.34%; women: 8.98		
	Medina-Mirapeix (2016)		*ICC: 0.92 (0.62 to 0.91)	*LoA: (-1.9 to 2.11)		
	Alfonso-Rosa (2014)		ICC: 0.98 (0.95 to 0.99)	SEM: 0.31 (3.5%); SDC95: 0.85 (7.0%); % CV: 6.46; LoA: -0.10 (-1.01 to 1.21)		
Timed Up and Go	Beauchamp (2021)		ICC: 0.80 (0.72 to 0.86)	SEM: 0.97; SDC90: 2.26		

Measurement instrument	Article/year	Subgroup or specific analyses	Reliability	Measurement error	Internal consistency	Responsiveness
	Brooks (2006)					SRM: 1.1
	Galhardas (2020)		ICC: 0.99 (0.99 to 1.00)	SEM: 0.5; SDC95: 1.5		
	Hwang (2016)		ICC: 0.93	SEM: 0.04; SDC95: 0.11; LoA: 0.02 (-0.09 to 0.12)		
	Kristensen (2019)	Medical hospital units	ICC: 0.96 (0.89 to 0.98)	SEM: 1.2		
		Outpatient gariatric center	ICC: 0.98 (0.93 to 1.00)	SEM: 0.7 (6.0%); SDC95: 3.3		
	Marques (2016)		ICC: 0.92 (0.86 to 0.96); *ICC: 0.99 (0.99 to 0.99)	SEM: 0.97 (12.1%); SDC95: 2.68 (33.5%); LoA: 0.05 (-1.91 to 2.00); *LoA: 0.06 (-0.56 to 0.45)		
	Mkacher (2017)		ICC: 0.91 (0.86 to 0.95)	SEM: 1.18 (9.0%); SDC95: 3.01 (23.8%)		
	Rockwood (2000)		ICC: 0.56			
	Rodrigues (2023)		ICC: 0.97			
	Suzuki (2019)	Total	ICC: 0.88 (0.87 to 0.90)	SDC: 0.37 (6%)		
		Men	ICC: 0.88 (0.84 to 0.90)	SDC: 0.44 (8%)		
		Women	ICC: 0.89 (0.87 to 0.90)	SDC: 0.35 (6%)		
	van Iersel (2008)					SRM: 0.9 (1.1%); RI: 1.9 (2.6%); effect size: 0.1

Note. All values are test-retest reliability unless otherwise indicated by an asterisk*, which are inter-rater reliability. The color of the cells indicates the COSMIN RoB methodological quality of the study that reported the finding. Green cell: "very good"; yellow cell: "adequate"; orange cell: "doubtful"; red cell: "inadequate". Abbreviations used: ICC: intraclass correlation coefficient; LoA: limits of agreement; SEM: standard error of the mean; CV: coefficient of variation; SDC: smallest detectable change.

Appendix 3: Validity of tests

Measurement instrument	Article (year)	Validity results
1-RM bench/chest press	Nunes (2020)	Correlations between 1-RM chest press and 1-RM knee extension r=0.76 (0.65 to 0.84); and 1-RM preacher curl r=0.68 (0.55 to 0.78); isokinetic knee extension at 60°/s r=0.52 (0.34 to 0.66); isokinetic knee extension at °/s r=0.53 (0.36 to 0.67); isokinetic knee extension 300°/s r=0.50 (0.32 to 0.65); isometric knee extension r=0.50 (0.31 to 0.64).
1-RM leg press	Verdijk (2009)	Correlations between 1-RM leg press and isokinetic dynamometer isometric peak torque r=0.76 (0.49 to 0.89); isokinetic peak torque at 2.09 r=0.60 (0.24 to 0.82); isokinetic peak torque at 3.14 r=0.64 (0.30 to 0.84); isokinetic peak torque at 4.19 r=0.58 (0.21 to 0.81); and isokinetic peak torque at 5.24 r=0.63 (0.28 to 0.83).
1-RM knee/leg extension	Nunes (2020)	Correlations between 1-RM knee/leg extension and 1-RM preacher curl r=0.60 (0.44 to 0.72); isokinetic knee extension at 60°/s r=0.68 (0.55, 0.78); isokinetic knee extension at 180°/s r=0.72 (0.60 to 0.81); isokinetic knee extension at 300°/s r=0.67 (0.53 to 0.77); and isometric knee extension r=0.64 (0.50 to 0.75). See above for correlation with 1-RM chest press.
	Verdijk (2009)	Correlations between 1-RM knee/leg extension and isokinetic dynamometer isometric peak torque r=0.93 (0.83 to 0.97); isokinetic peak torque at 2.09 r=0.75 (0.49 to 0.89); isokinetic peak torque at 3.14 r=0.77 (0.52 to 0.90); isokinetic peak torque at 4.19 r=0.76 (0.49 to 0.89); isokinetic peak torque at 5.24 r=0.81 (0.59 to 0.92).
1-RM Preacher curl	Nunes (2020)	Correlations with 1RM preacher curl and isokinetic knee extension at 60°/s r= 0.51 (0.33 to 0.65); isokinetic knee extension at 180°/s r=0.52 (0.34 to 0.66); isokinetic knee extension at 300°/s r=0.51 (0.33 to 0.65); isometric knee extension r=0.46 (0.28 to 0.62). See above for correlation with 1-RM chest press and 1RM knee extension.
Isokinetic knee extension at 60°/s	Nunes (2020)	Correlations with isokinetic knee extension at 60°/s r=0.93 (0.89 to 0.95); isokinetic knee extension at 300°/s r=0.89 (0.84 to 0.93); isometric knee extension r=0.90 (0.85 to 0.96). See above for 1-RM chest press, 1-RM knee extension, and 1-RM preacher curl.
Isokinetic knee extension at 180°/s	Nunes (2020)	Correlations with isokinetic knee extension at 300 degrees r=0.951 (0.93 to 0.97); and isometric knee extension r=0.86 (0.79 to 0.91). See above for 1RM chest press, 1RM knee extension, 1RM preacher curl, and isokinetic knee extension at 60.
Isokinetic knee extension at 300°/s	Nunes (2020)	Correlations with isometric knee extension r=0.83 (0.75 to 0.89). See above for 1RM chest press, 1-RM knee extension, 1-RM preacher curl, and isokinetic knee extension at 60 and 180.

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Appendix 3: *Continued*

Measurement instrument	Article (year)	Validity results
GymAware power tool	Sherwood (2019)	Absolute agreement of velocity values between GA and video recording: ICC=0.94 (0.89 to 0.97); consistency of velocity values ICC=0.95 (0.91 to 0.97); absolute agreement of power values: ICC=0.98 (0.96 to 0.99); consistency of power values ICC=0.98 (90.96 to 0.99).
Four Square Step Test	Batting (2019)	Correlations between FSST and figure 8 walk r=0.7; LoA: (1.6 to −0.8); and BBS r=-0.60; LoA: (3.9 to −2).
	Işik (2015)	Correlations between FSST and single leg stance test r=-0.35; functional reach r=-0.232; TUG r=0.60; BBS r=-0.64.
Functional Gait Assessment	Beninato (2016)	The revised scoring criteria of the FGA may have affected item hierarchy. The results of Rasch modeling suggest that the FGA is a measure of walking balance ability in older adults that is clinically appropriate and has construct validity.
	Marques (2021)	A factor analysis resulted in two factors explaining 53.3% of the total variance. Correlations between the FGA and gait speed r=0.65; BBS r=0.80.
	Wrisley (2010)	Correlations between FGA and ABC r=0.53; BBS r=0.84; TUG r=-0.84; DGI r= 0.94.
Timed Up and Go	Brooks (2006)	Correlations between TUG and 2MWT at admission r=0.59; FIM at admission r=0.59; 2MWT at discharge r=0.42; FIM at discharge r=0.47.
	Hwang (2016)	Correlations between TUG and 6-MWT r=-0.81; 10-MWT performed at a comfortable pace r=0.80; 10-MWT performed at a fast pace r=0.88; better QoL r=-0.31; younger age r=0.44; and lower NYHA functional class r=0.45.
	Lin (2004)	Correlations between TUG and Tinetti Balance r=-0.53; walking speed r=0.66; ADL scale r=-0.45.
	McLay (2020)	Correlations between TUG and BBS r=-0.61; ABC scale r=-0.51; chair stands r= -0.73; 6-MWT r=-0.68; PF-10 r=-0.41; BODE index r=0.50; and mMRC dyspnea scale r=0.37.
	Rockwood (2000)	Correlations between TUG and OARS ADL r=-0.69; OARS IADL r=-0.70; cumulative illness rating scale r=0.26; and frailty scale r=0.60.
	Rolenz (2016)	In predicting prospective fallers, TUG has a sensitivity of 20.0 and a specificity of 94.6.
10-meter Walk Test	Chan (2020)	Correlations between 10-MWT and 2MWT r=0.98; 6-MWT r=0.89; EMS r=0.57; BBS r= 0.66; MBI r=0.55.
6-minute Walk Test	Rikli (1998)	Correlations between 6-MWT and treadmill walking r=0.78 (0.62 to 0.88); functional ability r=0.63 (0.48 to 0.75).

6-minute Walk Test (continued)	Uszko-Lencer (2017)	Moderate-to-good correlations were observed with measures of maximal exercise capacity. The strongest correlation was found with maximal power output (r=0.69). No-to-fair correlations were found with measures of body composition, lung function, LVEF, and with symptoms of anxiety and depression (r=0.04 to 0.49). There was no significant correlation with LVEF (r= −0.05, p=0.37). Correlations with various health outcomes.
Continuous Scale Physical Functional Performance	Cress (1996)	The CS-PFP detected a significant difference in scores between 3 groups of residents (dependent residents, independent residents, and community-dwellers) (p<0.001), whereas the IADL could not. Correlations between CS-PFP and bicep strength r=0.55; knee extensor strength r=0.68; shoulder flexion r=0.23; step reaction time r=-0.65; VO2 max r=0.65; hip flexion r=-0.19.
Short Physical Performance Battery	Gómez (2013)	A factor analysis showed that the three SPPB tests resulted in a single factor with high factor loadings.
5-times Sit to Stand	Goldberg (2012)	Correlations between 5STS and TUG r=0.64; functional reach r=-0.36.
	Medina-Mirapeix (2018)	Correlations between 5STS and TUG r=0.70; 4MGS r= −0.583; knee ROM of flexion r= −0.23; knee ROM of extension r=0.08.
	Özden (2020)	Correlations between 5STS and Harris Hip Score r=0.52; TUG r=0.73.
	Schaubert (2005)	Correlations between 5STS and TUG at baseline r= 0.73; week 6 r=0.88, and week 12 r= 0.92; and gait speed at baseline: r=-0.82; week 6 r=-0.78; week 12 r=-0.94.
	Whitney (2005)	Correlations between the 5STS and the DGI r= −0.68; ABC r= −0.58.
30-seconds Sit to Stand	Tolk (2019)	Adequate construct validity could not be confirmed for the 30-s CST as only 4/9 (44.4%) of the predefined hypotheses were confirmed.
Stair Climb Test	Tolk (2019)	Adequate construct validity could not be confirmed for the 10-step SCT as only 36 of the predefined hypotheses were confirmed

4

Establishing a Core Outcome Set to Evaluate the Effects of Power Training in Older Adults: a Delphi Study

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Mohamed el Hadouchi
Jaap van Dieen
Francois Maissan
Timon Eskes
Cindy Veenhof
Henri Kiers

Abstract

Background: Studies evaluating the effects of power training in older adults use a variety of measurement tools and outcome parameters, limiting the comparability of results between studies and calling the validity of conclusions into question. This study aimed to identify a core outcome set (COS) of measurement instruments to evaluate the effects of power training in older adults, encompassing ICF health domains.

Methods: Twenty-one previously-identified tests were evaluated regarding their ability to measure the concept of muscle power and evaluate the effects of power training. Our methodology consisted of two Delphi survey rounds and an expert panel meeting using a modified Nominal Group Technique. The COS consisted of tests considered most feasible for use in clinical practice and least burdensome for older adults.

Results: The COS, aligning with ICF health domains, included the Squat Jump Test and Timed Up-and-Go Test for the function and activities domain, respectively. There was no specific test identified for the participation domain, however, experts proposed using daily-life accelerometery until more suitable outcome measures are defined and validated.

Conclusions: This study addresses a critical research gap in standardized assessment protocols, and contributes to a multifaceted approach to measuring the impact of power training in older adults.

Keywords: power training; older adults; core outcome set; Delphi; consensus

Introduction

As the global population ages, it becomes increasingly important to implement effective strategies to sustain physical functioning and foster functional independence among older adults.[1–3] One such strategy focuses on a crucial element of physical functioning, namely, muscle power, which reflects the capacity of muscles to generate high levels of force while contracting rapidly.[4–6] Previous research has named muscle power as a discriminative variable in the natural decline of physical functioning associated with ageing. Muscle power declines faster with age than muscle strength,[7–11] and is essential for maintaining and improving physical functioning as it directly influences an individual's ability to perform daily activities and engage in physical exercise.[12,13] Additionally, muscle power allows for quick reactions to prevent falls after stumbling or losing balance.[14] Examples from everyday life where muscle power plays an important role include activities such as rising from a chair, climbing a flight of stairs, or lifting objects from the ground.

One of the most effective strategies for maintaining and improving muscle power is progressive power training, a type of exercise focused on quick muscle contractions and explosive movements.[15,16] Studies indicate that older adults who participate in power training demonstrate enhanced muscular power as well as improved physical functioning and physical performance.[17–20] However, the interpretation of these findings is hindered by several limitations. First, studies evaluating the effects of power training in older adults used a wide selection of measurement tools and outcome parameters, which limits direct comparison of results between studies. A recent review found consistent challenges in the reliability, validity, and responsiveness of the tests used to assess the effects of power training in older adults,[21] highlighting the need for further research to identify measurement instruments with sufficient clinimetrics. Second, there is a discrepancy between the domains in which outcomes are measured and conclusions are drawn. For instance, muscle power may be measured at the body function level of the International Classification of Functioning, Disease, and Health (ICF), but interpretations are often made at the activity or participation level, without clear justification for this extrapolation. Changes in muscle power may influence an individual's ability to perform specific tasks (activities) and engage in daily life and societal activities (participation), but this depends on many factors beyond muscle power alone and requires careful evaluation.

The interconnected nature of ICF health domains necessitates a comprehensive approach to assessing the effects of power training on physical functioning in older adults. In this study, we aimed to reach a consensus on a core outcome set of measurement instruments that

can be used to evaluate the effects of power training in older adults. This core outcome set should cover the function, activities, and participation domains of the ICF.

Methods

Study Design

The development of a core outcome set to measure the effects of power training in older adults was achieved using two consensus group methodologies, namely the Delphi technique for survey rounds 1 and 2, followed by an expert panel meeting using a modified Nominal Group Technique (m-NGT).[22,23] The NGT is a method for structuring expert meetings aimed at gathering information and achieving consensus on a pre-specified topic, with a specific focus on a singular objective.[22,24] In this study, adjustments were made to the manner in which experts were assigned tasks to facilitate a better evaluation and categorization of measurement instruments across the ICF domains. This is explained more thoroughly under the header titled expert panel meeting.

The study utilized a workgroup comprising five members, including two members from the research team (MeH and FM) and three clinical experts specializing in geriatric care (TE, EN, and RP). Ethical approval and participant consent for our Delphi process and expert meeting was not required based on the Dutch Medical Research Involving Human Subjects Act (WMO).

Selection of Participants

Participants were recruited within the professional networks of Vrije Universiteit Amsterdam and Hogeschool Utrecht (University of Applied Sciences Utrecht). Additional participants were enlisted by consulting established experts in the field, who recommended peers with relevant expertise. This snowball sampling method allowed for a wide spectrum of expertise across all stakeholders involved in training and treatment of older adults, ensuring a diverse and well-balanced representation of knowledge and skills. To be eligible for inclusion, participants had to have: a) a minimum of 5 years of clinical experience in physical therapy or experience conducting research related to power training, exercise physiology, sports performance, physiotherapy care, or geriatrics; and b) possession of a postgraduate degree (Master or PhD) in one of the aforementioned fields or a related discipline, and specialized in one of the areas under investigation.[25,26]

The recruitment process consisted of three phases: (1) distribution of formal written invitations to identified experts; (2) a two-week deliberation period; and (3) personalized follow-up

via email and telephone to those who had not responded. We invited 20 participants for Delphi survey rounds 1 and 2 and anticipated to receive between 12 to 16 responses.[23]

Study Procedure

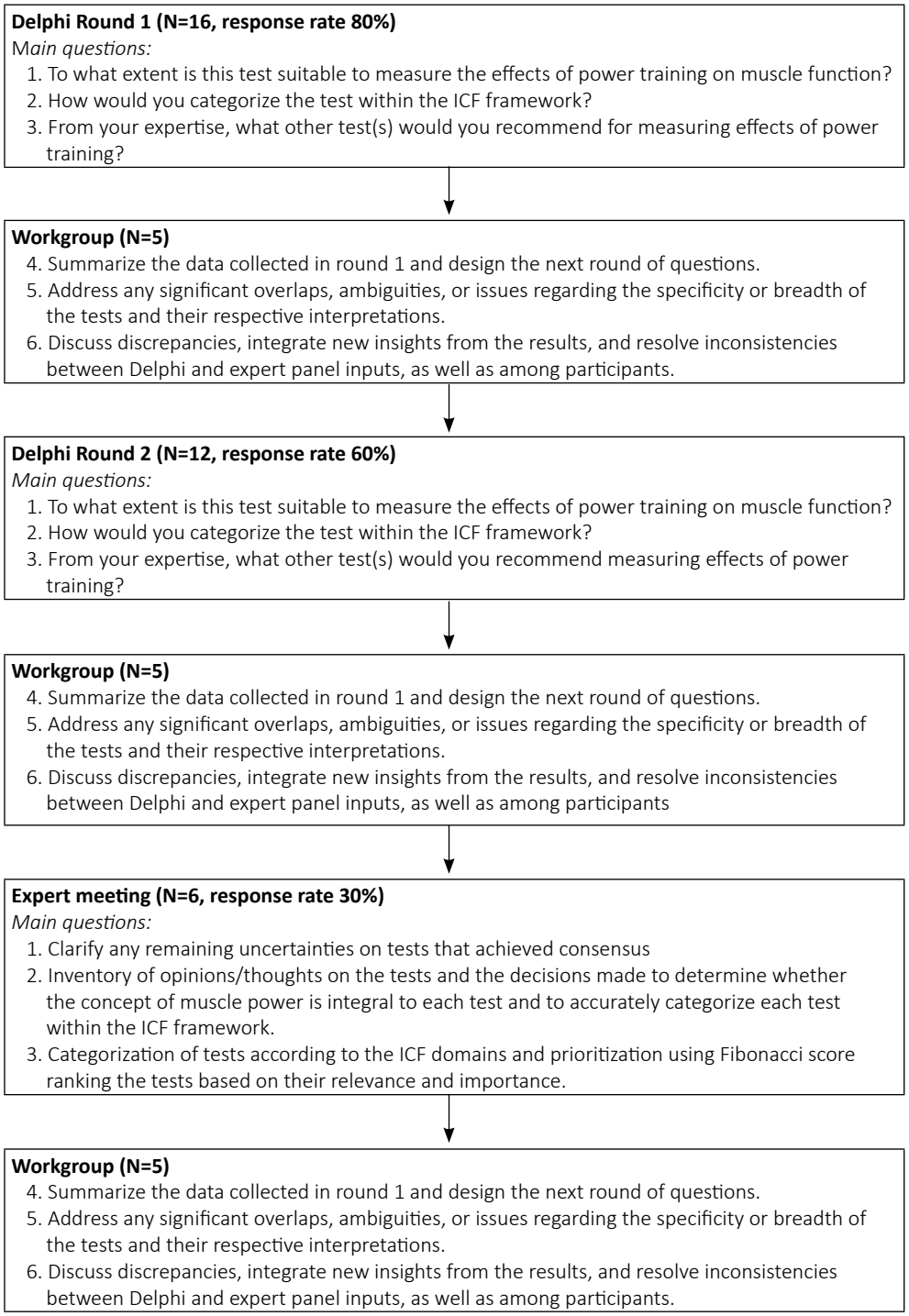
Upon accepting the invitation, study participants received an introduction letter and instructions for completing the digital Delphi survey between November 2022 and March 2023. Participants were further provided with information regarding the objective and construct of each test, the theoretical framework related to the concepts and ICF domains, and relevant terminology **(Appendix 1).** Reminder calls and emails were sent after 4 and 6 weeks if the survey had not yet been returned. The survey remained open for a total of 12 weeks to maximize the response rate, but any surveys received after this period were excluded from the analysis. This study's procedural framework is summarized in **Figure 1.**

Delphi survey rounds 1 and 2

The Delphi survey consisted of two rounds. In the first round, the starting point was formed by the 21 tests identified in a previous systematic review.[21] Participants were asked to: (a) respond to the suitability of the test for measuring the effects of power training; (b) identify which health domain of the ICF the test assessed; and (c) share any additional tests that they recommended for measuring (the effects of) power training. Following the first Delphi round, the workgroup summarized the data: tests with low levels of agreement (<60%) were excluded from further analyses; tests with uncertain levels of agreement (between 60-70%) or tests that were suggested by study participants in round 1 were carried forward to round 2 of the Delphi survey; and tests with >70% agreement were considered to have reached consensus, and were carried forward to the expert panel meeting.

The second round of the Delphi survey was structured and executed in the same manner as the first round, but more detailed explanations were provided for each test to resolve any unclarities that could have contributed to the uncertain levels of agreement. Additionally, participant were asked to which extent the tests were suitable for measuring the concept of muscle power. Following Delphi round 2, the workgroup summarized the data: tests with low levels of agreement (<60%) were excluded from further analysis, while the remainder of tests (both tests with uncertain levels of agreement (60-70%) and tests that achieved consensus (<70%) were carried forward to the expert panel meeting. In both rounds of the Delphi survey, participants had the opportunity to submit remarks to explain their choices or share any ambiguities. These remarks were used by the workgroup to improve the work process, and also influenced the selection of tests carried forward to the next round (i.e. if several participants shared their doubt regarding a certain test, this test was carried forward to the next round regardless of its level of agreement).

Figure 1: Flowchart of study procedural framework.



Expert panel meeting

All Delphi survey participants were invited to the expert panel meeting organized in June 2023. Additionally, three members of the research team (MeH, FM and TE) joined the meeting to support the process, but were explicitly instructed not to sway the participants.[23] Prior to the expert panel meeting, participants received a digital file containing a summary of the Delphi survey results, as this knowledge was the starting point for the meeting.

Following a brief introduction and explanation of the purpose of the expert panel meeting, the structure of the meeting was as follows: (a) discussion on whether each tests could measure the effect of power training, and if so, categorization of the test within the ICF domain(s); (b) arrangement of the tests into quadrants defined by two axes (ICF quadrant). In **Figure 2**, the horizontal axis represents the health domain of the ICF, while the vertical axis differentiates the activities domain in terms of capacity and performance; and (3) prioritization of tests within ICF quadrants using a Fibonacci Scoring principle. [24] To identify the most important tests for measuring the effects of power training, each participant independently assigned Fibonacci scores (choosing from the following values: 1, 2, 3, 5, 8, 13, 21, 34 and 55) to a test based on: (1) the test's ability to measure the concept muscle power; (2) the test's feasibility for use in clinical practice; and (3) the test's feasibility in older adults. If tests received equal scores, the workgroup selected the test that was least burdensome.

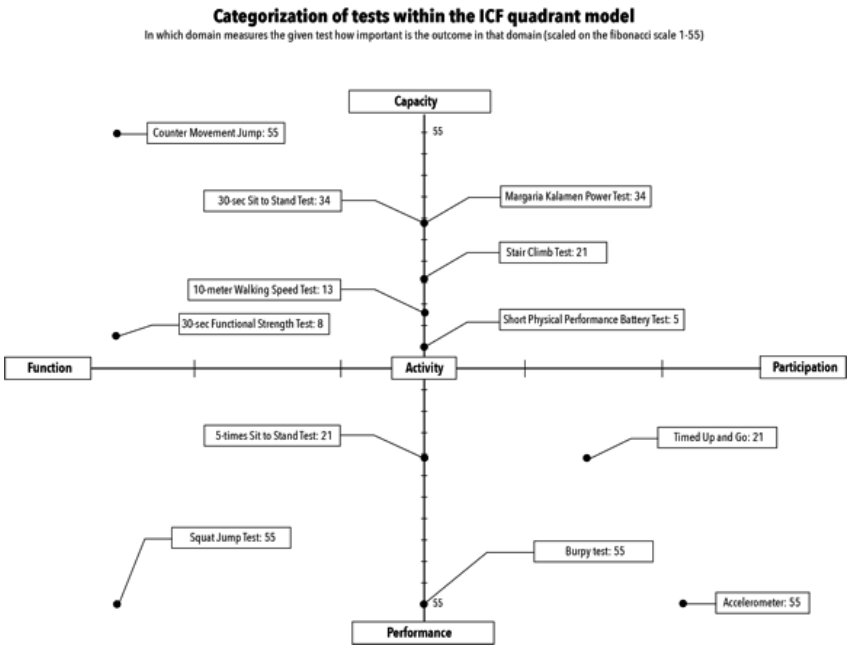


Figure 2: Allocation of the tests within the ICF quadrant model.

Results

Study Participants

Of the 20 invited experts, 16 (80% response rate) responded to the first round of the Delphi survey and 12 (75% response rate compared to round 1) responded to the second round of the Delphi survey. These participants included academics (n=4), sports physiotherapists (n=4), geriatric physiotherapists (n=4), exercise scientists (n=2), and clinical exercise physiologists (n=2). The four participants who dropped out of the study following the first survey round did so due to limited availability. The names of all 16 panel members are mentioned in the acknowledgements section, and participant characteristics are summarized in **Table 1.**

Table 1: Participant characteristics (N=16).

Characteristics	N (%)
Gender, male	8 (50%)
Education	
PhD or PhD candidate	8 (50%)
MSc	8 (50%)
Healthcare providers (sport and geriatric physiotherapist)	7 (44%)
Combination of research, lecture and clinical practice	9 (56%)
Occupation at the time of the study	
Academic	4 (25%)
Sports physiotherapist	4 (25%)
Geriatric physiotherapist	4 (25%)
Exercise scientist	2 (13%)
Clinical exercise physiologist	2 (13%)

Delphi Survey Round 1

Of the 21 tests included in the first round of the Delphi survey, nine tests reached consensus (agreement level >70%), three tests had uncertain agreement scores (60-70%), and the remaining nine tests had low agreement scores (<60%) regarding their suitability for measuring the effects of power training **(Table 2).** The nine tests that reached consensus were classified within the activities domain of the ICF. A complete overview of agreement scores per test can be found in **Appendix 2 and Appendix 3.**

A total of eight tests were carried over to the second round of the Delphi survey, which consisted of the three tests with uncertain agreement scores (the Stair Climb Test, 30-sec Functional Strength Test, and 400-meter Walking Test) and an additional four tests submitted by participants in Delphi survey round 1 (Burpee Test, GymAware Linear Positional Transducer, Margaria-Kalamen Power Test, and daily-life accelerometry). Additionally, some participants

Table 2: Delphi survey round 1.

	Test	Agreement on the suitability of the test for measuring the effects of power training	Extent of agreement across ICF domains	Consensus achieved ?
1	5-times Sit to Stand Test	**100%**	Function: 6% **Activity: 94%** Participation : 0	**YES**
2	30-sec Sit to Stand Test	**94%**	Function: 6% **Activity: 94%** Participation: 0%	**YES**
3	Timed Up and Go Test/8Foot Up and Go Test	**94%**	Function: 0% **Activity: 94%** Participation: 6%	**YES**
4	Squat Jump Test	**81%**	Function: 25% **Activity: 75%** Participation: 0%	**YES**
5	Counter Movement Jump	**81%**	Function: 31% **Activity: 69%** Participation: 0%	**YES**
6	10-meter Walking Speed Test	**75%**	Function: 0% **Activity: 100%** Participation: 0%	**YES**
7	Medicine Ball Thow Test	**70%**	Function: 12% **Activity: 88%** Participation: 0%	**YES**
8	Short Physical Performance Battery Test	**70%**	Function: 0% **Activity: 100%** Participation: 0%	**YES**
9	Wingate Test	**70%**	Function: 25% **Activity: 75%** Participation: 0%	**YES**
10	Stair Climb Test	**69%**	Function: 6% **Activity: 82%** Participation: 12%	**UNCERTAIN**

Continues on next page

Table 2: *Continued*

11	30-sec Functional Strength Test	**63%**	**Function: 63%** Activity: 37% Participation: 0%	**UNCERTAIN**
12	400-meter Walking Test	**60%**	Function: 0% **Activity: 88%** Participation: 12%	**UNCERTAIN**
13	The Four Square Step Test	**59%**	Function: 0% **Activity: 94%** Participation: 6%	**NO**
14	1-RM Test	**56%**	**Function: 88%** Activity: 12% Participation: 0	**NO**
15	Isokinetic Dynamometer	**56%**	**Function : 100%** Activity: 0% Participation: 0%	**NO**
16	Continuous Scale Physical Functional Performance Test	**50%**	Function: 0% **Activity: 88%** Participation: 12%	**NO**
17	Sit to Rise Test	**50%**	Function: 0% **Activity: 88%** Participation: 12%	**NO, BUT NEEDS DISCUSSION**
18	6-min Walk Test	**38%**	Function: 0% **Activity: 88%** Participation: 12%	**NO**
19	6- &10-meter Timed Walk Test	**38%**	Function: 6% **Activity: 88%** Participation: 6%	**NO**
20	Functional Gait Assessment	**38%**	Function: 0% **Activity: 88%** Participation: 12%	**NO**
21	Timed Balance Test	**31%**	Function: 12% **Activity: 81%** Participation: 6%	**NO**

expressed doubts regarding the use of the Sit to Rise test. Despite a clear description of the test in the survey, different interpretations had led to questions surrounding the test's ability to measure muscle power. To clear any ambiguities among respondents, the Sit to Rise test was also included in the second round of the Delphi survey.

Delphi Survey Round 2

Of the eight tests included in round 2 of the Delphi survey, five tests reached consensus (agreement level >70%) and three tests had low agreement (<60%) regarding their suitability for measuring the effects of power training **(Table 3)**. One of the tests with low agreement, accelerometry, received several remarks by participants. The ability of the accelerometer to measure a wide range of physical activities and movements patterns led to confusion regarding its consistent use and application. To clarify its use among participants, this test was carried forward to the expert panel meeting. A complete overview of agreement scores per test can be found in **Appendix 4 and 5**.

After two Delphi survey rounds, a total of 15 tests was identified and carried over to the expert panel meeting, of which 14 tests achieved consensus regarding their ability to measure the effects of power training **(Table 4)**.

Expert Panel Meeting

Of the sixteen invited study participants, six attended the expert panel meeting (response rate: 37.5%). Attendees were sports physiotherapists (n=2), geriatric physiotherapists (n=2), academic (n=1), and a clinical exercise physiologists (n=1). In addition, three workgroup members (MeH, FM and TE) joined to support the process.

During group deliberations, the panel of experts reached a consensus on 11 tests regarding their ability to measure the effects of power training in older adults. The remaining four tests (accelerometry, GymAware Linear Power Transducer, Medicine Ball Throw, and the Wingate test) were excluded for various reasons. The accelerometer and the GymAware Linear Power Transducer were considered measurement tools intended to measure physical activity, and unlike performance evaluations that directly gauge physical capabilities through structured challenges, they collect data on movement patterns. They thus provide insight into the intensity and duration of activities rather than being standalone tests. The Medicine Ball Throw test was not ideally suited for assessing the effects of power training in older adults as this test requires a certain level of coordination and motor skills, which may not align with age-related declines in motor control and coordination. Also, the Medicine Ball Throw Test does not reflect daily physical activities commonly engaged in by most older adults. The Wingate test, while effective for measuring anaerobic capacity, was considered to be less suitable for

Table 3: Delphi survey round 2.

#	Test	Suitability of the test for measuring the effects of power training			Suitability of the test for measuring the concept muscle power		
		Agreement, %	Extent of agreement across ICF domains	Consensus achieved?	Agreement, %	Extent of agreement on "speed" across ICF domains	Consensus achieved?
1	GymAware Linear Position Transducer	100%	**Function: 50%** **Activity: 50%** Participation: 0%	**YES**	**100%**	Power: 33% Activity emphasizing speed: 42%	**YES**
2	Margaria Kalamen Power Test	100%	Function: 8% **Activity: 92%** Participation: 0%	**YES**	**92%**	Power: 8% Activity emphasizing	**YES**
3	30-sec Functional Strength Test	91%	**Function: 75%** Activity: 25% Participation: 0%	**YES**	**73%**	speed: 58% Power: 58%	**YES**
4	Burpee Test	75%	Function: 0% **Activity: 100%** Participation: 0%	**YES**	67%	Activity emphasizing speed: 8%	**UNCERTAIN**
5	Stair Climb Test	75%	Function: 0% **Activity: 100%** Participation: 0%	**YES**	58%	Power 0% Activity emphasizing speed: 75%	**UNCERTAIN**
6	Sit to Rise Test	58%	Function: 8% **Activity: 84%** Participation: 8%	NO	17%	Power: 8% Activity emphasizing	NO
7	400-meter Walk Test	42%	Function: 8% **Activity: 92%** Participation: 0%	NO	8%	speed: 50% Power: 8%	NO
8	Accelerometry	33%	Function: 16% **Activity: 42%** **Participation: 42%**	NO, BUT NEEDS DISCUSSION	33%	Activity emphasizing speed: 8% Power: 8%	NO

assessing muscle power in older adults as it requires maximal effort, is demanding, and can be potentially dangerous for older individuals with age-related physical limitations. The test's focus on brief, high-intensity performance does not reflect the sustained, moderate-intensity muscle power needed for performing activities of daily life, making it less appropriate for older adults.

The 11 tests for which consensus was reached were categorized into the ICF quadrant model **(Figure 2).** The Counter Movement Jump and Squat Jump were categorized under the function domain, both receiving a score of 55 on the Fibonacci scale. The remaining tests were categorized within the activity or participation domain, and further classified into sub-domains based on whether they focused on generic capacity or capacity with an emphasis on speed. The highest scoring tests were the Timed Up-and Go-Test and the Margaria Kalamen Power Test with 34 points each, and the Stair Climb Test, and 30-seconds Sit-to-Stand with 21 points each, and; the 5-times Sit-to-Stand and 10-meter Walking Speed Test scored 13 points each. Participants agreed that the Counter Movement Jump, the Squat Jump Test, 10-meter Walking Speed Test, and the Stair Climb Test were specific for measuring muscle power.

Following group deliberations, agreement was reached that the Countermovement Jump and the Squat Jump Test should be used with the GymAware LPT measurement tool for measuring muscle power output at the function level. Since these tests scored equally on the Fibonacci scale, the workgroup selected the Squat Jump Test for the function domain based on its practicality and lower burden on older adults. Additionally, it was agreed that the 30-sec Functional Strength Test primarily measures muscle strength at the functional level rather than muscle power. Given that the core outcome set is focused on assessments of power, the 30-sec Functional Strength Test was excluded. At the activity level, there was consensus that the Timed Up-and-Go, Margaria Kalamen Power Test, Burpee Test, and the 5-times Sit to Stand measure capacity with an emphasis on speed, while the 30-sec Sit to Stand focuses on general capacity, and therefore, was excluded. The Timed Up-and-Go and Margaria Kalamen Power Test received equal scores, however, the workgroup chose the Timed Up-and-Go for its feasibility in an older population. No definitive test or measurement instruments could be agreed upon for the participation domain. However, it was decided that daily-life accelerometry could be used to map activity patterns at the participation level. Its effectiveness in assessing the impacts of power training remains uncertain. It primarily tracks general physical activity while giving insights into intensity and duration. Yet, if coupled with an appropriate relevant outcome, daily-life accelerometry could provide important insights with regard to the participation domain. The proposed COS to measure the effects of power training in older adults is summarized in **Table 5.**

Table 4: Tests identified following two Delphi survey rounds.

	Test
1	Short Physical Performance Battery Test
2	30-sec Sit to Stand Test
3	5-times Sit to Stand Test
4	Counter Movement Jump
5	Medicine Ball Thow Test
6	Timed Up and Go /8-Foot Up and Go Test
7	Squat Jump Test
8	Wingate Test
9	10-meter Walking Speed Test
10	Stair Climb Test
11	30-sec Functional Strength Test
12	GymAware Linear Position Transducer
13	Burpee Test
14	Margaria Kalamen Power Test
15	Daily-life accelerometry

Table 5: Core outcome set for measuring the effects of power training in older adults.

ICF health domain	Test
Function	Squat Jump Test
Activities	Timed Up and Go Test
Participation	Daily-life accelerometry

Discussion

Summary of Main Results

This study aimed to achieve consensus on a core outcome set of tests to measure the effects of power training in older adults that covered the function, activities, and participation domain of the ICF. Our methods consisted of a two-round Delphi survey and expert panel meeting (m-NGT). The final core outcome set consisted of the Squat Jump Test for the function domain and the Timed Up-and-Go Test for the activities domain. These tests were selected according their ability to measure power output and related activities, making them particularly well-suited for assessing the effects of power training. There were no tests identified that were suitable for assessing the participation domain of the ICF. However, based on the discussion in the expert panel, the use of daily-life accelerometry was suggested as a preliminary instrument, given the lack of feasible alternatives for assessing outcomes within the participation domain.

An accelerometer is not a specific test, but a device that can be used to measure various activities, causing the accelerometer to reflect the ICF domain of the test it is paired with. Therefore, the relevance of an accelerometer for measuring muscle power or speed depends on the specific activities assessed. If an accelerometer is used to monitor daily activities (i.e. daily life accelerometry), this could be relevant for measuring the effects of power training within the participation domain. Additionally, if an accelerometer is used to estimate power output or speed of performing certain activities, like rising from a chair, it may be particularly well-suited for assessing the effects of power training.[31]

Comparison with Previous Studies

Current literature demonstrates a trend of assessing power training impacts primarily at the body function level, focusing on aspects such as capacity and activation of specific muscles, while neglecting the broader implications for activity performance and participation in daily life.[32,33] Instead, evaluating the effects of power training and measuring physical functioning in older adults calls for a multifaceted approach.[34,35] For instance, Alcazar et al. (2018) highlighted the importance of assessing various performance elements to thoroughly evaluate power training effectiveness in older individuals,[36] and Zhang et al. (2024) emphasized the need for ICF-based functional assessment tools specifically tailored for older adults.[37] Our study directly addresses this gap by providing a core set of tests categorized within the ICF framework specifically targeted at evaluating power training effects. Our approach is also in line with O'Neill et al.'s (2020) advocacy of a comprehensive test battery to assess physical function as a clinical outcome,[38] and is consistent with other studies emphasizing muscle strength, physical performance and functional outcomes in older adults participating in power-based training interventions.[36,39,40]

The lack of standardized outcome measures has been a key limitation in previous research, leading to inconsistencies across studies. Byrne et al. (2016) noted significant variability in outcome measures used in power training studies, making meta-analyses challenging.[40] Establishing a core outcome set, as proposed by this study, directly addresses this issue by taking a crucial step towards standardization in this field. While previous research has focused primarily on narrow outcome sets, our research incorporates a broader range of ICF domains that aligns with calls for more holistic assessments in geriatric research.[41]

Our approach to developing a core outcome set for power training in older adults aligns with and builds upon established methodologies in the field. Williamson et al. (2012) outlined key considerations for developing core outcome sets, emphasizing the importance of stakeholder involvement and consensus-building processes.[42] We adhered to these principles through the use of a Delphi survey and modified Nominal Group Technique (m-NGT), ensuring diverse

expert input and systematic consensus development. Similarly, our methodology resonates with the OMERACT filter 2.0 framework proposed by Boers et al. (2014).[43] This framework emphasizes the need for core outcome sets to be valid and feasible, which aligns with our strategy of categorizing tests across different ICF domains and utilizing a workgroup to assess practical feasibility of the tests in measuring the effects of power training in older adults.[21]

Prinsen et al. (2016) provided guidelines for selecting outcome measurement instruments for core outcome sets.[44] Our study's process of expert consensus aligns with their recommendation for a systematic approach to instrument selection. However, while Prinsen et al. suggest a two-step approach of first defining core outcome domains and then selecting measurement instruments, our study combined these steps in a single consensus process. This modification was made to streamline the process and ensure that selected outcomes were immediately linked to feasible measurement tools.

Strengths and Limitations

This study's primary strength lies in its methodological rigor, particularly in achieving consensus among a diverse group of experts. The utilization of Delphi and modified Nominal Group Technique (m-NGT) methods ensured a comprehensive and systematic input, aligning with best practices in consensus-building research. This approach minimized individual bias and enhanced the applicability of the identified core outcome sets. The involvement of a working group and collaboration with geriatric physiotherapists further ensured systematic classification and practical relevance of the selected tests for the older adult population.

However, several limitations warrant consideration. Despite efforts to include diverse expertise, potential selection bias in expert participation may have influenced outcome prioritization. The lower response rate for the expert panel meeting compared to the Delphi survey rounds could have impacted the final consensus. Another limitation of this study is its emphasis on performance-based measures, which may not fully reflect the subjective experiences of older adults undergoing power training. This gap underscores the need for further research to combine both objective performance measures and subjective patient experiences, offering a more comprehensive evaluation of the effects of power training in older adults. Future research should also focus on validating these core outcome sets in diverse populations and settings to ensure broad applicability and to address the identified limitations. Additionally, rapid advancement of assessment technologies may necessitate periodic updates to the core outcome set, potentially affecting the long-term consistency and comparability of research.

Clinical Implications and Future Research

By incorporating instruments that cover the health domains of the ICF, this study proposes a comprehensive evaluation of the impact of power training on the physical functioning of older adults. The establishment of a COS paves the way for more consistent and comparable research and facilitates evidence-based practices. This not only enhances the comparability of studies but also contributes to the cumulative knowledge in the field of power training and its broader implications for physical function in older adults. Clinicians, researchers, and practitioners can benefit from a clear framework for evaluating the effectiveness of power training interventions, leading to more comparable and transferable results across studies. This standardization will also facilitate meta-analyses and systematic reviews, contributing to a more robust evidence base for best practices in power training for older adults.

Future research should focus on validating these core outcome sets in diverse populations and settings to ensure their broad applicability. Exploring the integration of new and emerging measurement technologies could further enhance the assessment of power training effects. Additionally, investigating implementation challenges and opportunities associated with adopting these standardized outcomes in clinical and research settings will be crucial for their successful integration into practice.

Conclusions

This study established a consensus-based COS for measuring the effects of power training in older adults. The selected measures, aligned with ICF domains, include the Squat Jump test and the Timed Up-and-Go Test for the function and activities domain, respectively. For the participation domain, experts propose using daily-life accelerometry until more suitable outcome measures have been defined and validated.

This comprehensive framework reflects a multifaceted approach to evaluating the impact of power training interventions in older adults. Through standardization, this COS has the potential to significantly improve the quality, comparability, and clinical relevance of future research. Ultimately, this advancement may lead to more robust evidence-based practices, informing clinical decisions and public health strategies aimed at enhancing the functional capacity and well-being of older adults through power training interventions.

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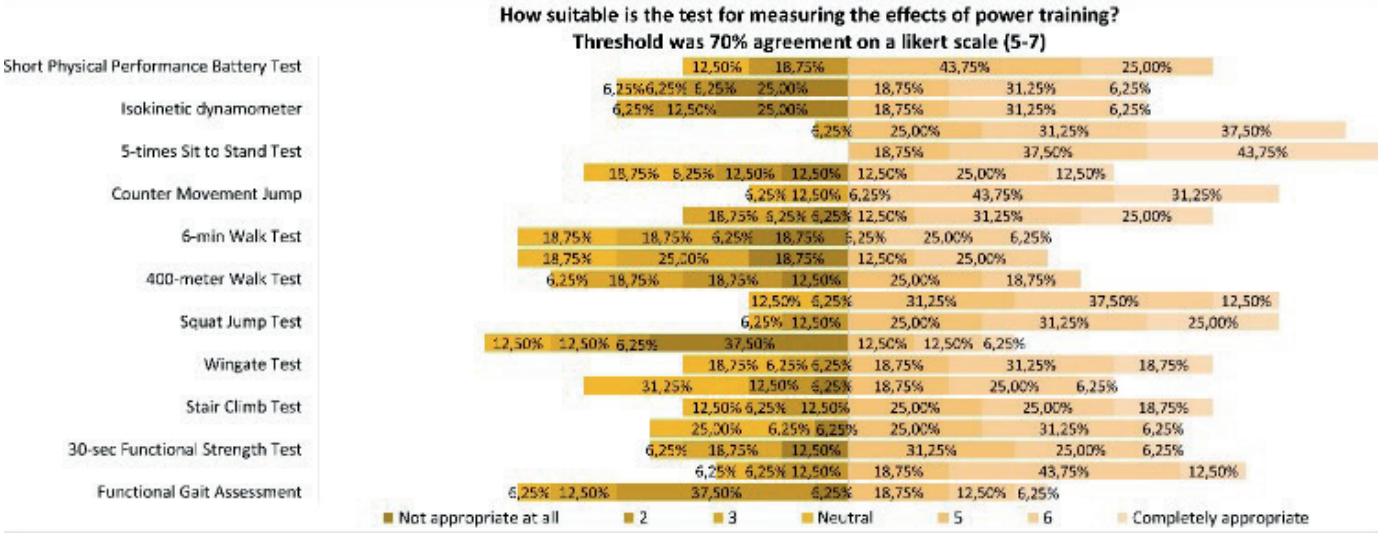
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Appendix 1: Theoretical framework and definitions

Concept	Definition
Core area	An aspect of health or a health condition that needs to be measured to appropriately assess the effects of a health intervention. Core areas are broad concepts consisting of a number of more specific concepts called domains.[43,45,46]
Domain or subdomain	A concept to be measured, a further specification of an aspect of health, categorized within a core area.[43,45,46]
Outcome	Any identified result in a (sub)domain arising from exposure to a causal factor or a health intervention measurement.[43,45,46]
Measurement instrument	A tool to measure a quality or quantity of a variable, in this context a (sub)domain or a contextual factor.[43,45,46]
Core outcome measurement set	The minimum set of outcome measurement instruments that must be administered in each intervention study for a certain health condition within a specified setting to adequately cover a corresponding core domain set; it describes how to measure.[43,45,46]
Activities	The 'activities' component, along with participation, is the core construct of disability and functioning. It is viewed as the outcome of interactions between body impairments resulting from health conditions (diseases, disorders, and injuries) and contextual factors. In this study, the focus lies on the two different constructs covered by the 'activities' component of the ICF, namely performance and capacity.[3]
Physical activity	Physical activity is defined as any bodily movement produced by skeletal muscles that requires energy expenditure. It is behavior that encompasses all forms of activity, including walking and cycling.[3]
Physical fitness	Physical fitness is one's ability to execute daily activities with optimal performance, endurance, and strength with the management of disease, fatigue, and stress and reduced sedentary behavior. Fitness also falls into two major categories—one related to health and the other to the abilityto perform a task or sport. to perform a task or sport.
Muscle power	Muscle power is the product of force produced by the muscle and its shortening velocity, which reflects the ability of the muscles to produce force at high velocity.[47]

Appendix 2: Response to whether each test was suitable for measuing the effect of power training in Delphi survey round 1



Appendix 3: Detailed response to Delphi survey round 1

#	Test	ICF domain	N (%)	ICF domain subtype	N (%)	If capacity, further specification of capacity type	N (%)
1	**Short Physical Performance Battery Test**	Activity	16 (100%)	Performance	1 (6%)		
				Capacity	15 (94%)	Generic capacity	9 (60%)
						Capacity with emphasis on speed	6 (40%)
2	**1-RM Test**	Function	14 (88%)	Strength	12 (86%)		
				Power	2 (14%)		
		Activity	2 (12%)	Capacity	2 (100%)	Generic capacity	2 (100%)
						Capacity with emphasis on speed	0 (0%)
3	**Isokinetic dynamometer**	Function	16 (100%)	Strength	15 (94%)		
				Power	1 (6%)		
4	**30-sec Sit to Stand Test**	Function	1 (6%)	Power	1 (100%)		
		Activity	15 (94%)	Performance	1 (7%)		
				Capacity	14 (93%)	Generic capacity	3 (21%)
						Capacity with emphasis on speed	11 (79%)
5	**5-times Sit to Stand Test**	Function	1 (6%)	Power	1 (100%)		
		Activity	15 (94%)	Performance	1 (7%)		
				Capacity	14 (93%)	Generic capacity	3 (21%)
						Capacity with emphasis on speed	11 (79%)
6	**Continuous Scale Physical Functional Performance Test**	Activity	14 (88%)	Performance	5 (36%)		
				Capacity	9 (64%)	Generic capacity	5 (56%)
						Capacity with emphasis on speed	4 (44%)
		Participation	2 (12%)				

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Appendix 3: *Continued*

	Test	ICF domain	N (%)	ICF domain subtype	N (%)	If capacity, further specification of capacity type	N (%)
7	**Counter Movement Jump**	Function Activity	5 (31%) 11 (69%)	Power Performance Capacity	1 (100%) 2 (18%) 9 (82%)	 Generic capacity Capacity with emphasis on speed	 7 (78%) 2 (22%)
8	**Medicine Ball Throw test**	Function Activity	2 (12%) 14 (88%)	Power Performance Capacity	1 (100%) 3 (21%) 11 (79%)	 Generic capacity Capacity with emphasis on speed	 9 (82%) 2 (18%)
9	**6-min Walk Test**	Activity Participation	14 (88%) 2 (12%)	Performance Capacity	3 (21%) 11 (79%)	 Generic capacity Capacity with emphasis on speed	 6 (55%) 5 (45%)
10	**6- &10-Meter Timed Walk Test**	Function Activity Participation	1 (6%) 14 (88%) 1 (6%)	Power Performance Capacity	1 (100%) 7 (50%) 7 (50%)	 Generic capacity Capacity with emphasis on speed	 4 (57%) 3 (43%)
11	**400-meter Walk Test**	Activity Participation	14 (88%) 2 (12%)	Performance Capacity	3 (27%) 11 (73%)	 Generic capacity Capacity with emphasis on speed	 6 (55%) 5 (45%)

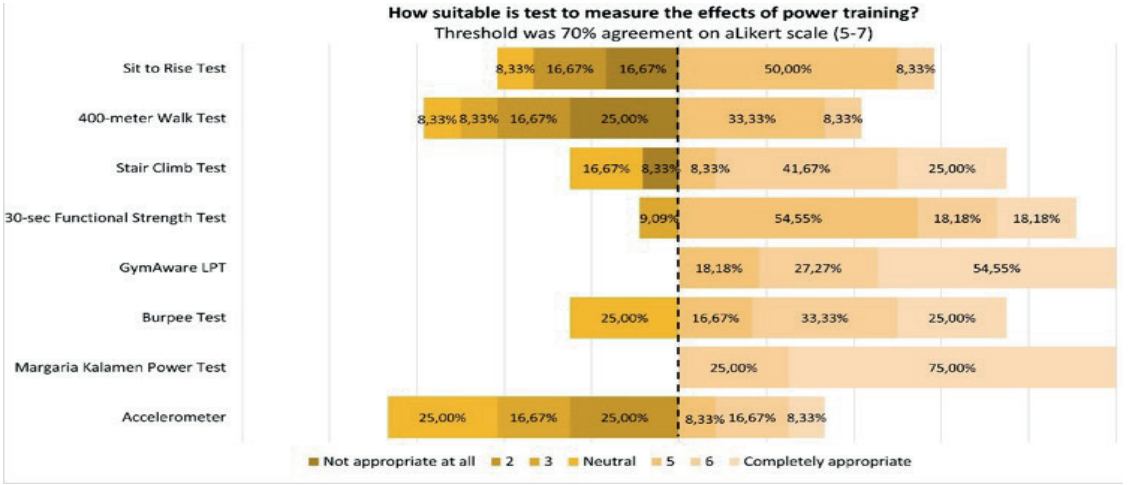
12	**Timed Up and Go /8-foot Up and Go Test**	Activity Participation	15 (94%) 1 (6%)	Performance Capacity	4 (21%) 11 (79%)	 Generic capacity Capacity with emphasis on speed	 0 11 (100%)
13	**Squat Jump Test**	Function Activity	4 (25%) 12 (75%)	Power Performance Capacity	1 (100%) 1 (8%) 11 (92%)	 Generic capacity Capacity with emphasis on speed	 7 (64%) 4 (36%)
14	**Timed Balance Test**	Function Activity Participation	2 (12%) 13 (81%) 1 (6%)	Power Performance Capacity	1 (100%) 0 (0%) 13 (100%)	 Generic capacity Capacity with emphasis on speed	 13 (100%) 0 (0%)
15	**Wingate Test**	Function Activity	4 (25%) 12 (75%)	Power Performance Capacity	1 (100%) 2 (17%) 10 (83%)	 Generic capacity Capacity with emphasis on speed	 2 (20%) 8 (80%)
16	**Sit To Rise Test**	Activity Participation	14 (88%) 2 (12%)	Performance Capacity	4 (27%) 10 (73%)	 Generic capacity Capacity with emphasis on speed	 10 (100%) 0

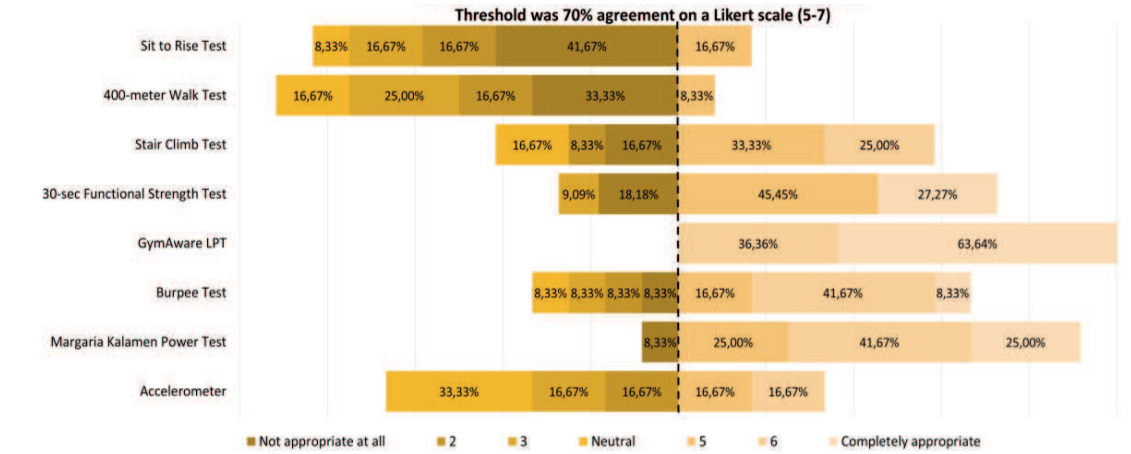
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Appendix 3: *Continued*

	Test	ICF domain	N (%)	ICF domain subtype	N (%)	If capacity, further specification of capacity type	N (%)
17	**Stair Climb Test**	Function	1 (6%)	Power	1 (100%)		
		Activity	13 (81%)	Performance	3 (23%)		
				Capacity	10 (77%)	Generic capacity	5 (50%)
						Capacity with emphasis on speed	5 (50%)
		Participation	2 (12%)				
18	**The Four Square Step Test**	Activity	15 (94%)	Performance	3 (20%)		
				Capacity	12 (80%)	Generic capacity	1 (8%)
						Capacity with emphasis on speed	11 (92%)
		Participation	1 (6%)				
19	**30-sec Functional Strength Test**	Function	10 (63%)	Power	4 (40%)		
				Endurance	6 (60%)		
		Activity	6 (37%)	Performance	1 (17%)		
				Capacity	5 (83%)	Generic capacity	3 (60%)
						Capacity with emphasis on speed	2 (40%)
20	**10-meter Walking Speed Test**	Activity	16 (100%)	Performance	4 (25%)		
				Capacity	12 (75%)	Generic capacity	0 (0%)
						Capacity with emphasis on speed	12 (100%)
21	**Functional Gait Assessment**	Activity	14 (88%)	Performance	2 (14%)		
				Capacity	12 (86%)	Generic capacity	10 (83%)
						Capacity with emphasis on speed	2 (17%)
		Participation	2 (12%)				

Appendix 4: Response to whether test was suitable to measure the effects of power training and to measure the concept of muscle power in Delphi survey round 2





Appendix 5: Detailed response to Delphi survey round 2

#	Test	ICF domain	N (%)	ICF domain subtype	N (%)	If capacity, further specification of capacity type	N (%)
1	**Sit to Rise Test**	Function	1 (8%)	Power	1 (100%)		
		Activity	10 (84%)	Performance	2 (20%)		
				Capacity	8 (80%)	Generic capacity	7 (88%)
						Capacity with emphasis on speed	1 (12%)
		Participation	1 (8%)				
2	**400m Walk Test**	Function	1 (8%)	Power	1 (100%)		
		Activity	11 (92%)	Performance	0 (0%)		
				Capacity	11 (100%)	Generic capacity	6 (55%)
						Capacity with emphasis on speed	5 (45%)
3	**Stair Climb Test**	Activity	12 (100%)	Performance	5 (42%)		
				Capacity	7 (58%)	Generic capacity	1 (14%)
						Capacity with emphasis on speed	6 (86%)
4	**30-sec Functional Strength Test**	Function	9 (75%)	Power	7 (78%)		
				Endurance	2 (22%)		
		Activity	3 (25%)	Performance	0 (0%)		
				Capacity	3 (100%)	Generic capacity	2 (67%)
						Capacity with emphasis on speed	1 (33%)
5	**Gymaware LPT**	Function	6 (50%)	Power	4 (67%)		
				Endurance	2 (33%)		
		Activity	6 (50%)	Performance	0 (0%)		
				Capacity	6 (100%)	Generic capacity	1 (17%)
						Capacity with emphasis on speed	5 (83%)
6	**Burpee Test**	Activity	12 (100%)	Performance	2 (17%)		
				Capacity	10 (83%)	Generic capacity	1 (10%)
						Capacity with emphasis on speed	9 (90%)

7	**Margaria Kalamen Power Test**	Function Activity	1 (8%) 11 (92%)	Power Performance Capacity	1 (100%) 4 (36%) 7 (64%)	 Generic capacity Capacity with emphasis on speed	 0 (0%) 7(100%)
8	**Accelerometery**	Function Activity Participation	2 (16%) 5 (42%) 5 (42%)	Power Performance Capacity	2 (100%) 5 (100%) 0 (0%)		

Part 2

"From Theory to Practice:
Evaluating of Effects and Clinical Applicability of Power Training in Older Adults"

5

Effectiveness of Power Training Compared to Strength Training in Older Adults: a Systematic Review and Meta-analysis

Eur Rev Aging Phys Act. 2022 Aug; 19(1): 18

Mohamed el Hadouchi
Henri Kiers
Ralph de Vries
Cindy Veenhof
Jaap van Dieen

Abstract

Background: Research suggests that muscle power is a more critical determinant of physical functioning in older adults than muscle strength. The objective of this study was to systematically review the literature on the effect of power training compared to strength training in older adults on tests for muscle power, two groups of activity-based tests under controlled conditions: generic tests and tests with an emphasis on movement speed, and finally, physical activity level in daily life.

Methods: A systematic search for randomized clinical trials comparing effects of power training to strength training in older adults was performed in PubMed, Embase, Ebsco/CINAHL, Ebsco/SPORTDiscus, Wiley/Cochrane Library and Scopus. Risk of bias was assessed using the Cochrane Collaboration Tool, and quality of evidence was evaluated using GRADEpro Guideline Development Tool. Standardized mean differenence (SMD) and 95% confidence intervals (CI) were calculated for outcomes separately using a random effects model.

Results: Fifteen trials and 583 participants were included in the meta-analysis. Results indicated a statistically significant benefit of power training on all reported outcomes (muscle power SMD: 0.99, 95% CI: 0.54 to 1.44, $p<0.001$; generic activity-based tests SMD: 0.37, 95% CI 0.06 to 0.68; $p=0.02$, activity-based tests emphasizing movement speed SMD: 0.43, 95% CI 0.23 to 0.62, $p<0.001$). None of the included studies used physical activity level in daily life as outcome.

Conclusions: Power training offers more potential for improving muscle power and performance on activity tests in older adults than strength training. Future research should assess exercise parameters for power training in older adults. In addition, the validity and reliability of the tests used must be evaluated to establish a standardized test protocol. This protocol should also include measurements of physical activity in daily life.

Keywords: muscle power, muscle strength, activity tests.

Introduction

The ageing process is characterized by the degeneration of various physiological systems, including the neuromuscular system, which may lead to a loss of muscle strength (the ability to produce large muscle force) and muscle power (the ability to produce a large muscle force at high contraction velocity).[1-3] This decline may cause daily tasks, such as getting up from a chair or climbing stairs, more difficult to perform, often resulting in a loss of independence. Intervention studies have indicated that both strength and power training can improve functional capacity in older adults, consequently improving their ability to maintain independence.[4-9]

Several studies have revealed that the annual decline in muscle power is larger than the annual decline in muscle strength in older adults.[10–16] The actual percentages of annual decline in muscle power and muscle strength varied between studies and were largely dependent on age and sex. However, the conclusion that muscle power declined more rapidly than muscle strength was consistent. Furthermore, in daily activities, such as getting up from a chair, the ability to move with a sufficiently large speed (emphasizing muscle power) is more often the limitating factor than the ability to produce a sufficiently large moment.[10,17] These findings signify the potential importance of emphasizing muscle power in the training and rehabilitation of older adults instead of focusing on strength.[6]

Several studies have shown that training specifically aimed at increasing muscle power can improve the ability to generate high power output even in older adults. [7,17,18] Power training consequently also improved physical functioning in daily life. The effects appeared even larger than after strength training and endurance training.[3,4,7–9,17–19] Two reviews have systematically evaluated the effect of power training in older adults,[8,19] but methodological limitations, namely high hetereogeneity between studies, limited search strategy, variation in outcomes measures, variation in the exercise methods, and non-specific definitions of power training influenced the comparison of power training against strength training.

The aim of this study was to systematically review the literature on the effect of power training compared to strength training in older adults with muscle power, activity based tests, and physical activity level in daily life as outcomes.

Methods

Protocol and Registration

The present study was developed in according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[20] and was registered in the International Prospective Register of Systematic Reviews (PROSPERO 2021: CRD42020167877).

Data Sources and Search Strategy

This review included randomized controlled trials (RCT) that compared a power training intervention with a strength training intervention in older adults. A comprehensive search was performed in collaboration with a medical librarian using the bibliographic databases PubMed, Embase, Ebsco/CINAHL, Ebsco/SPORTDiscus, Wiley/Cochrane Library and Scopus up until 18 September 2020. The search strategy combined thesaurus terms and free texts words. The PubMed search string **(Appendix 1)** was constructed first and used as a template for the other databases. All references from the selected articles were checked to identify additional relevant articles that were missed in the systematic search. To minimize publication bias, an additional search for grey literature was performed in the open access thesis and dissertation database and the World Health Organization (WHO) international clinical trials registry platform using the search terms “power training”, “physical performance” and “elderly”.

Study Selection

The study selection was performed independently by two co-authors (HK and MeH) in two stages, and regular meetings were organised to form consensus in the selection and scoring of studies within each stage. In the first stage, all abstracts from the systematic search were preliminarily screened on eligibility criteria using the online application ’Rayyan’.[21] In the second stage, full text articles were read to ensure that the selected studies met eligibility criteria.

RCTs comparing a power training group with a strength training group were included if they met the following eligibility criteria: (a) the study population consisted of older adults (mean age >65 years) recruited from a healthy population, regardless of their level of physical functioning. Healthy was defined according to the WHO definition for health, in which individuals can be considered healthy despite the presence of (chronic) disease [22]; (b) the intervention was power training. This was assessed in two ways: (1) the authors defined their intervention as power training; or (2) the intervention met the definition of muscle power training proposed by Haff and colleagues: [23] “an intervention primarily aimed at muscle power, movement speed or rate of force development”; (c) the study included outcome measures for

muscle power, activity based tests, or a measure for physical functioning in daily life. These measurements had to be performed in a laboratory or clinical setting. We divided these tests in two categories, 'generic tests' and test with an emphasis on the speed of execution ('speed tests'); (d) the strength training control group was age-matched and received at least partially supervised strength training; and (e) studies were published in English, Dutch, or German language. Studies were excluded if the study population consisted solely of participants with specific musculoskeletal, neurological or psychological diseases on the basis of non-generalizability. Studies were also excluded if the interventions were home-based or solely internet-based interventions in view of concerns regarding adherence.

Data Extraction

First, relevant outcome data and participant and intervention characteristics were extracted. Secondly, if required, standard errors were converted to standard deviation for activity tests to allow between-study comparisons. From the selected studies that included a non-training control group in addition to power training and strength training groups, data were extracted for a separate meta-analysis of power training versus a non-training control group to test the assumption that power training is superior to non-training.

Risk of Bias

The methodological quality of the selected studies was assessed using the Cochrane Collaboration Risk of Bias tool. [24] The category for blinding of outcome assessment was scored as high risk of bias by default due to the difficulty in maintaining true blinding during post-intervention measurements. Studies were upgraded to unclear or low risk of bias if attempts were made to blind the outcome assessment for patients or assessors (e.g. blinding of patients to former assessment). Blinding of participants and personnel was not included in the risk of bias assessment as the nature of the studies does not allow for true blinding of the participants for the intervention that is received. All other types of bias were assessed according to the guidelines in the Cochrane handbook.[24] Studies were considered high risk of bias when three or more items were scored unclear or high, or when two items were scored high.

Statistical Analysis

A meta-analysis was performed comparing the difference in intervention effects for tests measuring muscle power, performance on the two types of activity based tests, and level of physical activity using RevMan 5.3 software (2014). The secondary meta-analysis comparing power training with a non-training control group was performed using the same procedure and software. Meta-analysis results are presented separately for each outcome, in forest plots using standardized mean differences (SMD) with 95% confidence intervals (CI). In studies with more than one follow-up measurement, the follow-up measurement directly follow-

ing the intervention was included in the meta-analysis. A random effects model was selected a priori to account for between-study variation in intervention protocol, duration, intensity, and participant characteristics. Statistical heterogeneity was evaluated using the p-value from the chi-square tests for heterogeneity and the I^2 statistic.[24] The I^2 statistic was interpreted as follows: 0-40% likely unimportant; 30-60% may represent moderate heterogeneity; 50-90% may represent substantial heterogeneity; and 75-100% considerable heterogeneity.[24]

Random effects models were used in the meta-analyses to account for the fact that the various tests used different units of measurement (meters, seconds, reps, Watts). Furthermore, whereas an improvement measured in timed tests is shown by decreasing values (a 400-Meter Walk Test in 5 minutes is better than one in 7 minutes), an improvement in meters, repetitions, or Watt/kg is reflected in increasing values (10 repetitions of a chair rise is better than 8 repetitions). To account for this difference in measurement scales, the test outcomes of timed tests were switched between power training and strength training groups to adequately reflect the more superior intervention.

Quality of Evidence Assessment

The PEDro scale (Physiotherapy Evidence Database, 1999) was used to assess the internal validity of each randomized controlled trial included in the systematic review. Trials with a score of 0-4 are considered 'poor', 4-5 'fair', 6-8 'good', and 9-10 'excellent'.

The quality of the evidence was assessed using the GRADEpro Guideline Development Tool (Evidence Prime, 2015). The initial GRADE score began as "high" because each of the selected studies were RCTs and was downgraded as a result of limitations with respect to risk of bias, inconsistency, indirectness, imprecision, or publication bias. The criteria for downgrading a level of evidence was based on the Grade Handbook [25] and the Cochrane Handbook[24]. Publication bias was additionally evaluated by visually assessing the distribution of effect sizes through funnel plot symmetry. In a symmetrical funnel plot the intercept on the X-axis should be close to 0, whereas with asymmetry it deviates considerably from 0 and suggests publication bias.[26]

Results

Study Selection

The initial search yielded 2759 articles, of which 1.534 entered preliminary screening after removal of duplicates. The screening of abstracts produced 62 full-text articles to be read in entirety for eligibility in phase 2. Forty-six studies were excluded and 16 studies were included. One of these studies [27] was excluded from quantitative analysis on the basis of using interquartile range (IQR) as a distribution parameter, which did not comply with the remaining 15 studies that were used in the meta-analyses. A PRISMA flow diagram of the literature search and study selection is shown in **Figure 1**.

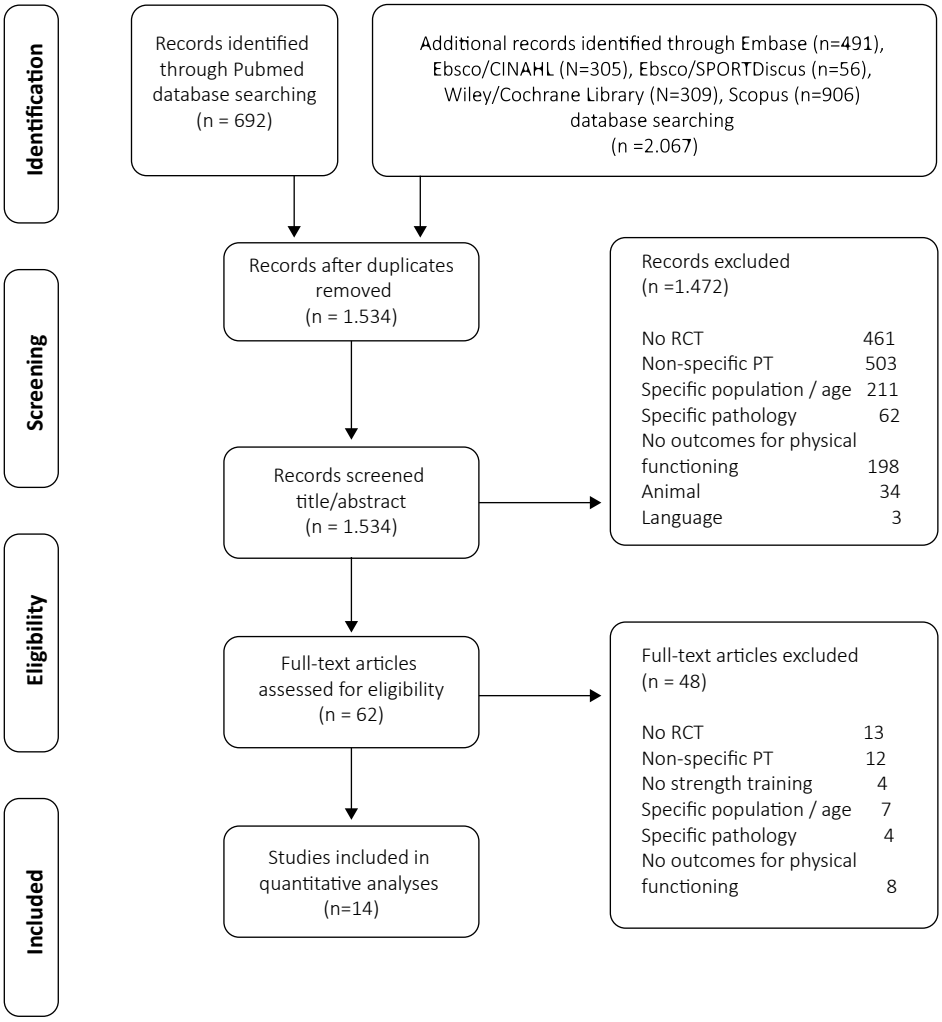


Figure 1: PRISMA flow diagram of literature search and study selection
RCT = randomized controlled trial; PT = power training; ST = strength training.

A total of 16 studies were included in the review. The total study population for the main comparison of power training versus strength training consisted of 583 participants, of which 277 participants received power training (47.5%). The study population for the secondary analysis of power training versus a non-training control group was 272, of which 134 participants received power training (49.3%).

Outcome Assessment

The selected studies used a variety of tests to measure muscle power and performance on activity tests. In the included studies, the construct of muscle power was captured with the Chest Press for upper extremity muscle power, and the Leg Press for lower extremity muscle power. Our analyses used the power and acceleration outcomes reported in the original studies. Tests with an emphasis on movement speed were tests in which the instruction was to perform the test "as quickly as possible". The activity tests categorised as having an emphasis on movement speed were Countermovement Jump, Chair Rise (seconds), Short Physical Performance Battery, Walking Speed, Timed Up and Go, Stair Climb (timed), and Floor Rise to Stand (timed). Generic tests were tests for which there was no instruction regarding the rate of force development. The activity tests categorised as generic were the 6-Minute Walk Test, 400-Meter Walk Test, Chair Rise (reps), Sit to Stand (Watt and repetitions), and a summary measure for Balance. None of the included studies used the level of physical activity in daily life as an outcome. The characteristics of the included studies included are shown in **Table 1**.

Risk of Bias

An overview of the risk of bias assessment for the included studies is provided in **Figure 2**. In conclusion, 47% of the studies were considered to be low risk of bias [3,28–33] while the remaining studies were scored as being unclear to high. [4,5,7,9,34–37]

Muscle Power

The statistical analyses for muscle power as outcome was performed separately for the upper extremity (UE) and lower extremity (LE) **(Figure 3)**. For UE muscle power, a meta-analysis of 6 RCTs showed a significant benefit of power training compared to strength training (SMD: 0.99, 95% CI: 0.34 to1.65, p=0.003). A significant chi-square test for heterogeneity (p=0.001) indicates a concern for statistical heterogeneity, which was corroborated by an I^2 statistic of 75% indicating substantial to considerable heterogeneity . For LE muscle power, a meta-analysis of 10 RCTs showed a significant benefit of power training compared to strength training (SMD: 1.00, 95% CI: 0.40 to 1.60; p=0.001). A significant chi-square test for heterogeneity (p<0.001) indicates a concern for statistical heterogeneity, which was corroborated by an I^2 statistic of 86% indicating considerable heterogeneity. The overall combined effect for UE and LE muscle power clearly favors power training (SMD: 0.99, 95% CI: 0.54 to 1.44, p<0.001) over strength training.

Table 1: Characteristics of the studies included in the meta-analyses evaluating muscle power, activity-based tests, and physical activity level in daily life in older adults.

Study	Type	Frequency and duration	Intensity	N	Mean age, years (SD)	Sex, female	Relevant outcomes	Tests used
Balachandran et al.2014)	PT ST	2x/wk for 15 wks 2x/wk for 15 wks	50-80% 1RM 70% 1RM	8 9	71.6 (7.8) 71.0 (8.2)	8 (100%) 8 (88%)	Muscle power Physical capacity	Chest Press Leg Press Chair Rise (s) SPPB Stair Climb (s)
Bean et al. (2009)	PT ST	3x/wk for 16 wks 3x/wk for 16 wks	11-16 RPE 11-16 RPE	59 58	74.7 (6.8) 76.1 (6.9)	50 (69%) 45 (68%)	Muscle power Physical capacity	Leg Press SPPB
Bottaro et al. (2007)	PT ST	2x/wk for 10 wks 2x/wk for 10 wks	40-60% 1RM 40-60% 1RM	11 9	66.6 (5.8) 66.3 (4.8)	0 (0%) 0 (0%)	Muscle power Physical capacity Physical functioning	Chest Press Leg Press Timed Up and Go Chair Rise (reps)
Cadore et al. (2013)	PT *MT	2x/wk for 12 wks 4x/wk for 12 wks	40-60% 1RM 30 min/day	11 13	93.4 (3.2) 90.1 (1.1)	NR NR	Physical capacity Physical functioning	Walking speed Timed Up and Go Chair Rise (reps) Sit to Stand (W) Balance
Fielding et al. (2002)	PT ST	3x/wk for 16 wks 3x/wk for 16 wks	70% 1RM 70% 1RM	15 15	73.2 (1.2) 72.1 (1.3)	15 (100%) 15 (100%)	Muscle power	Leg press
Henwood et al. (2006)	PT ST	2x/wk for 8 wks 2x/wk for 8 wks	50-75% 1RM 45-75% 1RM	21 20	70.7 (5.5) 70.2 (5.0)	14 (60%) 11 (50%)	Muscle power Physical capacity Physical functioning	Chest Press Chair Rise (s) Walking Speed Stair climb (s) Floor Rise to Stand 400m Walk Test
Henwood et al. (2008)	PT ST	2x/wk for 24 wks 2x/wk for 24 wks	50-75% 1RM 75% 1RM	19 19	71.2 (1.3) 69.6 (1.1)	12 (63%) 12 (63%)	Muscle power Physical capacity Physical functioning	Chest Press Leg Press Chair Rise (s) Walking Speed Stair Climb (s) Floor Rise to Stand 400m Walk Test

Continues on next page

Table 1: *Continued*

Study	Type	Frequency and duration	Intensity	N	Mean age, years (SD)	Sex, female	Relevant outcomes	Tests used
Lopes et al. (2014)	PT ST	3x/wk for 12 wks 3x/wk for 12 wks	70-90% 1RM 70-90% 1RM	11 13	63.3 (3.9) 67.0 (6.1)	NR NR	Muscle power	Leg Press
Marsh et al. (2009)	PT ST	3x/wk for 12 wks 3x/wk for 12 wks	70% 1RM 70% 1RM	12 11	76.8 (6.4) 74.6 (5.4)	7 (58%) 9 (82%)	Muscle power Physical capacity	Leg Press SPPB
Miszko et al. (2003)	PT ST	3x/wk for 16 wks 3x/wk for 16 wks	50-80/40% 1RM 50-80% 1RM	11 13	72.3 (6.7) 72.8 (5.4)	6 (55%) 7 (54%)	Muscle power Physical capacity	Chest Press SPPB
Orr et al. (2006)	PT ST ST	2x/wk for 10 wks 2x/wk for 10 wks 2x/wk for 10 wks	80% 1RM 50% 1RM 20% 1RM	24 25 25	69.0 (6.4) 68.1 (4.5) 69.4 (5.8)	17 (61%) 17 (61%) 17 (61%)	Physical functioning Muscle Power Physical functioning	Balance Leg Press Balance
Ramirez-Campillo et al.(2014)	PT ST	3x/wk for 12 wks 3x/wk for 12 wks	45%- /75% 75% 1RM	20 20	66.3 (3.7) 68.7 (6.4)	20 (100%) 20 (100%)	Muscle Power Physical capacity Physical functioning	Chest Press Leg Press CMJ (cm) Walking Speed Timed Up and Go Chair Rise (reps) Sit to Stand
Reid et al. (2013)	PT ST	2x/wk for 16 wks 2x/wk for 16 wks	40% 1RM 70% 1RM	27 25	78.3 (5.0) 77.6 (4.0)	15 (56%) 18 (72%)	Muscle power	Leg Press
Tiggeman et al. (2016)	PT ST	2x/wk for 12 wks 2x/wk for 12 wks	45-65% 1RM 45-65% 1RM	12 13	64.4 (4.0) 65.6 (5.3)	12 (100%) 13 (100%)	Physical capacity Physical functioning	CMJ (cm) Chair Rise (s) Timed Up and Go Stair Climb (s) 6 Min. Walking Test
Zech et al. (2012)	PT ST	2x/wk for 12 wks 2x/wk for 12 wks	10-16 RPE 10-16 RPE	16 18	77.4 (6.2) 77.8 (6.1)	NR NR	Physical capacity Physical functioning	SPPB Sit to Stand Balance

Caption: PT=power training; ST=strength training; MB mobility training; 1RM= 1-repetition maximum; RPE=rate of perceived exertion; s=seconds reps=repetitions; W=Watt; SPPB=Short Physical capacity Battery; CMJ: countermovement jump; NR: not reported.

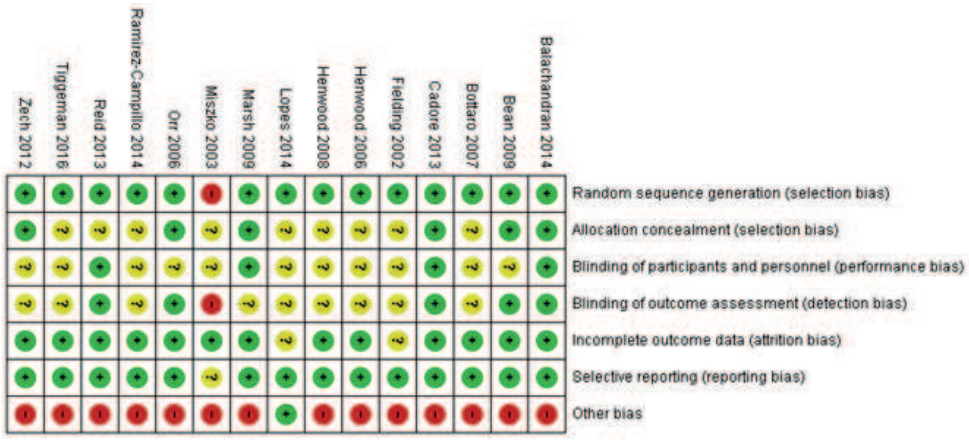


Figure 2: Risk of bias for the studies included in the meta-analysis.

The secondary meta-analysis showed that power training was also significantly improved UE muscle power (SMD: 0.81, 95% CI: 0.35 to 1.27, p<0.001) and LE muscle power (SMD: 1.38, 95% CI: 0.90 to 1.86, p<0.001) compared to to not training **(Appendix 2)**. Statistical heterogenity for the secondary analyses is likely 'unimportant' to 'moderate'. The overall combined effect for UE and LE muscle power also favors power training (SMD: 1.12, 95% CI: 0.75 to 1.48, p<0.001) over not training.

Generic Activity Tests

Five different tests were used in this category. A subgroup analysis was performed for each test **(Figure 4)**. In the subgroup analyses, the Chair Rise (p=0.02), the Sit to Stand (p=0.04), Balance (p<0.001), 400- Meter Walk Test (p=0.66), and 6-Minute Walk Test (p=0.66) all favored power training. The overall effect of functional performance was calculated by pooling the effects of all subgroup analyses, which showed a significant benefit of power training over strength training (SMD: 0.43, 95% CI 0.23 to 0.62, p<0.001). Statistical heterogeneity was of no concern for the subgroup or overall analyses .

The secondary analysis showed that power training group also significantly improved the performance on the generic tests (SMD: 0.73, 95% CI 0.48 to 0.99; p<0.001) compared to not training **(Appendix 3)**. Within the subgroup analyses, the Chair Rise (p<0.001), the Sit to Stand (p=0.02), Balance (p=0.003), and 400-Meter Walk Test (p=0.14) all favored power training. Statistical heterogeneity was of no concern in the overall analyses, however, the chi-square test for heterogeneity in the 400-Meter Walk Test (p=0.01) and an I^2 statistic of 84% indicated there may be substantial to considerate heterogeneity .

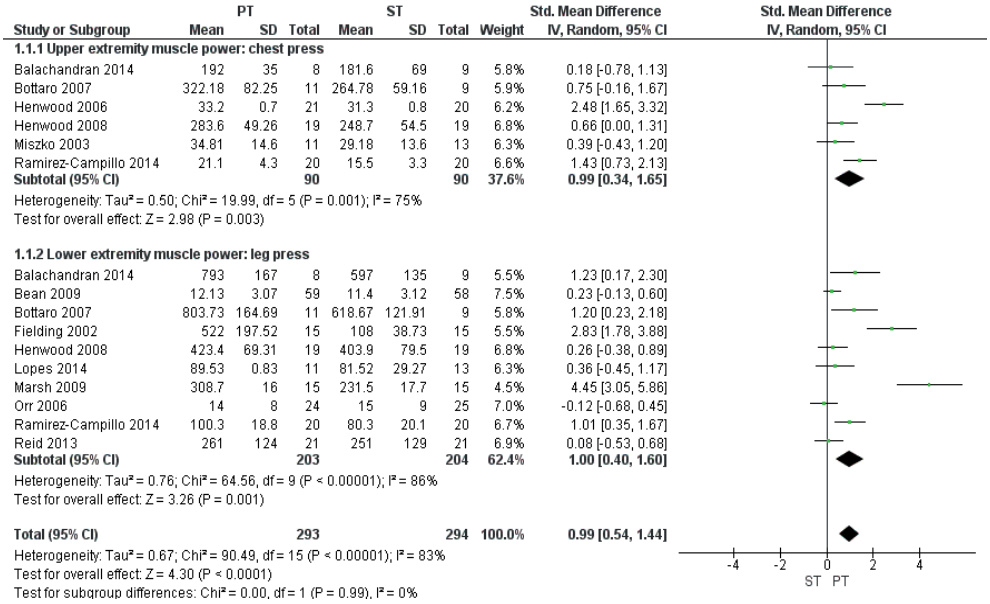


Figure 3: Forest plot showing the standardized mean difference between power training and strength training in older adults according to chest press and leg press (muscle power).
PT = power training; ST = strength training; SD = standard deviation; IV = intravitreal; CI = confidence interval.

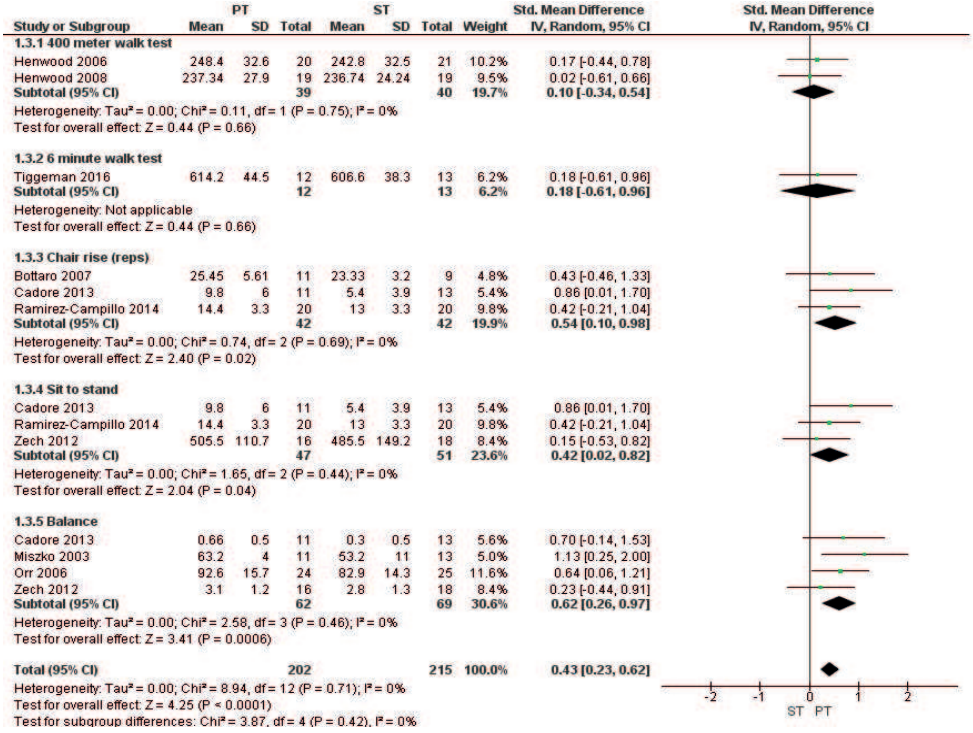


Figure 4: Forest plot showing the standardized mean difference between power training and strength training in older adults according to 400-m walk test, 6-minute walk test, chair rise (reps), sit to stand transfer, and balance. The sit to stand transfer and the chair rise in Cadore et al. is, in fact, the same performance test but interpreted in two different manners: sit to stand is considered to be a performance while chair rise is considered to be a physical function.
PT = power training; ST = strength training; SD = standard deviation; IV = intravitreal; CI = confidence interval

Activity Tests with an Emphasis on Movement Speed

Seven different tests were used in this category, and a subgroup analysis was performed for each test **(Figure 5)**. Within the subgroup analyses, the Sttair Climb (p=0.04), Chair Rise (p=0.19), Walking Speed (p=0.22), Short Physical Perforance Battery (SPPB) (p=0.75), and the Timed Up and Go (p=0.19) favored power training, while the Countermovement Jump (CMJ) (p=0.86) and the Floor Rise to Stand (p=0.43) favored strength training. Statistical heterogeneity may be a cause for concern in Chair Rise, Walking Speed, SPPB, Stair Climb, and Floor Rise to Stand, for which a significant p-value and an I^2 statistic above 70% indicated substantial to considerable heterogeneity. The overall effect was calculated by pooling the effects of each subgroup analysis, which showed a significant benefit of power training compared to strength training (SMD: 0.36, 95% CI 0.06 to 0.68, p=0.02). Statistical heterogeneity may be cause for concern as well, as a significant chi-square test for heterogeneity (p<0.001) and an I^2 statistic of 78% indicate substantial to considerable heterogeneity.

The secondary analysis showed that power training also significantly improved performance on the speed tests (SMD: 0.74, 95% CI 0.50 to 0.98, p<0.001) compared to not training **(Appendix 4)**. A significant chi-square test for heterogeneity (p=0.002) indicated a concern for statistical heterogeneity, which was corroborated by an I^2 statistic of 46% indicating moderate heterogeneity. Within the subgroup analyses, the CMJ (p=0.06), Chair Rise (p<0.001), Walking Speed (p=0.004), the Timed Up and Go (p=0.05), Stair Climb (p=0.03), SPPB (p=0.32), and Floor Rise to Stand (p=0.07) all favored power training. The chi-square test for heterogeneity indicated a cause for concern in Walking speed, for which the I^2 statistic was 71% .

Quality of Evidence

The quality of evidence for each outcome is shown in the GRADE quality of evidence table **(Table 2)**. The effect estimates for LE muscle power, generic and speed-based activity tests, were scored as having a 'high' amount of certainty, while UE muscle power was scored as having a 'moderate amount' of certainty. Within the certainty assessment, risk of bias was graded as 'serious' for each outcome, largely due to the lack of allocation concealment the selected studies. Indirectness was graded as 'very serious' for LE muscle power as a result of the inconsistent point estimates and high levels of statistical heterogeneity in the meta-analysis. For the activity tests with an emphasis on speed, criteria for indirectness (differences in outcome measures) and imprecision (risks of random errors) within the GRADE were scored as 'not serious'.

Publication bias was also assessed separately for each outcome through the use of funnel plots **(Appendix 5-7)**. The funnel plot for muscle power is a-symmetrical, indicating that publication bias may be present.

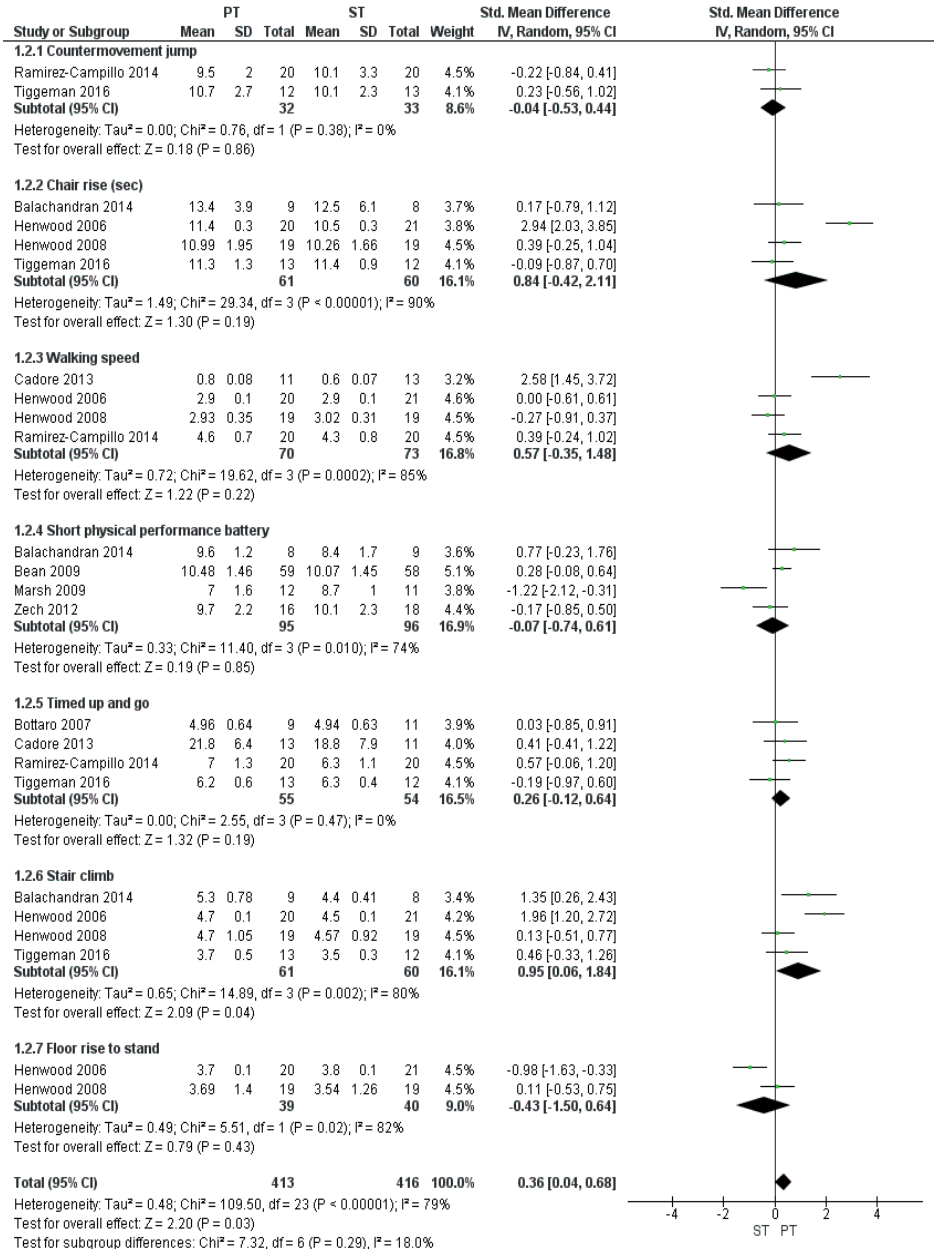


Figure 5: Forest plot showing the standardized mean difference between power training and strength training in older adults according to the countermovement jump, chair rise, walking speed, short physical capacity battery, timed up and go, stair climb, and floor rise to stand.
PT = power training; ST = strength training; SD = standard deviation; IV = intravitreal; CI = confidence interval.

Table 2: GRADE quality of evidence table for estimates using muscle power, activity-based tests, and physical activity level in daily life in older adults.

Certainty assessment						Number of patients		Effect		Certainty	Importance
Number of studies	Study design	Risk of bias	inconsistency	indirectness	Other considerations	Power Training	Strenght Training	Relative (95%CI)	Absolute(95%CI)		
Muscle power (upper extremity)											
6	randomized trials	serious[a]	not serious[b,c,d]	not serious[e,f,g]	all plausible residual confounding would suggest spurious effect, while no effect was observed	90	90	-	SMD **0.99 SD higher** (0.34 to 1.65 higher)	⊕⊕⊕⊕ HIGH	IMPORTANT
Muscle power (lower extremity)											
10	randomized trials	serous [a]	very serious [b,i,j]	not serious [e,f,g]	publication bias strongly suspected. Very strong association. All plausible residual confounding would suggest spurious effect, while no effect was observed	203	204	-	SMD **1.00 SD higher** (0.40 to 1.60 higher)	⊕⊕⊕◯ MODEATE	IMPORTANT
Generic tests											
11	randomized trials	serous [a]	not serious [b,c,j]	not serious [e,f,g]	strong association. All plausible residual confounding would suggest spurious effect, while no effect was observed	424	429	-	SMD **0.43 SD higher** (0.23 to 0.62 higher)	⊕⊕⊕⊕ HIGH	CRITICAL
Tests with emphasis on movement speed											
9	randomized trials	serous [a]	not serious [b,d,i]	not serious [e,f,g]	strong association. All plausible residual confounding would suggest spurious effect, while no effect was observed	202	215	-	SMD **0.36 SD higher** (0.04 to 0.6 higher)	⊕⊕⊕⊕ HIGH	IMPORTANT

Caption: [a.] Studies that carried large weight for the overall effect estimated as high risk of bias due to lack of construct validity for the intervention and the test and a lack of allocation concealment; [b.] (Unexplained) Inconsistency, with point estimates different; [c.] Substantially overlap in confidence interval; [d.] I2 is less than 60%; [e.] No differences in population; [f.] Substantial differences in outcome measures; [g.] Substantial differences in interventions; [h.] 95% confidence interval showed a moderate to good effect of power training in all articles; [i.] Confidence intervals do not overlap; [j.] I2 is more than 60%.

The funnel plots for the activity tests do not show asymmetry, indicating that publication bias is less of a concern. The PEDro score of each of the selected studies is illustrated in **Appendix 8**. Five studies were considered to have 'good' internal validity [3,29,31,33,36], 8 studies were classified as 'poor' to 'fair'[4,5,9,28,30,34,35,37], and 1 study was classified as having 'poor' interal validity. [7]

Discussion

Summary of Main Results

The results of this meta-analysis indicate a significant benefit of power training compared to strength training on muscle power and activity tests with SMD's varying between 0.99 for muscle power, 0.43 for generic tests, and 0.36 for tests with an emphasis on movement speed. Compared to non-training control groups, the effect was even larger with SMD's of 1.12 for muscle power, 0.73 for generic tests, and 0.74 for tests with an emphasis on movement speed. These results support the findings of previous intervention studies [3,4,7–9,17–19] and systematic reviews[8,19], both of which found power training to be more effective at improving physical and functional outcomes. No publications reporting the effect of muscle power training on physical activity level were found.

In a meta-analysis comparing power training with strength training, Tschopp et al. [8] reported an SMD of 0.42 for muscle power (95% CI-0.02 to 0.85), whereas we found an SMD of 0.99 (95% CI: 0.54 to 1.44; p<0.001). However, some of the studies included in the meta-analysis by Tschopp et al. were actually investigations of different intensities of power training rather than a comparison of power training against strength training.[8] The heterogeneity between studies has consequences for their overall conclusion that power training interventions are more effective than strength training. The meta-analysis from Steib et al.[19] reported an SMD of 1.66 for muscle power (95% CI 0.08 to 3.24) compared to progressive resistance training. However, the authors deemed the level of evidence as 'moderate' due to the large between-study variation. Furthermore, Byrne et al. found that muscle power was a superior predictor of functional performance compared to muscle strength, however, pooled effect estimates were not provided.[38]

Although these reviews found a similar trend as the present study, their methodological limitations prevented a direct comparison between power training and strength training. The present study reviewed the literature on the effect of power training compared to strength training in older adults using clear differentiation between the constructs muscle power, activity based tests and physical activity level in daily life. Therefore, this review makes a unique contribution to the body of evidence for the effect of power training in older adults.

The present study is, to our knowledge, the most comprehensive systematic review on this topic to date. The literature search for the present study used broad inclusion criteria to obtain as many studies comparing power training with strength training as possible. Each of the selected studies was thoroughly and independently examined by two researchers. The method in which risk of bias and quality of evidence were determined in the selected studies used the highest quality guidelines for systematic reviews.

While the following was not part of eligibility criteria, it is relevant to note that all of the interventions from the selected studies were longer than 8 weeks in duration which complies with the the American College of Sports Medicine (ACSM) guidelines. In these guidelines a minimum duration of 6 weeks is recommended for a measurable improvement caused by increased neurological efficiency.[39] A period to 8-weeks is considered to be the minimum amount of time required for physiological changes in muscle structure and strength.[40,41]

The present study encountered several limitations that provide opportunities for future research. There was a substantial amount of variability in the activity based tests used to measure outcomes in each of the selected studies, making comparibility between some studies more difficult. As a result, the overall quality of evidence was downgraded for each comparison based on 'indirectness' and a random effects model was selected for the meta-analyses. Due to a lack of detailed information in the included studies, this review has not evaluated the protocols of the power and strength training interventions and, therefore, cannot guarantee that total workload, rest intervals, exercises prescribed, muscle groups stimulated and ranges of motion were comparable between power and strength training across the studies included. Future research should assess the validity of power and strength training interventions in older adults and future studies comparing power and strength training should provide more detailed information on training dosage.

Another limitation of the included studies is the lack of information about the degree of muscle power loss. Power training should ideally be targeted in persons with an established decline in muscle power. However, differences in baseline muscle power between participants of the included studies were not taken into account. Some studies included older adults in a geriatric care setting where muscle power is likely lower than in community-dwelling older adults. Other age- (young old versus oldest old), sex-, or ethnicity-related differences between participants were also not accounted for, but are important determinants of the decrease in muscle power with increasing age.[11,13,42] Because this review only included participants aged on average over 65 years, it is reasonable to assume that a decrease in muscle power as a result of ageing had occurred, but it is also possible that in subgroups with a relative larger decline in muscle power the effect of power training is larger.

Another possibility for an underestimation of the effect of power training in our review, is the heterogeneity between the interventions themselves. Some of the interventions used in the selected studies trained muscle power using the low velocity and high force approach, as opposed to the high velocity and low force approach. Literature suggests that the in older adults, muscle power is best trained through the high velocity and low force approach. The degeneration of fast twitch fibers, which are responsible for explosive power, occurs more rapidly than the decrease of muscle strength.[43] Thus, age-related decrease in muscle power is determined by a decrease in velocity more than by a decrease in force produced, indicating that training should emphasize velocity more than force.[10,17] The definition of power training used in the present study does not specify the load at which power training is to be performed, resulting in a combination of different power training intensities included in the meta-analysis. Literature suggests an ideal load of 20-30% of the 1- repetition maximum (1RM) when training muscle power in older adults.[44–46] The above could also be the reason for the smaller effects we found on speed based tests. A high velocity, low force approach can be expected to result in larger effects on speed based tests.

Despite our efforts to evaluate publication bias through the use of funnel plots, we acknowledge that asymmetry could also be caused by small sample sizes and poor methodological quality of the included studies.[47] Lastly, this systematic review compared post-intervention measurements directly following the intervention and did not include a follow-up period beyond what was required for post-intervention measurements. Therefore, no inferences can be made on the long-term effects of the interventions.

Several important themes emerged that could be beneficial for future research. Currently, there is no broadly accepted, validated and standardized and coherent test protocol for measuring muscle power, related activity tests, and physical activity in daily life. To ensure comparibility between studies, further research is required to develop such a testprotocol. Especially the lack of measurements of physical activity in everyday life is important. Neither an increase in muscle strength nor a better performance on activity tests guarantees an effect on a physical activity in daily life (participation domain). Future research evaluating the validity and reliability of power training parameters (frequency and intensity) is also important. This will provide further guidance on the best approach to power training (high or low velocity, low or high force). Additional factors that could influence the results of power training, such as age-, sex-, and ethnicity-related differences in muscle power and the role of drop-outs in exercise interventions in older adults, have te be taken into account in design and report of future studies.

Conclusions

Power training offers more potential for improving muscle power and performance on activity based tests in older adults than strength training. The level of evidence for this comparison was rated as being moderate to high. Future research should focus on appropriate power training programs with correct training parameters and valid and reliable outcome measurements through the use of a standardised testing protocol.

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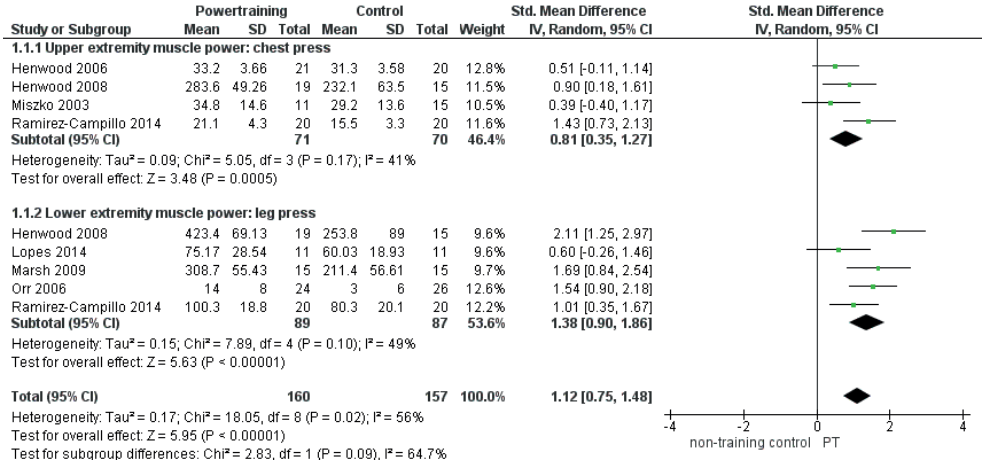
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Appendix 1: Search String use in PubMed

(("Aged"[Mesh] OR "Aging"[Mesh] OR "Homes for the Aged"[Mesh] OR "Housing for the Elderly"[Mesh] OR "Geriatrics"[Mesh] OR "Geriatric Nursing"[Mesh] OR "Health Services for the Aged"[Mesh] OR (elder*[tw] OR eldest[tw] OR frail*[tw] OR geriatri*[tw] OR old age*[tw] OR oldest old*[tw] OR senior*[tw] OR senium[tw] OR very old*[tw] OR septuagenarian*[tw] OR octagenarian*[tw] OR octogenarian*[tw] OR nonagenarian*[tw] OR centarian*[tw] OR centenarian*[tw] OR supercentenarian*[tw] OR older people[tw] OR older subject*[tw] OR older patient*[tw] OR older age*[tw] OR older adult*[tw] OR older man[tw] OR older men[tw] OR older male*[tw] OR older woman[tw] OR older women[tw] OR older female*[tw] OR older population*[tw] OR older person*[tw]) OR aging[tiab] OR ageing[tiab] OR community-dwell*[tiab]) AND ("Self Efficacy"[Mesh] OR "Activities of Daily Living"[Mesh] OR "Quality of Life"[Mesh] OR self efficac*[tiab] OR "activities of daily living"[tiab] OR "activity of daily living"[tiab] OR "activities of daily life"[tiab] OR "activity of daily life"[tiab] OR daily living activit*[tiab] OR daily life activit*[tiab] OR adl[tiab] OR iadl[tiab] OR "quality of life"[tiab] OR life qualit*[tiab] OR living qualit*[tiab] OR "quality of living"[tiab] OR "qol"[tiab] OR "hrql"[tiab] OR "hrqol"[tiab] OR functional abilit*[tiab] OR physical abilit*[tiab] OR functional perform*[tiab] OR physical perform*[tiab] OR functional independen*[tiab] OR physical independen*[tiab] OR "Personal Autonomy"[Mesh] OR functional autonom*[tiab] OR physical autonom*[tiab] OR "Physical Fitness"[Mesh] OR Independent living[tiab] OR Living independent*[tiab] OR high function*[tiab] OR higher function*[tiab] OR physical function*[tiab]) AND ((power[tiab] OR plyometric*[tiab] OR high velocit*[tiab] OR high intens*[tiab] OR explosive strength[tiab]) AND ("Exercise"[Mesh] OR "Sports"[Mesh] OR "Exercise Therapy"[Mesh] OR training[tiab] OR physical activity[tiab] OR exercise[tiab]))) AND (randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized[tiab] OR randomised[tiab] OR placebo[tiab] OR randomly[tiab] OR trial[tiab] OR groups[tiab])

Appendix 2:

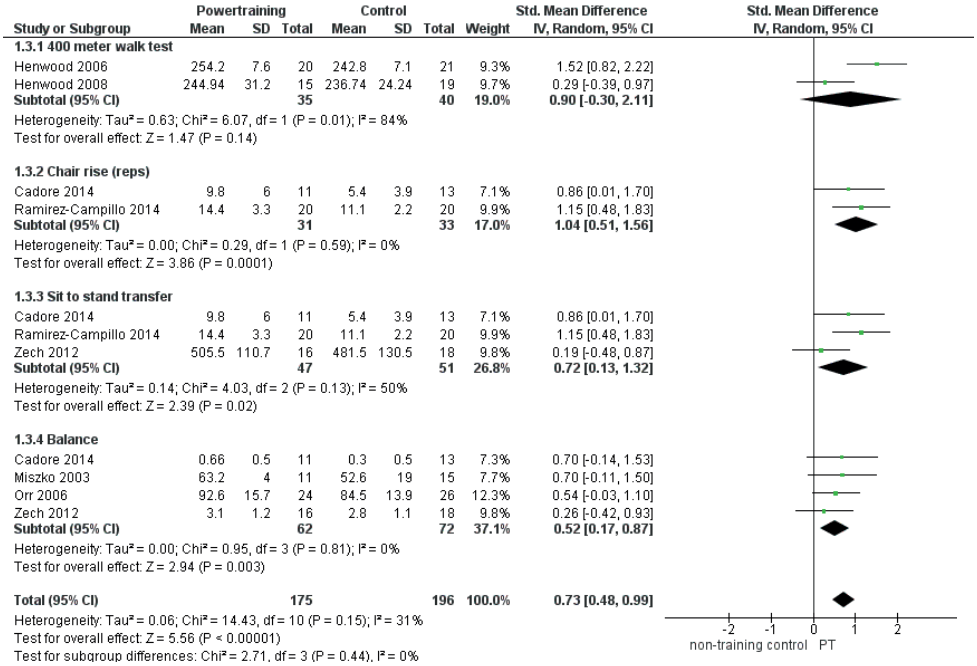
Forest plot comparing power training to non-training control group using muscle power.



Caption: Forest plot showing standardized mean difference between power training and non-training control group in older adults according to chest press and leg press. PT=power training; SD=standard deviation; IV=intravitreal; CI=confidence interval.

Appendix 3:

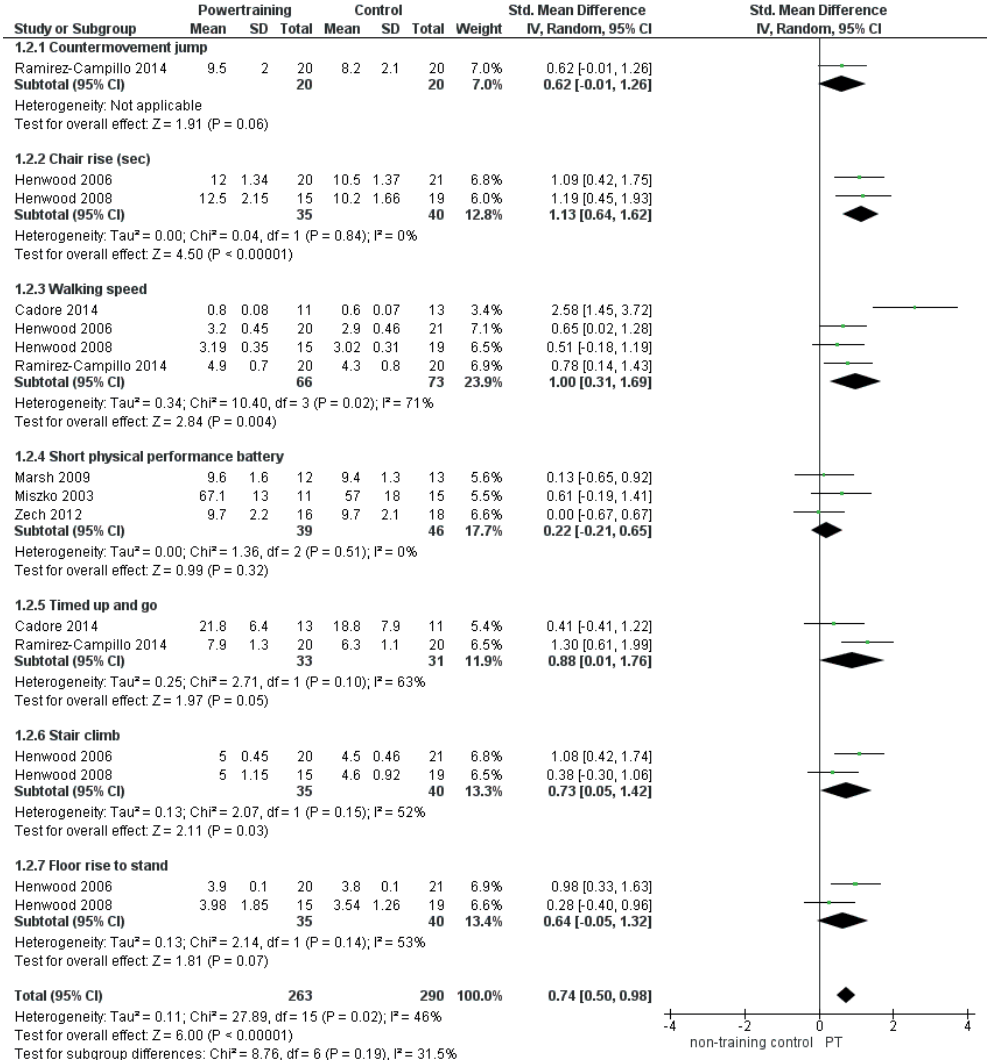
Forrest plot comparing power training to non-training control group using generic tests.



Caption: Forest plot showing standardized mean difference between power training and non-training control group in older adults according to the 400 meter walk test, 6 minute walk test, chair rise (reps), sit to stand transfer, and balance. The sit to stand transfer and the chair rise in Cadore et al. is, in fact, the same performance test but interpreted in two different manners. Sit to stand is considered to be a performance while chair rise is considered to be a physical function. PT=power training; SD=standard deviation; IV=intravitreal; CI=confidence interval.

Appendix 4:

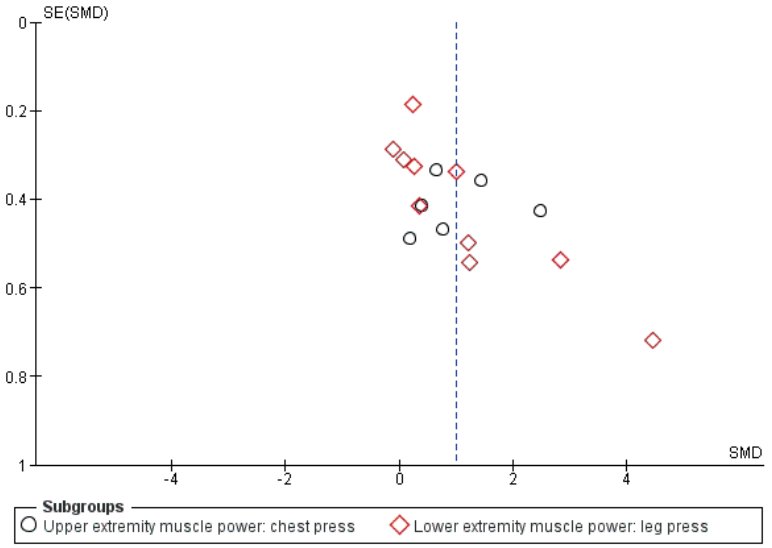
Forest plot comparing power training to non-training control group using tests with emphasis on movement speed.



Caption: Forest plot showing standardized mean difference between power training and non-training control group in older adults according to the countermovement jump, chair rise, walking speed, short physical performance battery, timed up and go, stair climb, and floor rise to stand. PT=power training; SD=standard deviation; IV=intravitreal; CI=confidence interval

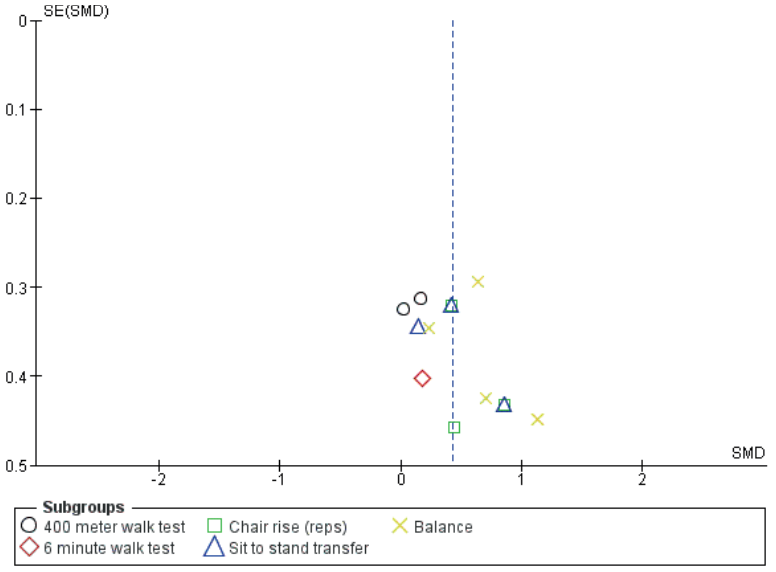
Appendix 5:

Funnel plot comparing power training to strength training in older adults using muscle power.



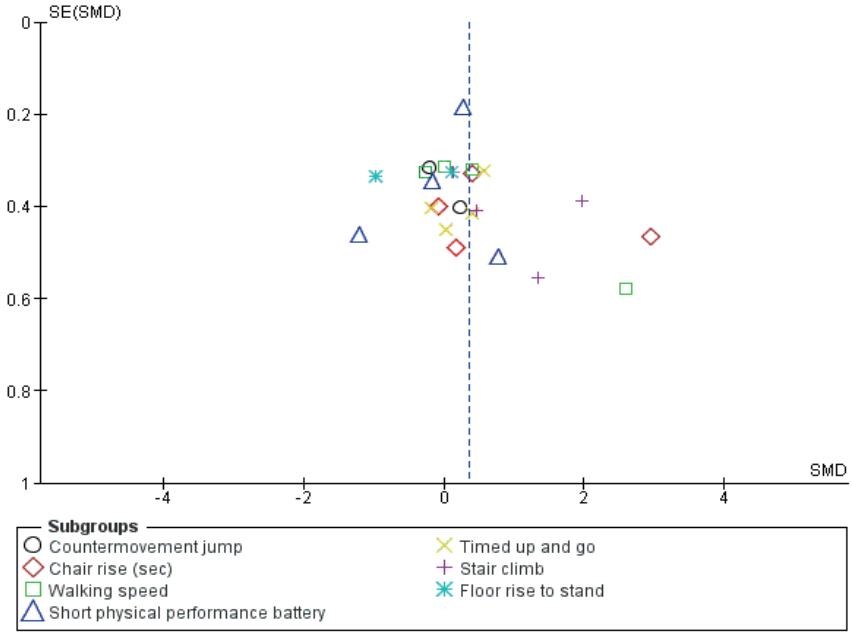
Appendix 6:

Funnel plot comparing power training to strength training in older adults using generic tests.



Appendix 7:

Funnel plot comparing power training to strength training in older adults using tests with an emphasis on movement speed.



Appendix 8: PEDro score for the studies included in the meta-analyses.

Study	PEDro score (out of 10)
Balachandran et al. (2014)	5
Bean et al. (2009)	6
Bottaro et al. (2007)	4
Cadore et al. (2013)	6
Fielding et al. (2002)	4
Henwood et al. (2006)	5
Henwood et al. (2008)	4
Lopes et al. (2014)	6
Marsh et al. (2009)	4
Miszko et al. (2003)	3
Orr et al. (2006)	6
Ramirez-Campillo et al. (2014)	4
Reid et al. (2013)	6
Tiggeman et al. (2016)	4
Zech et al. (2012)	7

6

Power Training in Older Adults: A Pilot and Feasibility Study

J Rehabil Res Pract. 2023; 4(1): 22-29

Mohamed el Hadouchi
Henri Kiers
Brittany A. Boerstra
Roos Pijpers
Cindy Veenhof
Jaap H.van Dieen

Abstract

Background: Previous research shows that power training can increase power output in older adults and may also improve physical performance, physical functioning, and independence. However, power training interventions have not been optimized for older adults. The aim of this study was to assess the feasibility and preliminary effectiveness of a power training program called Powerful Ageing in older adults.

Methods: A total of 28 older adults participated in a 12-week power training intervention at an intensity of 20-30% 1-repetition maximum (1-RM). The primary outcome, feasibility, was assessed through intervention retention, adherence (attendance and compliance), and safety. Secondary outcomes were measured in health domains of the ICF. In the function domain, muscle power and anaerobic power were assessed using a weighted squat and Wingate test, respectively. In the activities domain, physical performance was measured using the 6-minute walk test, and in the participation domain, physical activity in daily life and health status were evaluated using an accelerometer and the SF-36 questionnaire, respectively.

Results: With intervention retention and adherence at 100%, and 0% drop-out due to injuries, Powerful Ageing was considered feasible and safe for older adults. Power training significantly improved muscle power, anaerobic power, and physical performance in older adults, but did not have a significant effect on physical activity in daily life or health status.

Conclusions: Preliminary results suggest that Powerful Ageing is a feasible and safe intervention that may improve muscle power, anaerobic power, and physical performance in older adults. Randomized clinical trials are necessary to fully assess the potential of power training as an exercise intervention for older adults.

Keywords: power training, older adults, feasibility, muscle power, physical performance, physical functioning in daily life, health status, accelerometer

Introduction

Global ageing has led to a greater proportion of older adults and is one of the factors contributing to the increase in annual healthcare expenditure. People live longer despite the presence of chronic health conditions.[1] To offset rising healthcare costs, it is expected that older adults continue to live independently at home for as long as possible.[2] However, older adults must maintain their physical performance and physical functioning to facilitate independent living.

Ageing is associated with a decrease in both muscle strength and muscle power,[3–8] causing daily tasks, such as rising from a chair or climbing a flight of stairs, to become more difficult. Muscle power, the product of contraction force and velocity, is best trained through targeted power training, which is a form of exercise that involves moving resistance at higher velocities than traditional strength training.[4,5,9,10] Studies have shown that power training generates high power output even in older adults,[10–12] allowing for older adults to maintain or regain the ability to perform everyday activities, which may lead to increased independence and improved quality of life. Despite this, power training is rarely used as an intervention in practice as little is known about the exercise physiology and effectiveness of power training in older adults,[9,12,13] and some consider explosive muscular contractions a risk for injuries. Information on how power training should be implemented in older adults is lacking,[9,12,14] making it unsurprising that current exercise guidelines do not include recommendations for power training.

Therefore, the aim of this study was to assess the feasibility of a power training intervention called Powerful Ageing in older adults. In addition, we performed a preliminary evaluation of the effectiveness of Powerful Ageing within the function, activities, and participation domains of the International Classification of Functioning, Disability, and Health (ICF).

Methods

Setting and Study Design

A cohort of older adults participated in a 12-week power training intervention called Powerful Ageing. Training, testing, and data collection occurred at the physical therapy practice and fitness center Sports & Science located in Lochem, the Netherlands. The study was longitudinal in design, with measurements obtained at baseline (week 0) and following the completion of the intervention (week 12).

Participant Selection

Study participants were recruited from an open population in the municipality of Lochem, the Netherlands, from October through December 2015. The recruitment process was aimed at older adults and consisted of flyers distributed by local healthcare services, newspaper ads, social media, and information available on the website of the Sports & Science Center. To be eligible to participate in the study, participants had to be >55 years of age, live at home, and experience difficulties in participating in activities of daily life. It was required that participants spoke the Dutch language and had the ability to come to the training location independently. Participants were excluded from the study if they had been diagnosed with a condition that would prohibit full participation in testing or training (e.g. Alzheimer's disease, neurological disorders, musculoskeletal injuries, or complications associated with acute cardiovascular disease). Participants with a body mass index (BMI) <19 or >35 kg/m2 or blood pressure >150/90 mmHg were also excluded in view of participant safety. Lastly, older adults who had participated in a different exercise or training intervention 3 months prior to the start of the current training intervention were also excluded. Individuals who did not meet eligibility criteria were offered an alternative exercise intervention.

Following inclusion, participants were informed of the study's purpose, procedures, and potential risks and benefits verbally during a group gathering and in writing. Informed consent was obtained from each participant prior to testing. This study had been approved by the Ethical Commission of Research at the University of Applied Sciences Utrecht.

Training Protocol

Based on our previous work, a power training program called Powerful Ageing was created based on the theoretical concepts and practical requirements of a power training intervention [15–17] submitted manuscript by el Hadouchi et al; manuscript under review by el Hadouchi et al]. The rationale behind Powerful Ageing is largely based on the velocity component of muscle power, as the ability to move with a sufficiently large speed is more often the limiting factor than the ability to produce sufficient muscle force.[10,18] To train high contraction velocity, the resistance used in power exercises should be lower so that the movement speed can be higher. Therefore, Powerful Ageing uses a training load of 20-30% of the 1-repetition maximum (1RM), which has been proposed as the ideal power training load for older adults,[19–21] and was also chosen for feasibility and safety. Training sessions were led by an experienced professional trainer and supervised by a sport's physical therapist, both of whom ensured correct technique, intensity, and number of sets. To allow personal instruction, participants were divided into two training groups of 15 individuals.

Participants completed a 45-minute power training session twice a week for 12 weeks. Each session began with an explanation of the training goal and instructions on what was expected from participants (e.g. emphasis on movement speed). A 10-minute warmup consisted of movements and functional exercises with either no weight or a minimal load, which offered participants familiarization with the exercises, and provided trainers a chance to verify each participant's technique. The exercises used in the intervention were chosen based on their ability to generate a high power output.[22] Each training session consisted of three components: (1) Olympic weightlifting, such as deadlift high pulls, clean and press, back squats, and snatches; (2) sprint and agility training; and (3) functional movement training, including step-up lunges, burpees, and stair climbing.

During the training session, participants were instructed to perform 3 sets of 5-7 repetitions within a specific period of time, e.g. 10 seconds (s). Exercises were performed at a controlled tempo, concentrating on a fast explosive concentric phase and a slow and steady eccentric phase (the movement speed followed a <1s–0s–3s–0s pattern). The instruction for the power exercises was to be "as fast as possible". In between exercises, participants took a 2-5 minute break as needed, ensuring that each participant was able to complete the exercise using their maximum movement velocity. The training load gradually increased in both the number of sets and the 1-RM load. Participants were instructed to add greater resistance when they could easily perform the number of repetitions of an exercise in the predetermined time (e.g. 5 hang cleans in 10 seconds). **Table 1** summarizes the test protocol using criteria from the Template for Intervention Description and Replication Checklist (TIDieR) checklist.[23]

Feasibility

Feasibility was used as an umbrella term encompassing retention, adherence (attendance and compliance), and safety.[24] We defined retention as the proportion of participants who completed all follow-up assessments compared to the number of participants who completed baseline assessments. Adherence was defined using the World Health Organization definition as the extent to which a person's behavior corresponds with agreed recommendations[25] and incorporates both the number of training sessions attended as well as the compliance with the prescribed power training program. Compliance was determined through training records of a participant's progression, duration of the exercise, intensity, and level of difficulty of the exercises. The safety of the intervention was monitored through structured weekly screenings that aimed to assess any new physical complaints lasting longer than 48 hours related to the intervention, and adverse events that occurred during the intervention. The intervention was considered feasible if retention and adherence (attendance and compliance) were at least 90%, and drop-out due to injuries was below 15%.[24]

Table 1: Training protocol

	Criteria	Power training intervention
1	Intervention	Powerful Ageing
2	Rationale	Ageing causes muscle power, the product of force and velocity, to deteriorate. Specifically, older adults often miss the velocity component of muscle power. Therefore, power training interventions that use the high velocity and low force approach would be expected to be optimal for older adults (20-30% 1RM).
3	Materials	Various exercise equipment commonly available at fitness centers
4	Procedure	Each session began with a 10-minute warm-up consisting of movements and functional exercises that were featured in that day's training with either no weight or a minimal load. The power training consisted of 3 components: Olympic weightlifting, sprint and agility training, and functional movement training.
5	Person	The intervention was administered by an experienced professional trainer and under supervision of a sport's physical therapist.
6	Modes	In-person group training of 15 participants
7	Location	Indoor sports facility
8a	Sessions	24 sessions
8b	Frequency	2x per week
8c	Duration	45 minutes
8d	Intensity	30% of 1RM
8e	Type of exercises	The exercises used were explosive strength exercises. Each session consisted of Olympic weightlifting (including deadlifts, high pulls, clean and press, back squats), sprint and agility training, and functional movement training (including step-up lunges, burpees, and stair climbing).
8f	Level	Participants were instructed to concentrate on a fast explosive concentric phase and a slow and steady eccentric phase. The movement speed followed a <1s–0s–3s–0s pattern.
8g	Combination	Not available
9	Tailoring	Participants were instructed to add greater resistance when they could easily perform the number of repetitions of an exercise in the predetermined time (e.g. 5 hang cleans in 10 seconds).
10	Modification	None
11	Adherence	Acceptable intervention adherence was set at 90% for both attendance and compliance.
12	Deliverance	The intervention was delivered as planned.

Caption: 1-RM: 1-repetition maximum.

Preliminary Effectiveness

Secondary outcomes were measured in the health domains of the ICF, as shown in **Table 2.** Within the function domain, muscle power was assessed using weighted squat and anaerobic power was assessed using the Wingate test. Within the activies domain, physical performance was measured using the 6-minute walk test (6-MWT), and within the participation domain, physical activity in daily life and health status were evaluated using an accelerometer and the SF-36 questionnaire, respectively.

Table 2: Primary outcomes and their ICF domains

ICF domain	Outcome	Test
Function	Muscle power Anaerobic power	Weighted squat Wingate Test
Activities	Physical performance	6-MWT
Participation	Physical activity in daily life Health status	Accelerometer SF-36

Caption: ICF: International Classification of Functioning, Disability, and Health; ICF: International Classification of Functioning, Disability, and Health; 6-MWT: 6-Minute Walk Test; SF-36: 36-item Short Form Health Survey.

Muscle Power

The weighted squat was assessed using a GymAware device (Kinetic Performance Technology, Canberra, Australia), a portable Linear Positional Transducter (LPT with angle measurement), which can be attached to free weights. 26–28 Participants were instructed to sit on a box and rise to stand at a controlled tempo, while simultaneously holding two 6kg dumbbells at shoulder height. The assessed outcome variables were peak and mean power (Watt) and peak and mean velocity (m/s).

Anaerobic Power

The Wingate test consisted of a 5-minute warm-up, a 30-second sprint, and a 2-minute cool down performed on a Wattbike Pro/Trainer (Wattbike, Nottingham, United Kingdom). Participants were instructed to try to reach their maximum cycling speed early in the sprint and to try to maintain this speed for 30-seconds. Outcome variables were average power (Watt), peak power (Watt), cadence (revolutions per minute), and fatigue factor (%).

Physical Performance

The 6-MWT was conducted in a training facility on a flat surface of 12 meters long. Participants were instructed to walk as far as possible during the 6 minutes and were told to be able to take breaks as needed but to continue walking again as soon as they deemed this possible. Outcome variables were the total distance covered in 6 minutes and the BORG scale for exhaustion conducted following the 6-MWT. [29–31]

Physical Activity in Daily Life

Participants were instructed to wear a MoveMonitor (McRoberts, the Hague, the Netherlands) around their waist for 7 consecutive days, removing the device only when bathing/showering/swimming, or sleeping. The MoveMonitor is an accelerometer that records physical activity by measuring movement parameters, such as the duration of movement and the

number of long and short episodes of movement. A walking bout ranging between 1 to 24 seconds was considered a short walking bout, while walking bouts >24 seconds were considered long walking bouts. A daily journal was also kept in which participants noted their daily activities and any special circumstances throughout the day. Outcome variables were gait activity, the total time a participant wore the accelerometer, total number of walking bouts, and total number of short and long walking bouts. Gait activity is an expression use by McRoberts for the duration of activity and number of walking bouts measured in 24 hours.

Health Status

The health status of participants was evaluated using the SF-36, a widely used and validated instrument that assesses the health and well-being of individuals through a self-administered questionnaire [32] Although the complete SF-36 questionnaire was administered, our primary focus lies on five specific domains: physical functioning, energy/fatigue, emotional well-being, social functioning, and general health.

Additional Baseline Measurements

The following demographic, anthropometric, and clinical variables were also obtained from participants: age, sex, level of education, smoking status, cholesterol, presence of chronic disease, medication use, blood pressure, resting heart rate, weight, fat index (%), fat and muscle mass (kg), BMI, working status, participation in sports, and whether there were any injuries/functional limitations.

Statistical Analyses

Participant data obtained at baseline (week 0) and following the intervention (week 12) were entered manually into Excel (Microsoft, Redmond, USA), and cleaned prior to data analysis using SPSS (IBM, Chicago, USA). Continuous variables are presented as mean (standard deviation) or median (interquartile range), whereas categorical variables are presented as frequency (percentage per category). The preliminary effectiveness of Powerful Ageing was evaluated by testing the differences between measurements at baseline (week 0) and following the intervention (week 12) using a paired samples t-test or Wilcoxon signed rank test. The level of significance was set at $p < 0.05$.

Results

Participant Characteristics

A total of 110 visitors to the Sport & Science Center were eligible to participate in the study. Thirty individuals were invited at random to participate in the study and all of them accepted. Two participants were excluded from analyses evaluating preliminary effectiveness due to an error in the registration of accelerometers, leaving 28 participants for which these outcome data were available. However, the two participants were included in the analyses evaluating feasibility. Participant characteristics at baseline are shown in **Table 3.**

Feasibility

Feasibility results are summarized in **Table 4.** The retention rate throughout the full trial period was 100%, as all 28 participants whom completed baseline assessment also completed the power training intervention. The attendance of training sessions was 100%, and a review of training records indicated that all 30 participants were able to complete the prescribed exercises within the 45-minute training sessions, making the compliance rate also 100%. Throughout the study period, there were no reports of new injuries, physical complaints lasting longer than 48 hours, or adverse events related to power training. The drop-out rate due to injury was 0%.

Preliminary Effectiveness

Results for the preliminary effectiveness of Powerful Ageing are summarized in **Table 5.** Within the function domain, significant improvement was measured in all outcome variables for muscle power and anaerobic power. Within the activities domain, the total distance walked during the 6-MWT improved significantly ($p<0.001$) while there was no change in the BORG test. Regarding physical activity in daily life in the participation domain, gait activity, total walking bouts, total short walking bouts, and total long walking bouts increased slightly, but not enough to reach statistical significance. For health status, a trend showing improvement in the energy/fatigue, emotional well-being, and general health domains of the SF-36 was found, but not enough to reach statistical significance. Scores for the physical functioning and social functioning domain of the SF-36 remained the same, and approached the maximum score of 100 points both at baseline and at week 12.

Table 3: Study population at baseline

Variable	Summary	N
Age (years)	68.25 (6.16)	28
Sex (male)	16 (57.10%)	28
Level of education Primary Secondary Post-secondary	3 (11.5%) 7 (26.9%) 16 (61.6%)	26
Smoker	1 (3.8%)	26
Cholesterol (mg/dL)	4.69 (0.66)	25
Presence of chronic disease	5 (20.00%)	25
Medication use	12 (46,2%)	26
Systolic blood pressure (mmHg)	159.4 (21.73)	26
Diastolic blood pressure (mmHg)	95.29 (14.97)	26
Resting heart rate (bpm)	77.87 (14.08)	26
Weight (kg)*	84.00 (23.50)	28
Fat index (%)	32.08 (9.97)	28
Fat mass (kg)*	25.70 (17.80)	28
Muscle mass (kg)*	58.90 (24.10)	28
BMI*	26.85 (8.50)	28
Currently working	3 (11.5%)	26
Participation in sports	10 (32.3%)	26
Injuries/ functional limitations	5 (17.90%)	28

Caption: Continuous variables are expressed as mean (SD) unless indicated by an asterisk*, in which case median (IQR) range are reported and categorical variables are expressed as frequency (% per category). BMI: body mass index.

Table 4: Feasibility of power training in older adults.

Feasibility outcome	Value
Retention	100%
Adherence Training attendance Compliance	 100% 100%
Safety (drop-out)	0%

Caption: N=30.

Table 5: Preliminary effectiveness of power training in older adults.

ICF domain	Outcome	Test	Variable	Week 0	Week 12	Significance
Function	Muscle power	Weighted squat	Concentric mean power (Watt)	91.54 (32.15)	117.84 (51.64)*	<0.001*
			Concentric peak power (Watt)	172.44 (72.58)	232.19 (118.73)*	<0.001*
			Eccentric peak power (Watt)	145.54 (61.84)	317.57 (60.44)*	<0.001*
			Concentric mean velocity (m/s)	0.49 (0.14)	0.59 (0.15)	<0.001
			Concentric peak velocity (m/s)	0.80 (0.26)*	1.05 (0.32)	<0.001*
	Anaerobic power	Wingate	Average power (Watt)	322.50 (114)*	368.44 (97.64)	0.001*
			Peak power (Watt)	396 (143)*	447 (147)*	<0.001*
			Cadence (rpm)	82.88 (10.27)	87.08 (11.06)	0.001
			Fatigue factor (%)	29 (25)*	40 (22)*	0.007*
Activities	Physical performance	6-MWT	Distance (meters)	436.5 (64)*	600 (117)*	<0.001*
			Borg test	11 (1)*	11 (3)*	0.947*
Participation	Physical activity in daily life	McRoberts Move Monitor	Gait activity	54.38 (25.60)*	60.38 (30.11)	0.904*
			Measuring period (days)	6.67 (0.05)*	6.25 (0.01)*	<0.001*
			Total walking bouts	1208.26 (479.17)	1377.77 (550.21)	0.206
			Total short walking bouts	1101.67 (446.56)	1253.65 (501.65)	0.214
			Total long walking bouts	99 (75)*	103 (137.25)	0.696*
	Quality of life	SF-36	Physical functioning	90 (10)*	90 (6.25)*	0.929
			Energy/fatigue	74.82 (14.04)	80 (11.25)*	0.372
			Emotional well-being	84.14 (10.01)	86 (16)*	0.806
			Social functioning	100 (25)*	100 (12.5)*	0.424
			General health	69.20 (16.32)	80 (35)*	0.093

Caption: Summary measures are expressed as mean (SD), and differences are tested using a paired samples t-test unless indicated by an asterisk*, in which case median (IQR) range are reported and differences are tested using Wilcoxon signed rank test. ICF: International Classification of Functioning, Disability, and Health; 6-MWT: 6-Minute Walk Test; SF-36: 36-item Short Form Health Survey.

Discussion

Results indicate that Powerful Ageing was highly feasible among older adults, as intervention retention, training attendance, and compliance rates were very high and the drop-out rate due to injuries was 0%. Furthermore, preliminary results with regards to the effectiveness suggest that Powerful Ageing may improve muscle power and anaerobic power (function domain), and physical performance (activities domain) in older adults. However, no significant effect was found for physical activity in daily life or health status (participation domain).

These results are in line with other studies evaluating the effects or feasibility of power training in older adults [12,33–35] However, the present study has several additional strengths that add to the current literature. Previous studies assessed their training protocol using tests that focused solely on the strength or velocity component of muscle power. [16] The sit-to-stand test is commonly used to measure muscle power, but this test predominantly measures the velocity component of muscle power and does not take the contraction force at which the motion is performed into account. In the present study, a weighted squat was performed using GymAware equipment to capture the strength and velocity components of muscle power simultaneously. Similarly, assessing anaerobic power in an older adult population is often done in brief and using measures that provide only an indication of their anaerobic capacity, such as ergometer or treadmill activities and post-exercise measurement of blood lactate levels [36,37] In contrast, the current study used the Wingate Test, which is considered a widely accepted standard and offers a more accurate reflection of an individual's anaerobic capacity. It is crucial that power training interventions are tailored towards older adults, including special considerations for the intensity of training, risk of injury, and safety of the participant.[22] Health practitioners and professionals might assume that performing skeletal muscle contractions “as fast as possible” may be dangerous and unsafe for older adults, particularly if clinical conditions are associated with advanced age. However, injuries caused by training in older adults occur most often when individuals exert themselves at or near maximal muscular force, or perform a combination of heavy and repetitive workloads until exhaustion.[38] Therefore, an exercise training aimed at increasing muscle power using lower external loads (20-30% 1RM) than strength training and performed without muscle exhaustion, can be expected to reduce the risk of injury. Additionally, it is of high importance to also take the individual’s health status and physical limitations into account and modify or tailor the exercises accordingly. Proper supervision and guidance throughout the intervention are crucial for ensuring safety and effectiveness.

Our results suggest that an increase in muscle power (function domain) and physical performance (activities domain) may not necessarily translate to heightened levels of physical activity in daily life (participation domain). These findings underscore the significance of additional factors, such as motivation, environmental barriers, and individual habits, which are likely to substantially contribute to individuals' engagement in physical activity and their overall health outcomes. Consequently, a singular emphasis on enhancing muscle power and physical performance may prove insufficient to effect substantial changes in daily physical activity among older adults.

Limitations to this study are the small sample size, short duration of the study, and the fact that the study was limited to one geographical area, which are characteristics of a pilot study. Future research in the form of a randomized controlled trial containing a larger sample size and longer follow-up period would be valuable in further investigating the effects of power training in older adults. A more extensive list of covariates should also be obtained, including diet, personal medical history, genetic history, and lifestyle factor, as such factors may influence results. Additionally, the ceiling effect observed in the SF-36 was a limitation to the present study, as this influenced our ability to measure an improvement in health status following the Powerful Ageing. At baseline, mean scores for SF-36 domains ranged between 69-100 points, suggesting that our study population may have been 'too fit' in certain domains of the SF-36 to capture a significant improvement. Future studies evaluating change health status following a power training intervention may need to use a different instrument or should aim specifically at participants of lower health status. We assumed that study participants had experienced age-related decreases in muscle power prior to the start of the intervention, however, it would have been better if measurements prior to baseline were taken to verify the assumed reduction in muscle power.

Conclusions

Powerful Ageing was feasible in older adults, with high rates of intervention retention, adherence, and safety. The intervention may also improve muscle power, anaerobic power, and physical performance in older adults, but appears not to affect physical activity in daily life and health status. Further research in the form of a randomized controlled trial using a validated measurement set is needed to evaluate the effects of power training in older adults.

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7

The Impact of Power Training on Muscle Power, Physical Performance, and Physical Functioning in Older Adults: a Descriptive Case Series

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Mohamed el Hadouchi
Henri Kiers
Cindy Veenhof
Jaap van Dieen

Abstract:

Purpose: Powerful Ageing (PA) is a power training intervention offered by Dutch municipalities to improve the physical functioning of its older residents, thereby reducing their reliance on assistive living devices and social support services. This study aimed to investigate the effects of PA on muscle power, physical performance, and physical functioning in older adults immediately following the intervention and 1-year following the intervention.

Patients and methods: The design of the study was a prospective longitudinal case series. Eligible older adults requesting social support services from their municipality participated in a 14-week power training intervention. Primary outcomes were categorized according to ICF health domains: within the function domain, muscle power was measured with a Power Squat Test and a lifting test (deadlift); within the activities domain, physical performance was assessed using the Star Agility Run and the Timed Up-and-Go Test; and within the participation domain, physical functioning was assessed using the patient-specific complaints questionnaire. The participant's level of motivation, a secondary outcome, was assessed using a short questionnaire.

Results: Participants showed statistically significant improvements performing the Power Squat Test, the Lifting Test, the Star Agility Run, and the Timed Up-and-Go Test immediately following PA. Additionally, activities of daily life became significantly less difficult to perform. Among participants who continued power training following the intervention, these improvements were even greater at 1-year follow up. Participant motivation was high throughout the duration of the study.

Conclusion: PA led to significant improvements in muscle power, physical performance, and physical functioning in older adults. Among participants who continued power training in the year following the intervention, improvements progressed even further, suggesting long-term benefits. Further research is needed to confirm the sustainability of the effects of power training in older adults.

Keywords: exercise intervention; elderly

Introduction

The global population is ageing rapidly, with projections estimating more than two billion individuals aged 60 years or older by 2050.[1] This shift in demographic underscores the importance of addressing age-related declines in physical functioning. Successful ageing involves maintaining an active lifestyle, independent functionality, and societal engagement. Unfortunately, ageing is characterized by a decline in muscle power, muscle mass, and muscle strength,[2–4] negatively affecting physical functioning and the ability to perform activities of daily life. Preserving physical performance and functioning is crucial for maintaining physical independence, and these aspects are closely linked to muscle power. Muscle power, defined as the product of muscle force and contraction velocity,[5,6] is vital for tasks requiring rapid muscle contractions, such as standing up from a chair, climbing stairs, and reacting to balance perturbations. Muscle power can be maintained and improved by power training, a form of resistance training with the emphasis on the ability to generate muscle force rapidly.[7–10] Power training appears to be a promising way to maintain or restore muscle power and physical performance in older adults.[11]

Powerful Ageing (PA) is a power training intervention offered by Dutch municipalities to improve the physical functioning of its residents, thereby reducing their reliance on assistive living devices and social support services. By increasing older residents' ability to live independently at home longer, healthcare costs can be reduced and quality of life can be increased. A recent pilot study demonstrated that the PA program is safe, feasible, and replicable in older adults.[12] Additionally, it was concluded that PA was therapeutically valid and met the proposed criteria for power training **(Appendices 1 and 2)**. Over the past five years, the implementation of PA across the Netherlands further shows the program's scalability and potential impact, while the adaptability to various settings and its integration into existing healthcare systems highlight its potential for promoting active ageing. However, further research is needed to investigate the intervention's effectiveness.

Therefore, the aim of this descriptive case series was to assess the effects of PA on muscle power, physical performance, and physical functioning in older adults immediately following the intervention and one year following the intervention. Compared to our previously-published pilot study, [12] this study used an older, larger, and more heterogeneous population of older adults and a wider range of outcome measurements.

Methods

Study Design

This study followed older adults who participated in PA, a 14-week power training intervention conducted at various primary care physiotherapy centers across the Netherlands. The design of the study was a prospective longitudinal case series, with measurements obtained as baseline (T0), immediately following PA (T1), and one year following PA during which participants continued to practice power training (T2). Ethical approval for this study was obtained from the Ethical Commission of Research at the University of Applied Sciences Utrecht.

Participant Selection

The Social Support Act is a Dutch government initiative that provides support to residents in the form of domestic help, a mobility scooter, or a chair lift to allow residents to continue to live independently. Since 2019, PA has been integrated into the Social Support Act, giving residents the opportunity to improve their physical functioning before requesting additional support. Older adults requesting support via the Social Support Act between October 2020 and April 2023 and who met eligibility criteria were invited to participate, and participant recruitment was facilitated by municipality consultants. A total of 17 municipalities participated: Almelo, Boxtel, Coevorden, Delft, Eemsdelta, Het Hogeland, Hoogeveen, Maassluis, Midden Delfland, Rheden, Schiedam, Smallingerland, Valkenswaard, Vlaardingen, Westland, Weststellingerwerf, and Zoetermeer.

To qualify for the study, participants had to be >55 years of age, reside at home, and be capable of independently traveling to the training facility. Individuals with chronic mental disorders or physical ailments that would hinder full participation in testing or training (e.g. Alzheimer's disease, neurological disorders, or acute cardiovascular disease) were not included in the study. Additionally, a fall risk assessment was conducted to determine participant eligibility for group training. The Fall Risk Assessment tool, comprising of three key questions, was utilized to rapidly identify individuals at increased fall risk.[13] Questions addressed recent fall history, concern about falling, and mobility difficulties. Participants responding negatively to all questions were classified as low risk, while an affirmative response to any question indicated increased risk. Those categorized as having increased fall risk were excluded from the study to ensure participant safety during group exercises.

Once eligibility was confirmed, participants were verbally briefed on study procedures and received written information about the purpose, procedures, as well as potential risks and benefits during a group session. Informed consent was then obtained from each participant before testing commenced.

Training Protocol

The training protocol for PA has been described elsewhere using criteria from the Template for Intervention Description and Replication Checklist (TIDieR).[14] The included older adults participated in a 45-minute power training session, twice a week, for 14 weeks under the guidance of an experienced physical therapist. Prior to leading the power training intervention, physical therapists completed a 3-day course which covered the PA training protocol, working with older adults, and integrating exercises into activities of daily life. Training groups were limited to eight participants to ensure individualized instruction and supervision such that proper technique, intensity, and set numbers were achieved. Following completion of the 14-week power training, some municipalities offered participants the opportunity to continue training, however, in most municipalities, this was not feasible to organizational factors and a lack of resources. Each training session began with an overview of the objectives and detailed instructions emphasizing movement speed. The 10-minute warm-up included movements and functional exercises from the day's training with minimal or no weight, allowing participants to become familiar with the exercises, while enabling the physical therapist to assess their technique. Each training session involved three components: (1) Olympic weight lifting, such as deadlift high pulls, clean and press, back squats, and snatches; (2) sprint and agility training; and (3) functional movement routines like step-up lunges, burpees, and stair climbing. Throughout the training sessions, individuals were directed to complete 3 sets of 5-7 repetitions within a designated timeframe (e.g., 10 seconds). The exercises were executed with deliberate control, focusing on rapid explosive muscle contraction and gradual relaxation (the movement rhythm followed a pattern with 1 second concentric contractions and 3 second eccentric contractions without rest in between). Between exercises, participants had the option to take a 2 to 5 minutes rest as required, ensuring they could perform at their peak velocity for each exercise.

The exercise load ranged from 20-30% of 1-repetition maximum (1-RM). The training load was gradually increased when a participant could comfortably complete the prescribed number of repetitions within the specified time frame (e.g., 5 hang-cleans in 10 seconds) by increasing the weight or the number of sets performed.

Outcome Measurements

Primary outcomes were categorized according to the health domains of the International Classification of Functioning, Disability and Health (ICF).[15] Additionally, participant level of motivation was assessed as a secondary outcome using 6 questions scored on a 5-point Likert scale. The maximum score was 30 points, and participants were considered 'motivated' if their score exceeded 18 points **(Appendix 3)**.

Muscle Power (function domain of the ICF)

Power Squat Test

A Power Squat Test was performed and measured with a GymAware device (Kinetic Performance Technologies, Canberra, Australia), which is a Linear Power Transducer used for measuring sport and performance.16 Participants were directed to maintain a controlled tempo moving from squatting to standing, holding a 6kg dumbbell at shoulder height. During the Power Squat Test, participants were instructed to perform a rapid and explosive squat movement, aiming for maximal power output. Outcome variables were the velocity (m/s) of movement and power output (Watt).

Lifting Test (Deadlift)

The lifting test required participants to lift a 6kg dumbbell at a controlled pace, extending their arms until the dumbbell reached hip height. Participants were instructed to push through their heels, simultaneously extend their knees and hips, and lift the dumbbell close to their bodies along the shins and thighs. It was emphasized to keep the arms straight and maintain a neutral back position, using the legs and hips to generate the lifting force. The test utilized the GymAware for data collection.

Physical Performance (activities domain of the ICF)

Star Agility Run

The star agility run test requires participants to move through a series of low training cones arranged in a square, with one cone positioned at the center. The goal was for the participant to tap each cone as they moved through the star-patterned course. We recorded the number of cones touched in 30 seconds.

Timed Up-and-Go Test

The Timed Up and Go assessment involved walking to a cone placed 3 meters away, circling around it, and returning to the chair. The time taken was recorded from when the participant began until they touched the chair again at the end of the test.

Physical Functioning (participation domain of the ICF)

PSK Questionnaire

The PSK questionnaire is a patient-specific complaint survey that asks respondents to identify and rate 3 activities of daily life they find difficult to perform. Participants rated the difficulty of the activity on a scale of 0-100, where 0 represents no difficulty and 100 signifies the activity is impossible for them. The first part of the PSK focuses on measuring these difficulties at the activity level. However, in this study, we used the second part to draw conclusions about participation in daily life activities at home, using the difficulty rating to make inferences about problems with participation in activities of daily life.

Statistical Analysis

Usual care data were collected at baseline (T0) and at 14-weeks following the intervention (T1). In the municipalities that offered continued power training following the intervention, measurements were also taken at 1-year follow-up (T2). The quality of the data was checked in Excel (Microsoft, Redmond, United States) prior to analysis in SPSS (IBM, Chicago, United States). Continuous variables were expressed as mean (standard deviation) or median (interquartile range), while categorical variables were presented as frequency (percentage per category). A paired t-test or Wilcoxon matched-pair signed rank test of complete cases was used to test differences in measurements taken at baseline (T0) and immediately following the intervention (T1). Due to a limited availability of data at 1-year follow up (T2), the effect of Powerful Ageing at 1-year following the intervention was not tested for statistical significance. Fewer participants were measured at T2 as a result of organizational factors, such as the lack of a municipality's ability to continue to provide power training to a growing group of older adults. Therefore, data measured at 1-year following the intervention were used to make observations about longitudinal trends and about program retention.

Results

Study Participants

Baseline data were available for a total of 484 older adults across 17 municipalities in the Netherlands **(Table 1)**. Participants were mostly female (34%), averaged nearly 79 years of age, with a body mass index (BMI) of 28.97 kg/m2. The majority of patients had self-reported injuries and/or chronic diseases.

Muscle Power (function domain of the ICF)

For the Power Squat Test, both mean power and peak power increased significantly from 353.91 and 592.30 Watt (W) at baseline to 427.10 and 761.21 W, respectively, following PA **(Table 2)**. Among participants who continued power training following the intervention, mean and peak muscle power increased to 502 and 945.4 W at 1-year follow-up **(Appendix 4)**. Mean and peak velocity increased similarly, from 0.41 and 0.72 m/s at baseline to 0.51 and 0.87 m/s immediately following the intervention. The overall time it took to perform 5x Power Squat Test also improved, from 19.97 s at baseline to 14.79 s. Among participants who continued power training, one year later, the time it took to complete 5x Power Squat Test was 11.10 seconds.

Table 1: Participant characteristics

Variable	Baseline value	N
Sex, male	170 (34.4%)	479
Age, years	78.8 (8.2)	484
BMI, kg/m2	29.0 (5.0)	122
Muscle mass, %	49.5 (12.5%)	122
Fat mass, %	30.1 (11.0)	121
SBP, mmHg	149.5 (20.6)	224
DBP, mmHg	88.1 (13.8)	221
Resting HR, bpm	72.8 (12.0)	214
Current smoker	29 (5.9%)	303
Current medication use	362 (73.1%)	412
Presence of injuries/chronic diseases*		408
Hip and lower limb conditions	143 (35.0%)	
Spinal and lower back Conditions	99 (24.3%)	
Upper limb conditions	60 (14.7%)	
General musculoskeletal conditions	49 (12.0%)	
Neurological conditions	41 (10.0%)	
Conditions related to chronic diseases	266 (65.2%)	
Specific conditions	25 (6.1%)	
Post-traumatic/surgical conditions	21 (5.1%)	
Non-specific symptoms	36 (8.8%)	
Currently working	11 (2.2%)	350
Municipality region		495
North	122 (24.7%)	
East	113 (22.9%)	
South	59 (11.9%)	
West	200 (40.5%)	
Living situation		402
Independent without stairs	155 (38.6%)	
Independent with stairs	247 (61.4%)	

Caption: Due to the pragmatic nature of the study, not all baseline measurements were available for all participants, leading to varying degrees of N. * = self-reported injuries/chronic diseases.

Table 2: Primary and secondary outcomes

Level	Outcome	Measurement instrument	Variable	Baseline (T0)	Immediately following PA (T1)	Significance	N
Primary	Muscle power	5x Power Squat Test	*Time, (s)	20.0 (10.5)	14.8 (6.7)	<0.001	252
			Mean muscle power, (W)	353.9 (132.5)	427.1 (150.8)	<0.001	201
			*Peak muscle power, (W)	592.3 (356.3)	761.2 (402.9)	<0.001	207
			*Mean velocity, (m/s)	0.4 (0.2)	0.5 (0.2)	<0.001	202
			Peak velocity, (m/s)	0.7 (0.2)	0.9 (0.2)	<0.001	207
		Deadlift	*Mean power, Watt	38.9 (19.7)	52.5 (23.7)	<0.001	203
			*Peak power, Watt	70.7 (40.9)	101.8 (63.2)	<0.001	204
			Mean velocity, (m/s)	0.7 (0.2)	0.9 (0.3)	<0.001	206
			*Peak velocity, (m/s)	1.1 (0.5)	1.4 (0.6)	<0.001	205
	Physical performance	Star agility run	*Number of cones touched	4.0 (2.7)	5.7 (3.0)	<0.001	317
		Timed Up-and-Go Test	*Time, seconds	10.2 (4.6)	7.8 (3.5)	<0.001	351
	Physical functioning	PSK questionnaire	*Activity 1 (0-100)	80.0 (20.0)	60.0 (40.0)	<0.001	324
			*Activity 2 (0-100)	80.0 (30.0)	60.0 (40.0)	<0.001	317
			*Activity 3 (0-100)	75.0 (30.0)	60.0 (40.0)	<0.001	243
Secondary	Motivation	Short survey	*Score (0-25)	27.0 (6.0)	30.0 (6.0)	<0.001	137

Caption: Note: Analysis reflects complete cases only. * = non-parametric variable: median (IQR) are reported and Wilcoxon matched-pairs signed ranks test was performed.

For the deadlift, mean and peak power increased from 38.93 and 70.68 W at baseline to 52.54 and 101.77 W immediately following the intervention. Among participants who continued power training, mean and peak power were 56.3 and 114.4 W at 1-year follow-up. Similarly, deadlift mean and peak velocity showed comparable improvements, from 0.68 and 1.06 at baseline to 0.94 and 1.39 following PA.

Physical Performance (activities domain of the ICF)

The number of cones touched in the Star agility run increased from 4.00 at baseline to 5.67 immediately following the intervention. This further increased to 9 at 1-year follow-up for participants who continued power training following intervention. For the Timed Up-and-Go test, the time to complete the task decreased from 10.18 s at baseline to 7.81 s following the intervention, and decreased to 6.8 s one year after the intervention among participants who continued power training.

Physical Functioning (participation domain of the ICF)

Scores on the PSK questionnaire for the three most challenging daily activities showed significant improvements: the difficulty scores for activities 1 and 2 both decreased from 80 to 60, and the difficulty score for activity 3 decreased from 75 to 60. One year after the intervention, PSK scores continued to decrease among participants who continued power training.

Motivation

Participants were considered motivated to participate in the Powerful Ageing intervention, as was reflected by motivation scores, with a mean of 27 at baseline and 30 following the intervention.

Discussion

Summary of Main Results

This study aimed to investigate the effects of PA on muscle power, physical performance, and physical functioning in older adults immediately following PA and at 1-year follow-up. Our results demonstrate significant improvements in muscle power, physical performance, and physical functioning following the PA intervention. These improvements appear to be maintained or further enhanced one year after the intervention in participants who continued to train, suggesting the impact of power training on the physical capabilities of older adults was durable. The high motivation scores increased over the training period, indicating high participant engagement and satisfaction with the intervention, while also mirroring the results of the previously-conducted feasibility study.[17]

The benefits of power training rely on both consistent participation and the implementation of a well-structured protocol. The program described in this study, PA, has been tested for its therapeutic validity and reproducibility, likely contributing to the positive results found in the present study. The study also supports the feasibility and acceptability of the Powerful Ageing intervention, as evidenced by high motivation scores and participant retention rates. These strengths underscore the potential of power training as a viable strategy to enhance physical function and independence among older adults.

Comparison with Previous Literature

The magnitude of improvement in our study corroborates and extends previous longitudinal studies on power training in older adults. Ramírez-Campillo et al. (2014) documented significant improvements in functional performance metrics after a 12-week power training intervention,[9] and Henwood et al.'s (2018) 24-week follow-up study after an 8-week high-velocity resistance training intervention showed maintained improvements in muscle strength and power relative to baseline, despite some performance decline.[18] Similarly, Pereira et al. (2012) reported significant functional performance improvements immediately after a 12-week power training program, with partial retention after 12 months of detraining.[19] Our study suggests not only maintenance, but improvements in muscle power and physical functioning over the course of one year in people who continued to train.

Strengths and Limitations

This study has several notable strengths. The multi-center design across multiple municipalities in the Netherlands enhances the generalizability of findings to a broader population of older adults. Additionally, it shows that power training interventions are able to be implemented in a practical community setting. Our use of objective measures for muscle power and physical performance in usual care provides robust data to support the observed improvements. Moreover, the follow-up at 1-year post-intervention offers a better understanding into the potential durability of the effects of power training, however, further research is needed to confirm the sustainability of these effects and compare these with a control group. Several limitations should be considered when interpreting the results of this study. First, the study design was a descriptive case series without a control group, limiting the strength of evidence considering the effectiveness of the intervention. Second, the study partially relied on self-reported outcomes measures, such as the PSK questionnaire, which could be subject to response bias. However, the use of such measures also allows for inclusion of patient-reported outcomes. Third, due to the pragmatic nature of the study, we encountered large differences in the availability of data between measuring points. This is a common limitation in usual care research, where a greater emphasis is placed on the intervention rather than research proceedings. However, this did limit our ability to assess the long-term effects of PA.

It is possible that the trend observed one year following the intervention is an overestimation, as it is likely that the 'healthiest' and 'fittest' participants will continue power training following the intervention.

Clinical Implications and Future Research

Care for older adults is shifting away from traditional forms of support, such as household assistance or providing aids, and instead, is actively promoting self-reliance in physical abilities. The significant improvements in muscle power, physical performance, and physical functioning observed following the PA intervention suggest that power training can be an effective component of rehabilitation and preventive care for older adults. Incorporating power training into standard physiotherapy practice or existing interventions for older adults could enhance the ability of older adults to maintain their independence, perform daily activities more efficiently, and potentially reduce the need for assistive devices or social support services. The improvements observed one year post-intervention suggest long-term benefits, which could be an important addition to regular care plans.

The high levels of motivation and participant satisfaction suggest that power training is a well-accepted and engaging form of exercise for older adults. This is critical for adherence and long-term success in maintaining physical activity levels. We should consider recommending power training as a key component of comprehensive care for older adults, especially for those who are at risk of functional decline. While these results are promising, they highlight the necessity for further research to confirm that power training is an effective intervention for improving and maintaining physical functioning in older adults, and if this is the case for all sub-groups as well (e.g. oldest old, those with specific injuries or disorders). To do so, a randomized controlled trial is needed to compare the efficacy of power training, traditional strength training, general conditioning exercises, and usual care provided by physiotherapy. Such a study would provide robust evidence to determine which approach best supports the physical independence and quality of life of older adults. By addressing this research gap, we can better inform clinical practice and optimize intervention strategies to support successful ageing. Future research should also aim to exploring the underlying mechanisms through which power training exerts its effects could provide valuable insights for optimizing exercise protocols. Investigating factors such as neuromuscular adaptations, changes in muscle architecture, and improvements in balance and coordination could help refine and enhance the effectiveness of power training interventions.

Conclusions

The findings of this study demonstrate that the Powerful Ageing intervention leads to significant improvements in muscle power, physical performance, and physical functioning among older adults. These improvements were not only found immediately following the intervention, but also seemed to be sustained one year later among participants who continued power training, indicating long-term benefits of power training. Furthermore, the increase in motivation scores suggests high levels of participant engagement and satisfaction with the intervention. Further research, in the form of a randomized controlled trial, is needed to confirm the effectiveness of power training in older adults, both in short and long term.

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Appendix 1: Therapeutic validity of Powerful Ageing

	CONTENT Criteria[18]	Powerful Ageing
1	The patient selection is described.	Patients were adequately described and contraindications to participation in Powerful Ageing were mentioned.
2	The patient selection is adequate.	Powerful Ageing is an intervention tailored to older adults who have experienced a decline in physical functioning. Our study population is older adults >65 years of age whom have requested assistance via the Social Support Act as a result of a decline in physical functioning.
3	Eligibility criteria for therapist and setting determined and adequate.	Physical therapy offices are required to meet various eligibility criteria (e.g., presence of a practice room and various materials, such as machines and free weights).
4	The therapeutic exercise is based on a-priori aims and intentions.	Prior research shows that power training has the ability to produce a high power output even in older adults. We hypothesized that power training would increase muscle power in older adults, positively effecting physical performance and physical functioning.
5	The rationale for the content and intensity of therapeutic exercise is described and plausible.	Prior research shows that power training interventions using a high-velocity and low-force approach are most effective in increasing muscle power in older adults. Powerful Ageing uses an intensity of 20-30% 1-RM and was tailored to the safety and feasibility of older adults.
6	The intensity of the therapeutic exercise described.	The intensity and additional training parameters of Powerful Ageing are described in **Table 2** using the TIDieR checklist.
7	The therapeutic exercise was monitored and adjusted when considered necessary.	Trainings were supervised by physical therapists and exercises were modified if needed. Once exercises became too easy, weight was added to make the exercise more difficult. Additionally, participants were monitored for injuries.
8	The therapeutic exercise was personalized and contextualized to the individual participant.	Prior to starting Powerful Ageing, participants were asked to identify the 3 most difficult activities encountered in daily life using the PSK questionnaire. During trainings, exercises were chosen that would aid in regaining the ability to perform those identified activities.
9	Adherence to the therapeutic exercise was determined and acceptable.	Adherence and training participation was recorded.
	Total score	9/9

Caption: Powerful Ageing is considered therapeutically valid.

Appendix 2: Power training criteria

	Concept	Criteria[12]	Powerful Ageing
1	Type of exercises	The training consists of exercises that emphasize the speed of the performance (e.g. Olympic weightlifting or strength exercises that have been adapted into power exercises).	√
2	Movement pace	The instruction and execution of the power exercises is "as fast as possible".	√
3	Rate of force development	Each exercise should be characterized by a fast and powerful concentric phase, followed by a slow and steady eccentric phase.	√
4	Training load	The resistance of the exercises is low. The intervention uses a training load of 20-30% of the 1-repetition maximum (1RM) OR, a build-up range is used between 0-60% 1RM (0-60% 1RM for lower extremity exercises and 30-60% 1RM for upper extremity exercises).	√
5	Duration of intervention	The minimum duration of the intervention is 8 weeks with a training frequency of at least twice a week.	√

Caption: Powerful Ageing meets the proposed criteria for power training.

Appendix 3: 6 questions to assess participant level of motivation

The short questionnaire used to assess participant level of motivation is based on elements from the Behavioral Regulation in Exercise Questionnaire (BREQ) and the Intrinsic Motivation Inventory (IMI). The short questionnaire consists of three questions related to the participant's intention and 3 questions related to the participant's self-efficacy. The answers to the questions are scored on a 5-point Likert scale. participants were considered 'motivated' if their score exceeded 18 points.

Intention

1. I intend to participate at least twice a week in power training for the next 14 weeks.

Completely disagree *1* *2* *3* *4* *5* *Completely agree*

2. I will attempt to participate at least twice a week in power training for the next 14 weeks.

Completely disagree *1* *2* *3* *4* *5* *Completely agree*

3. I expect to participate at least twice a week in power training for the next 14 weeks.

Completely disagree *1* *2* *3* *4* *5* *Completely agree*

Self-efficacy

4. If my intention is to participate at least twice a week in power training the next 14 weeks, I think I will achieve this regardless of the situation I find myself in.

Completely disagree *1* *2* *3* *4* *5* *Completely agree*

5. If my intention is to participate at least twice a week in power training the next 14 weeks, I think I will achieve this also when I take my home-life situation into account (support from partner, family, or friends, etc.).

Completely disagree *1* *2* *3* *4* *5* *Completely agree*

6. If my intention is to participate at least twice a week in power training the next 14 weeks, I think I will achieve this also when I take my daily schedule into account (work, hobby, or other activities).

Completely disagree *1* *2* *3* *4* *5* *Completely agree*

Appendix 4: Longitudinal outcomes measurements of Powerful Ageing

Outcome	Measurement instrument	Variable	Baseline (T0)			Following PA (T1)			1-yr follow-up (T2)		
			Mean (SD)	Median (IQR)	N	Mean (SD)	Median (IQR)	N	Mean (SD)	Median (IQR)	N
Muscle power	5x Power Squat Test	Time	21.7 (8.2)	20 (10.4)	383	15.8 (5.4)	18.8 (6.6)	300	12.6 (4.2)	11.1 (4.4)	57
		Mean power	349.9 (131.5)	328.4 (190.6)	322	429.9 (156.3)	409.5 (200.3)	279	502.0 (159.3)	466.6 (229.3)	54
		Peak power	641.1 (245.4)	591.9 (354.8)	328	803.3 (310.6)	757.2 (400.4)	277	952.6 (337.9)	945.4 (422.2)	54
		Mean velocity	0.4 (0.1)	0.4 (0.2)	323	0.5 (0.2)	0.5 (0.2)	279	0.6 (0.1)	0.6 (0.2)	54
		Peak velocity	0.7 (0.2)	0.7 (0.3)	327	0.9 (0.3)	0.9 (0.3)	278	1.0 (0.2)	1.0 (0.3)	54
	Deadlift	Mean power	39.9 (14.2)	39.0 (19.6)	338	53.4 (19.2)	53.0 (24.0)	275	54.3 (15.5)	56.3 (23.5)	58
		Peak power	75.4 (37.9)	70.7 (40.9)	338	109.9 (51.6)	101.8 (63.3)	276	111.4 (41.4)	114.4 (63.1)	58
		Mean velocity	0.7 (0.2)	0.7 (0.3)	340	0.9 (0.3)	0.9 (0.4)	276	0.9 (0.2)	1.0 (0.4)	58
		Peak velocity	1.1 (0.4)	1.1 (0.5)	340	1.4 (0.5)	1.4 (0.6)	275	1.4 (0.4)	1.5 (0.5)	55
Physical perfomance	Star agility run	Number of cones	4.6 (2.1)	4.0 (2.7)	460	6.1 (2.6)	5.7 (3.0)	332	8.7 (3.1)	9.0 (4.3)	59
	Timed Up-and-Go Test	Time	11.1 (4.4)	10.2 (4.6)	490	8.3 (2.7)	7.8 (3.4)	353	7.3 (2.3)	6.8 (2.7)	66
Physical functioning	PSK questionnaire	Activity 1 (0-100)	76.2 (17.6)	80.0 (20.0)	465	59.4 (26.4)	60.0 (40.0)	323	43.3 (28.6)	40.0 (40.0)	61
		Activity 2 (0-100)	74.0 (19.0)	80.0 (30.0)	458	59.1 (26.5)	60.0 (40.0)	317	42.7 (30.8)	40.0 (40.0)	57
		Activity 3 (0-100)	73.5 (18.9)	75.0 (30.0)	365	60.3 (25.9)	60.0 (40.0)	242	52 (32.1)	50.0 (53.0)	50
Motivation	Short survey	Score (0-25)	26.5 (3.2)	27.0 (6.0)	307	27.0 (4.5)	30.0 (6.0)	198	28.8 (2.1)	30.0 (1.0)	30

8

General Discussion

Mohamed el Hadouchi

General Discussion

Power training, which is characterized by high-velocity resistance exercises, has emerged as an intervention to counteract age-related declines in muscle power and functional performance.[1,2] However, its widespread implementation is hindered by inconsistencies regarding the content of the training, the lack of standardized methods to measure its impact, and limited research on the feasibility of power training in older adults. The studies presented in this dissertation were aimed to address these gaps in resesearch. In this general discussion, a summary of the main findings of each study will be presented, followed by a reflection on the results in which the strengths and limitations of the studies will be discussed. Moreover, the implications for both theory and practice are explored, highlighting scientific impact and influence on practice, research, policy and education . Lastly, future research directions are identified, and the chapter closes with final conclusions.

Summary of Main Findings

In **Chapter 2**, the therapeutic validity and replicability of power training interventions were examined. Our findings show that power training interventions were inadequately described, as none of the included studies provided a complete description of the intervention as proposed by the TiDieR checklist,[3] implying poor replicability. Key deficiencies included reporting on modification, adherence, and deliverance of the interventions. As a result, none of the included power training interventions met the CONTENT scale criteria for therapeutic validity either. Several critical aspects, including the rationale for intervention content and intensity, personalization of intervention, and adherence measures, were considered insufficient. Specific criteria for power training were lacking in the CONTENT scale, therefore we proposed criteria for the type of exercises, movement pace, rate of force development, training load, and duration. While most interventions met criteria related to type of exercises, movement pace, and rate of force development, only 36% met the criterion for training load, suggesting a lack of consensus on the optimal load for power training, which complicates standardization and comparison of study outcomes.

In **Chapter 3**, we evaluated 24 previously-identified tests that have been used to measure the effects of power training in older adults. Yet, literature on measurements properties was only available for 15 of these tests. The majority of tests demonstrated good reliability (ICC or correlation > 0.7), but their validity and responsiveness were either poorly described or not investigated. Based on the available evidence, the review suggested that the 1RM bench press, knee/leg flexion and extension, and ankle flexion/extension isometric and isokinetic

tests were the most promising tests for measuring the effects of power training in older adults. However, the review could not identify any validated assessment tools for measuring participation in daily activities, which highlights the need for developing assessment tools that are contextually relevant and representative of daily life functioning.

In **Chapter 4**, we aimed to achieve consensus on a core outcome set (COS) to measure the impact of power training in older adults covering the function, activities, and participation domain of the ICF. Following two Delphi survey rounds and an expert panel meeting, consensus was eventually reached on 11 tests. The prioritization of tests using a Fibonacci scoring method yielded as most important, practical, and feasible in older adults: the Squat Jump Test for the function domain and the Timed Up-and-Go test for the activities domain. There was no consensus on a test for the participation domain, however, daily-life accelerometry was proposed by some experts until a more suitable alternative is identified.

In **Chapter 5**, a meta-analysis compared the effectiveness of power training to strength training in improving muscle power, physical performance, and physical activity in daily life. Results showed that power training was more effective than strength training in increasing muscle power and physical performance, both within generic activity tests and within tests with an emphasis on movement speed. However, none of the included studies incorporated measurements instruments that assessed physical activity in daily life. This, again, highlights a significant gap in the literature with regards to measuring the participation domain of the ICF.

In **Chapter 6**, we evaluated the feasibility and preliminary effectiveness of a 12-week power training program named "Powerful Ageing" among older adults. Results showed that the intervention was highly feasible, evidenced by a 100% retention, attendance, and compliance rate among the 28 participants. The absence of injuries or adverse events supported the safety of the power training program for older adults. Additionally, significant improvements were observed in muscle power of the weighted squat and anaerobic power in the Wingate test, both categorized within the function domain of the ICF. Within the activities domain, physical performance showed improvement through significantly more distance covered on the 6-minute walk test, namely an average increase of 163.5 meters, more than three times the commonly accepted minimal clinically important difference (MCID) in older adults.[4] This indicates that power training may not only yield physiological improvements, but improvements in functional capacity as well. Within the participation domain, slight increases in gait activity and the number of walking bouts were observed, though these were not statistically significant. Lastly, the SF-36 indicated trends toward improvement in energy/fatigue, emotional well-being, and general health, but these also did not reach statistical significance.

In **Chapter 7**, the effects of "Powerful Ageing" power training were evaluated in an older, larger, and more heterogenous population of older adults, using a wider range of outcome measurements. This longitudinal study conducted across 17 municipalities in the Netherlands followed participants immediately following the intervention and at 1-year follow-up. Participants showed a significant increase in muscle power when performing the Power Squat Test and the Lifting Test (function domain), and also improved in the Start Agility Run and Timed Up-and-Go Test (activities domain). On average, participants reduced the time needed to perform the Timed Up-and-Go test by 2.4 seconds, double the MCID.[5] Additionally, activities of daily life became significantly less difficult to perform, suggesting a potential to impact participation and independence. Among participants who continued power training following the intervention, these improvements were even greater at 1-year follow-up.

Reflection on Results, Including Strengths and Limitations

Measuring Outcomes in Power Training

Valid and reliable assessment tools are critical for accurately measuring the effects of power training and for comparing results across different studies and tracking progress in clinical settings. The review on the reliability, validity, and responsiveness of tests used to measure the effects of power training in older adults **(Chapter 3)** addressed this by providing an overview of the tests identified in the systematic review and meta-analysis **(Chapter 5)**. The study described in **Chapter 3** was the first step towards creating a standardized test protocol for evaluating the effects power training in older adults, and its detailed analysis was the basis for the Delphi study **(Chapter 4)**. However, there were no tests that could be used to measure the impact of of power training within the participation domain, which was also a limitation in the systematic review and meta-analysis. A complete and comprehensive understanding of the effects of power training requires assessing outcomes both in activities of daily life (reflecting the performance qualifier within the activities domain) and in the participation domain of the ICF.

The Delphi study focused on achieving consensus on a core set of measurement instruments to measure the effects of power training in older adults within the function, activities, and participation domains of the ICF. This study was the first of its kind to do so, and while results are promising, further extension is necessary with regard to the selection of suitable instruments to assess the participation domain. While performance-based measures dominate current studies, instruments like accelerometers or patient-reported outcomes could be valuable additions to capture effects of power training in daily life. Future studies should integrate these tools to ensure a broader evaluation of power training effects. Ideally, this proposed core outcome set will be consistently adopted in future studies evaluating power

training, as was done in the studies described in **Chapters 6 and 7**. While these studies indicate positive effects of power training, future research should be powered for more rigorous assessment of participation-oriented measures. Doing so will enhance the evaluation of the clinical relevance of power training interventions in older adults, and offer a more holistic perspective aligned with the principles of the ICF framework.

Effectiveness of Power Training

The systematic review and meta-analysis provided a broad and rigorous synthesis of existing research by aggregating data from multiple studies showing that power training was more effective in improving muscle power and physical performance than strength training.The heterogenous study population included by the various studies supported the generalizability of our findings, thereby establishing a solid evidence base that informed our subsequent studies. However, the included studies exhibited considerable heterogeneity with regard to power training protocols and outcome measurements. This issue was also examined in our review evaluating the therapeutic validity and replicability of power training interventions **(Chapter 2)**, which highlighted a critical issue in the field of exercise science for older adults: the lack of standardized and comprehensive reporting of power training interventions. This deficiency not only hampers the replicability of study findings but also raises questions about the true effectiveness of power training interventions. The absence of detailed intervention descriptions prevents a clear understanding of what constitutes effective power training, thereby limiting its implementation in clinical practice. To address this issue, we recommend future research to adhere strictly to reporting guidelines, including the TIDieR checklist, the CONSORT statement, and the CONTENT scale.[3,6] Additionally, we proposed a set of power training criteria based on biomechanical and exercise physiology principles proposed by Kraemer et al. and Haff et al.[7,8] At the time this review was performed, there was no clear and comprehensive framework to specify the essential components of power training, thereby also not strictly differentiating power training from traditional strength training. The proposed set of power training criteria contains guidelines for the type of exercises, the movement pace, the rate of force development, the training load, and the duration of the intervention. These recommendations were the starting point from which the pilot and feasibility study **(Chapter 6)** and the longitudinal case-series were launched **(Chapter 7)**, as prior to conducting these studies we ensured that "Powerful Ageing" was therapeutically valid, replicable, and met the proposed criteria for power training.

Powerful Ageing: Evidence-Based Power Training

Power training should be therapeutically valid and feasible, and its outcomes should be measured in the function, activities, and participation domains of the ICF using a standardized core outcome set. We applied these criteria in the pilot and feasibility study **(Chapter 6)**, which

not only showed promising results regarding the effectiveness, but also reported high levels of participant motivation and satisfaction, indicative of positive participant engagement. These results complemented the quantitative data of the systematic review, suggesting that power training has potential to improve muscle power and functional performance in older adults and that power training is acceptable to the older adult population. However, the pilot and feasibility study's limitations included a small sample size, short duration, and use of a single geographical location, raising the question whether these results may be context-dependent. Therefore, the descriptive case series **(Chapter 7)** was conducted in a larger, older, and more diverse population of older adults. The findings reported in the descriptive case series supported the preliminary findings evidenced in the pilot study, adding depth to results on the efficacy of Powerful Ageing , while also supporting the idea that results are applicable to a broader segment of the older adult population. Nevertheless, to confirm these findings, future research should include a well-designed randomized controlled trial, complemented by an in-depth evaluation of participant experiences and a comprehensive analysis of the cost-effectiveness of the Powerful Ageing intervention.

Implications for Theory and Practice

In this dissertation, we conducted a comprehensive examination of power training in older adults across several different studies, and its results may have implications for both clinical practice and public health. These implications can be broadly categorized into impacts on theory, society, healthcare, and education.

Theoretical Considerations

The findings presented in this thesis contribute to a refined understanding of exercise science within gerontology, particularly concerning the role of muscle power in ageing populations. Traditionally, resistance training for older adults has prioritized muscle strength and mass, under the assumption that these were the primary determinants of physical function and independence. However, emerging evidence highlights the critical importance of muscle power, the capacity to generate force rapidly, for critical functional tasks. Moreover, the results presented in this thesis show the potential of power training to increase muscle power among older adults. The concept of overcoming inertia to initiate movement has been proposed as a prerequisite for effective functioning in older adults. This challenges traditional strength-centric exercise paradigms and suggest a more nuanced framework that incorporates power as a key component of physical function. Additionally, it provides a useful framework for understanding mobility limitations. Although this idea requires additional empirical validation, together with existing evidence and the findings described in this thesis, the notion is sufficient to promote the inclusion of power training in standard exercise recommendations

for older adults. Naturally, there is still a role for strength training among older adults if their deficits are strength-related; however, it should not be used as a one-size-fits-all solution to age-related declines in physical functioning.

Societal Impact

Given the growing societal challenges posed by an ageing population, such as rising healthcare costs, a shrinking workforce, and policy shifts encouraging older adults to live independently for longer, maintaining good physical functioning has become a prerequisite for successful ageing.[9,10] In this context, power training appears to offer significant potential. At a broader societal level, the widespread implementation of power training programs for older adults could lead to substantial public health benefits. It is known that, in general, resistance training offers numerous health benefits, including improved musculoskeletal function, maintenance of functional abilities, and reduction of risk factors associated with chronic disease.[11] It has also been associated with a reduced risk of falls and related injuries, which is a significant contributor to morbidity and healthcare costs in older populations.[10] However, the impact of power training should not be limited to physical functioning alone. Especially in older populations, the impact of an increased physical functioning (and increased participation in activities of daily life) on quality of life may is an equally or even more important goal. Unfortunately, current evidence, including our own research, does not yet clearly demonstrate that power training directly influences quality of life. One reason for this may be the lack of consistent inclusion of quality-of-life outcomes in existing studies. In our own research, a ceiling effect was observed when assessing quality of life using the SF-36 in the pilot and feasibility study of Powerful Ageing, indicating that participants already reported high levels of quality of life at baseline, limiting measurable gains.To fully realize the societal impact, future studies should not only focus on physical outcomes, but also systematically explore the effects of power training on broader domains of well-being and quality of life.

Integration into Healthcare Practice

Consistent with the findings presented in this dissertation, power training has emerged in the broader literature as a promising intervention for improving physical function in older adults. Additionally, there is growing evidence supporting the assessment of muscle power and the application of power training, particularly among older adults with conditions such as stroke and osteoarthritis.[12] This body of research highlights the value of integrating power training into standard physiotherapy and rehabilitation practices. Healthcare providers, particularly physiotherapists, need concrete guidance to translate this evidence into practice. This dissertation offers them a practical framework, based on validated criteria, for designing and applying power training in older populations. For the implementation of power training interventions, it is important that providers can identify the populations that are most likely

to benefit from power training, which are expected to be community-dwelling older adults who are starting to experience early functional decline.

While further research is needed to address limitations, including therapeutic validity and existing measurement protocols, current findings, including our research on feasibility, provide a framework for the safe and effective implementation of power training programs. Clinicians are encouraged to implement power training treatment plans for older adults in a variety of settings, ranging from community centers to specialized healthcare facilities, ensuring broader accessibility and impact.

Education

To support the integration of power training into clinical practice, the educational foundation regarding power training should be strengthened among students and healthcare professionals. Although the evidence base for power training in older adults is growing, it is not yet consistently embedded within the curricula of physiotherapy programs. More structural attention should be given to power training principles within both undergraduate and postgraduate education, including education on the specific characteristics of power training (e.g., high-velocity, low-load movements), its therapeutic potential in older adults, and how to tailor it to different levels of functional capacity and clinical conditions. In addition, continuing professional development courses, practical workshops, and clinical guidelines should include modules on therapeutic validity, patient selection, safety, and appropriate outcome monitoring. Providing healthcare professionals with accessible and applicable knowledge enables them to deliver high-quality, individualized interventions that address both functional goals and broader aspects of healthy ageing.

Practical Recommendations for Power Training

Practically, the findings of this dissertation highlight the need to re-evaluate traditional approaches to exercise prescription and rehabilitation for older adults. On the basis of the literature,the findings presented in this thesis, and years of clinical experience, I would personally propose the following:

Baseline Evaluations

Prior to initiating a power training program, health professionals should perform comprehensive initial evaluations of their participants to create a tailored training pogram that suits each individual's needs and abilities. A thorough baseline assessment also provides a benchmark to track progress over time. In addition to an individual's medical history and physical functioning goals, baseline evaluations should include:

1. Functional capacity tests: these assess how well a person can perform everyday activities.
2. Baseline power measurements: these establish a starting point for the person's power output. There are two main ways to do this:

a. Using accelerometers: These are small devices that measure the acceleration of a movement, through which values for speed and force can be derived. They provide accurate data about how a person moves, helping professionals understand and improve performance.

b. Conducting field tests: These are practical and functional tests, such as the Sit-to-Stand Test measures how quickly and forcefully a person can stand up from a seated position.
3. Measuring daily physical activity: this helps understand how active the person is in their everyday life.

Program Design

Power training programs should have a clear timeline, delineating the start and end of the exercise regimen, as well as specific goals, exercise doses, and rest periods. At each pre-defined time period, comprehensive assessments should be conducted to establish measurements of muscular power, functional performance, and performance in activities of daily living. The assessment protocol should align with the ICF framework, incorporating measures of activities and participation, to facilitate a comprehensive evaluation of power training efficacy, addressing both physiological adaptations and broader functional impacts.

Existing research supports our approach of a minimum of two power training sessions per week in older adults,[13] and recommendations regarding session duration have been substantiated by multiple investigations.[14–16] In my view, optimal physiological responses and fatigue management, in addition to superior adherence rates, occur with sessions of 45-60 minutes in duration. Additionally, it is important to incorporate warm-up, primary exercise stimulus, and cool-down phases, while monitoring appropriate fatigue management parameters [e.g. rated perceived exertion (RPE)]. Most notably, exercise prescription must be individualized, accounting for health status, functional capacity, and specific impairments, which, as mentioned above, should be measured at baseline. This personalized approach ensures optimal safety, maximizes physiological adaptations, and promotes long-term adherence. Training protocols should specifically address documented functional limitations while considering individual medical conditions and physical capabilities.

Exercise Selection and Progression

Power training requires a nuanced understanding of exercise physiology and biomechanics. Exercises should be carefully selected to target major muscle groups involved in functional activities of daily living. The core of the program should consist of compound movements

that mimic daily activities (e.g. squat-to-stand, step-ups), supplemented by more isolated exercises as needed. Functional exercises that emphasize speed and power should be selected to promote better functional transfer. For instance, power-based squat variations can improve lower body power for tasks like rising from a chair or climbing stairs, and upper body power exercises, such as medicine ball throws or rapid resistance band movements, can enhance abilities like reaching or lifting objects quickly. For enhancing explosive muscle power, exercises like plyometric jumps, medicine ball throws, and Olympic weightlifting movements are preferable over traditional strength exercises.

Movement speed should be maximized with a specific resistance, using lower loads than traditional strength training, varying between 0-60% of the 1RM, depending on the focus. For older adults, a relatively light resistance is advised to allow higher movement speeds, balancing strength and speed for optimal power output. Participants should be instructed to perform the concentric phase of exercises as rapidly as possible while still maintaining control. Exercise intensity and complexity should be gradually increased using the principle of progressive overload. This involves starting conservatively and gradually increasing the velocity of movements and/or the resistance used (intensity), volume, and complexity, as participants adapt and improve. In doing so, proper technique is the first priority. To maximize the benefits of power training, adaptive training models, such as velocity-based resistance training (VBRT) using real-time feedback, should be explored. The rate of progression should be carefully monitored and adjusted based on individual responses and adaptations. Systematic evaluation using validated instruments is crucial for monitoring progress and guiding program modifications in power training interventions.

Safety Considerations

Safety is critical in implementing power training for older adults. Training sessions should be led and supervised by qualified physical therapists who can provide real-time feedback and support. Practitioners should closely monitor exercise techniques to ensure proper form and reduce the risk of injury, which may include providing hands-on support and corrective feedback during sessions. Additionally, practitioners should educate participants on body awareness and the importance of controlled, deliberate movements, especially during high-velocity exercises. Power training should be designed to accommodate a range of (physical) abilities and be implemented utilizing appropriate equipment and a spacious, safe, and accessible training environment. Group sessions may foster social engagement within community settings. Lastly, appropriate rest periods can reduce injury risk.

Implementation

Implementing power training requires physiotherapists to have specific knowledge of exercise physiology and practical skills. This includes the ability to effectively teach the

methodology and technical execution of exercises, as well as the ability to periodize training programs. Periodization involves dividing a training program into different phases, each with its own specific goals and intensity, which helps to minimize injury risks and enhances the therapeutic validity and efficiency of power training. To support the long-term management of muscle power we should:

- Encourage continued training: motivate older adults to continue engaging in physical activity that challenges muscle power at least once or twice a week.
- Integrate power training into local activities: guide participants toward suitable community-based exercise options where power can be maintained.
- Individualize the power training protocol: Assist older adults in selecting activities that align with both their physical goals and personal preferences to increase long-term adherence.
- Monitor and revisit: offer follow-up opportunities (e.g., periodic check-ins or group sessions) to reassess progress and adjust the activity plan as needed.

Implications for Public Policy

Policymakers should recognize the value of power training and support its inclusion in public health initiatives aimed at promoting active and healthy ageing. Funding and resources should be allocated to develop and sustain power training programs, particularly in underserved communities where older adults may have limited access to exercise facilities and programs. The overall implications of power training in older adults can be profound, offering a multifaceted approach to enhancing physical function, quality of life, and independence. To support this, policymakers should consider:

1. Providing resources for community centers and healthcare facilities to create suitable exercise spaces and buying the necessary equipment.
2. Adding power training to national physical activity guidelines for older adults.
3. Running public awareness campaigns to educate older adults and their families about the benefits of power training.
4. Supporting long-term research on how power training affects health outcomes, physical performance, independence and quality of life in older adults.

Prioritizing power training in public health initiatives promises to improve the physical fitness, functional independence, and overall well-being of the ageing population, which aligns with the growing emphasis on promoting active, healthy ageing and maintaining quality of life well into advanced years. The practical implications of these findings on power training are broad and beyond the exercise recommendations as they require a comprehensive re-evaluation of how we address physical activity for older adults across healthcare, community, and policy domains. By embracing and implementing these evidence-based strategies, we can transform the ageing experience and support a more active, capable, and independent older population.

Future Research Directions

Future research should further deepen our understanding of power training in older adults, while also improving the quality of studies in this area. This can be achieved by investigating age-related neuromuscular adaptations, alterations in muscle architecture, and improvements in balance and coordination, in an effort to further refine and optimize the effectiveness of power training interventions in older adults. Research should focus on elucidating the biological mechanisms underlying the benefits of power training, potentially identifying novel targets to mitigate age-related functional decline. Additionally, the development and evaluation of integrated training approaches, such as combined power and balance training protocols, agility components (e.g., direction changes and reaction time), and multi-component programs, could further enhance the efficacy and applicability of such interventions.[17] Related to this is the development of personalized interventions and outcome measures, which are based on a comprehensive assessment of individual physical abilities at baseline, co-occurring conditions, and possibly even genetic factors. Personalized interventions would allow for more precise program design and progress tracking. Moreover, exploring the optimal load and intensity for power training within a personalized framework is particularly important for older adults with varying levels of baseline muscle power, ensuring safe and effective outcomes for each individual.

Researchers should also explore how to effectively implement power training programs in diverse community settings. This should address barriers to access, cultural adaptations, and strategies to promote long-term engagement. Such investigations will be vital for informing policies and ensuring equitable access to evidence-based interventions. Lastly, while the short-term effects of power training are well-documented, the long-term effects on functional outcomes and quality of life in older adults require further investigation. These studies should examine a wide range of outcomes (i.e., physical measures, functional abilities, quality of life, and healthcare utilization) and should also take the long-term cost-effectiveness of power training into account. Integrating relevant technological advancements, such as wearable devices and AI algorithms, offers promising ways to enhance training programs and closely monitor progress and adherence. Future research should prioritize examining how power training contributes to meaningful improvements in daily functioning to ensure its long-term effectiveness in promoting functional independence, minimizing disability, and enhancing the quality of life in older adults. Advancing these research directions will significantly deepen our understanding of power training's role in aging populations. By addressing these gaps, researchers can develop more tailored, evidence-based interventions that enhance physical capacity, autonomy, and overall well-being. As technological innovations progress and insights into the aging process expand, power training is well-positioned to play a pivotal role in optimizing physical performance and fostering healthy ageing.

Conflict of Interest Considerations

As a final note, it is important to note the dual role of the author, as a researcher and entrepreneur in healthcare, which introduces distinct methodological and ethical considerations. Both the pilot and feasibility study **(Chapter 6)** and the descriptive case series **(Chapter 7)** were based on the implementation of the Powerful Ageing power training intervention, which is a product of Health Research and Consultancy (HRC) of which the author has partial ownership. From the onset of this thesis, this relationships was fully disclosed and strict protocols were established to safeguard role separation. Throughout both of these studies, the author refrained from having any involvement in participant recruitment, data collection, or operational coordination of the intervention. All data were anonymized and analyzed independently by co-authors of each respective study, and all elements of research presented in this thesis were guided by academic advisors and subject to peer review. Concerning the valorisation of results, the research presented in this dissertation is openly accessible for everyone with no proprietary restrictions, as these findings are meant to contribute to the broader scientific foundation for implementing power training interventions in older adult care.

Although the duality of research and product ownership can be complex and requires clear and transparent agreements with regard to privacy, integrity, and dissemination of results, it is important that these complexities should not discourage collaborative engagement with practice partners or commercially involved entities. Instead, public-private partnerships should be stimulated to increase the impact of research findings and allow private parties to develop further, potentially resulting in both societal and economical benefits while also upholding standards of scientific credibility and public trust. .

Conclusions

This dissertation makes a significant contribution to physiotherapy and geriatric exercise science by establishing an evidence base for the effectiveness and feasibility of power training in older adults. It highlights the potential role of power training in preserving and enhancing physical function, thereby facilitating independence and improved quality of life among older adults. Additionally, it provides frameworks to address key gaps in power training definitions and standardization, including a core outcome set to measure the effects of power training in older adults. This work provides a foundation for integrating power training into both clinical and community-based settings, and future efforts should focus on translating these findings into clinical guidelines, public health initiatives, and policy recommendations to ensure widespread accessibility and long-term sustainability of power training as a strategy for healthy ageing.

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Appendix

- Summary
- Samenvatting
- Dankwoord
- Publications
- About the Author

Mohamed el Hadouchi

Summary

The global population is undergoing a significant demographic shift, as both the number of older adults and the growth of the "oldest-old" demographic is expected to increase. This trend presents substantial economic, societal, and health-related challenges. A critical concern is the progressive decline in physical function that comes with advancing age, which presents challenges for maintaining independence, autonomy, and active participation in daily life. Muscle strength, and especially muscle power, are fundamental components of physical functioning. Research has shown that muscle power deteriorates more rapidly and at an earlier age than muscle mass and strength, with losses of 10-30% per decade after age 40 and up to 70% of peak muscle power by age 80. This age-related decline in muscle power is strongly associated with functional decline in activities of daily living (ADLs) and an increased risk of falls, impeding the ability to perform everyday tasks, such as climbing stairs, rising from a chair, or recovering from a stumble.

While traditional views often assumed limited capacity for the improvement of muscle power in older adults, recent research challenges this, demonstrating that significant gains in muscle strength, power, and functional capacity are achievable through targeted exercise programs. Power training, defined as high-velocity resistance training that emphasizes rapid and explosive force production, holds significant promise for enhancing physical fitness and functional capacity in older adults. It targets fast-twitch (Type II) muscle fibers, which are particularly susceptible to age-related atrophy, and induces neuromuscular adaptations that lead to more efficient muscle activation and improved coordination. Despite its documented physiological benefits, power training remains underutilized in rehabilitation and fitness programs due to a lack of consensus regarding its definition, inconsistent implementation strategies, safety concerns, and varied assessment methodologies. This dissertation positioned power training within the International Classification of Functioning, Disability, and Health (ICF) framework, allowing for distinctions to be made between health-related and performance-related physical fitness, with a particular focus on performance-related aspects crucial for daily activities.

Aims of the Dissertation

This dissertation addresses the critical gaps between scientific evidence and the real-world application of power training for older adults. Specifically, it aims to:

1. Establish standardized assessment methods within the ICF framework to consistently and accurately measure the impact of power training.
2. Evaluate the effectiveness of power training in improving physical functioning in older adults.
3. Investigate the feasibility of implementing power training in practical settings.

This dissertation is structured into two main parts. **Part 1: "Harmonizing Outcomes: How to Measure the Impact of Power Training in Older Adults"** focuses on the methodological rigor and standardization of outcome measurement in power training research, and consists of the following chapters:

- **Chapter 2: Therapeutic validity and replicability of power training interventions in older adults: a review using the TIDieR checklist and CONTENT scale.**
  This chapter systematically reviewed existing power training interventions for older adults, assessing their therapeutic validity and replicability. The findings highlighted significant inconsistencies in the reporting of intervention details, often lacking sufficient information for accurate replication. Many studies did not fully adhere to criteria for therapeutic validity, posing challenges for the transferability and generalizability of research outcomes to clinical practice. This chapter underscores the urgent need for more transparent and detailed reporting of power training interventions to enhance research quality and practical applicability.
- **Chapter 3: The reliability, validity, and responsiveness of tests used to assess the effects of power training in older adults: A systematic review.**
  This systematic review critically evaluated the psychometric properties (reliability, validity, and responsiveness) of tests commonly used to assess the effects of power training in older adults. The results revealed considerable heterogeneity in the quality of measurement instruments. While some tests demonstrated acceptable reliability and validity for specific outcomes, there was a general scarcity of high-quality evidence regarding the responsiveness of these tests to changes induced by power training. This indicates a need for further development and rigorous validation of outcome measures that are sensitive to the unique adaptations elicited by power training in older populations.
- **Chapter 4: Establishing a core outcome set to evaluate the effects of power training in older adults: a Delphi study.**
  This chapter utilized a Delphi study, complemented by the Nominal Group Technique, to achieve consensus among experts on a core outcome set (COS) for evaluating power training effects in older adults. The study successfully identified a comprehensive COS that includes outcomes spanning muscle power, physical performance in daily activities, and aspects of functional independence. This COS provides a standardized framework for researchers and clinicians, ensuring consistency in outcome measurement across studies and facilitating more meaningful comparisons and syntheses of evidence. The established COS is crucial for guiding future research and improving the evidence base for power training interventions.

In the second half of the dissertation, **Part 2: "From Theory to Practice: Evaluating of effects and Clinical Applicability of Power Training in Older Adults"** evaluates the effectiveness and real-world applicability of power training based on empirical evidence. This section contains the following chapters:

- **Chapter 5: Effectiveness of power training compared to strength training in older adults: a systematic review and meta-analysis.**
  This systematic review and meta-analysis compared the effectiveness of power training with traditional strength training in older adults across various outcomes. The findings suggest that power training is superior to strength training for improving muscle power and specific functional performance measures that require rapid force production, such as stair climbing ability and gait speed. While both training modalities are beneficial, power training appears to offer distinct advantages for dynamic, everyday activities crucial for maintaining independence in older adults.
- **Chapter 6: Power training in older adults: a pilot and feasibility study.**
  This pilot and feasibility study investigated the practical implementation of a power training program in a real-world setting with older adults. The study assessed adherence rates, safety, and participant satisfaction. The results indicated that the power training protocol was highly feasible and well-accepted by older adults, with high adherence rates and no major adverse events. Participants generally reported positive experiences and perceived improvements in their physical capabilities. This chapter provides valuable insights into the practical considerations for integrating power training into existing community and clinical exercise programs, demonstrating its potential for widespread adoption.
- **Chapter 7: The impact of power training on muscle power, physical performance, and physical functioning in older adults: a descriptive case series.**
  This descriptive case series illustrates the direct impact of power training on individual older adults' muscle power, physical performance, and functional independence. Through detailed case examples, the chapter demonstrates tangible improvements in specific activities of daily life, balance, and overall physical capabilities following power training interventions. These real-world applications underscore the clinical relevance of power training and provide qualitative evidence of its potential to enhance the quality of life and autonomy in older adults.

Overall Discussion, Conclusions, and Implications

This dissertation provides a comprehensive exploration of power training for older adults, bridging critical gaps between theoretical understanding and practical application. It addresses the challenges related to the definition, measurement, effectiveness, and implementation of power training, and its findings highlight the significant potential of power training in mitigating age-related functional decline in older adults.

The establishment of a core outcome set **(Chapter 4)** provides a crucial foundation for standardizing future research and improving the comparability of study findings. The evidence of power training's superior effectiveness when compared to strength training **(Chapter 5)**, particularly for dynamic functional outcomes, reinforces its value. Furthermore, both the feasibility study and the descriptive case series **(Chapters 6 and 7)** demonstrate that power training can be safely and effectively implemented in real-world settings, debunking concerns about its applicability in older populations.

In conclusion, this dissertation strongly advocates for the increased integration of power training into exercise recommendations and rehabilitation programs for older adults. To maximize its benefits, future research should adhere to standardized reporting guidelines for interventions and consistently utilize the proposed core outcome set. Clinicians and practitioners are encouraged to consider power training as a key modality for enhancing muscle power, improving functional performance, and ultimately empowering older adults to maintain their independence and quality of life. This work offers a robust theoretical and empirical basis for advancing healthy aging strategies and promoting active lifestyles for the older adults.

Samenvatting

De mondiale bevolkingssamenstelling ondergaat een ingrijpende transformatie als gevolg van een dubbele vergrijzing: enerzijds neemt het absolute aantal ouderen toe, ook groeit het aandeel van de oudste ouderen, waaronder tachtigers, negentigers en honderdplussers. Deze demografische verschuiving brengt aanzienlijke maatschappelijke, economische en gezondheid gerelateerde uitdagingen met zich mee.

Een belangrijke zorg is de progressieve achteruitgang van het fysiek functioneren bij het ouder worden, waardoor zelfstandigheid, autonomie en actieve deelname aan het dagelijks leven onder druk komen te staan. Spierkracht, en in het bijzonder explosief spiervermogen (muscle power), vormen essentiële pijlers van fysiek functioneren. Onderzoek toont aan dat muscle power vanaf het vierde levensdecennium sneller afneemt dan spiermassa of spierkracht, met een geschat verlies van 10 tot 30% per decennium, oplopend tot circa 70% verlies van het piekvermogen rond het tachtigste levensjaar. Deze leeftijdsgebonden afname in muscle power hangt sterk samen met functionele beperkingen bij het uitvoeren van dagelijkse activiteiten en een verhoogd valrisico. Alledaagse activiteiten zoals traplopen, opstaan uit een stoel of het herstellen van een balansverstoring worden hierdoor in toenemende mate bemoeilijkt.

Waar voorheen werd aangenomen dat verbetering van muscle power op latere leeftijd slechts in beperkte mate mogelijk was, tonen recente studies overtuigend aan dat gerichte oefenprogramma's bij ouderen wel degelijk tot substantiële winst kunnen leiden op het gebied van spierkracht, muscle power en functionele capaciteit. Power training, een specifieke vorm van krachttraining gericht op het verbeteren van muscle power door middel van weerstandsoefeningen uit te voeren met hoge snelheid en explosieve kracht, blijkt effectief te zijn. Deze trainingsvorm richt zich specifiek op snel samentrekkende (type II) spiervezels, die extra kwetsbaar zijn voor leeftijdsgebonden atrofie. Bovendien bevordert power training neuromusculaire aanpassingen die resulteren in een efficiëntere spieractivatie en verbeterde coördinatie.

Ondanks deze fysiologische en functionele voordelen blijft power training ondervertegenwoordigd in revalidatie- en beweegprogramma's voor ouderen. Factoren die hieraan bijdragen zijn onder meer het ontbreken van een eenduidige definitie van power training, inconsistente implementatiestrategieën, en zorgen over de veiligheid en uiteenlopende meetmethodieken, aangezien studies sterk variëren in gebruikte uitkomstmaten terwijl consensus ontbreekt over welke instrumenten betrouwbaar, valide en responsief de effecten van power training binnen de verschillende ICF-domeinen weerspiegelen. In dit proefschrift wordt power train-

ing conceptueel gepositioneerd binnen het kader van de International Classification of Functioning, Disability and Health (ICF). Dit biedt een raamwerk om onderscheid te maken tussen gezondheidsgerelateerde en prestatiegerichte fysieke fitheid en benadrukt het belang van functionele prestaties voor het behoud van dagelijks functioneren bij ouderen. Het vormt daarmee een theoretisch fundament dat richting geeft aan toekomstig onderzoek en praktische toepassing."

Doelstellingen van het proefschrift

Dit proefschrift beoogt de kloof te overbruggen tussen wetenschappelijke evidentie en praktische toepassing van power training bij ouderen. De centrale doelstellingen zijn:

1. Het ontwikkelen van gestandaardiseerde meetmethoden binnen het kader van de ICF om de impact van power training op consistente en valide wijze te kunnen evalueren.
2. Het evalueren van de effectiviteit van power training in het verbeteren van het fysiek functioneren bij ouderen.
3. Het onderzoeken van de haalbaarheid van de implementatie van power training in praktische toepassingsomgevingen.

Het proefschrift bestaat uit twee hoofddelen.

Deel 1: "Harmonisatie van uitkomsten: hoe meet je de impact van power training bij ouderen?"

Het eerste deel van het proefschrift richt zich op methodologische consistentie en de standaardisatie van uitkomstmaten in onderzoek naar power training en omvat de volgende hoofdstukken:

- **Hoofdstuk 2:** In dit hoofdstuk wordt een systematische review gepresenteerd waarin de therapeutische validiteit en reproduceerbaarheid van bestaande interventies gericht op power training bij ouderen zijn geanalyseerd aan de hand van de TIDieR-checklist en de CONTENT-schaal. De resultaten tonen aanzienlijke variabiliteit en onvolledigheid in de rapportage van interventiecomponenten, waardoor de reproduceerbaarheid van studies en de implementatie de praktijk worden belemmerd. Een substantieel deel van de geïncludeerde studies voldeden niet aan de criteria voor therapeutische validiteit, wat de generaliseerbaarheid van de onderzoeksresultaten beperkt. Deze bevindingen onderstrepen het belang van transparante en gedetailleerde rapportage van power trainingsprotocollen voor verdere kennisontwikkeling en implementatie.
- **Hoofdstuk 3:** Dit hoofdstuk presenteert een systematische review waarin de meeteigenschappen van instrumenten die gangbaar zijn voor het evalueren van de effecten van power training bij ouderen zijn beoordeeld. De bevindingen wijzen op substantiële variatie in de kwaliteit van de onderzochte meetinstrumenten. Hoewel enkele testen robuuste psychometrische eigenschappen vertonen, ontbreekt voor veel instrumenten

overtuigend bewijs ten aanzien voor hun gevoeligheid voor verandering (responsiveness). Deze bevindingen benadrukken de noodzaak tot verdere ontwikkeling en validatie van meetinstrumenten die specifiek zijn afgestemd op het detecteren van veranderingen als gevolg van power training bij ouderen.

- **Hoofdstuk 4:** In dit hoofdstuk wordt door middel van een Delphi-consensusprocedure aangevuld met de Nominal Group Technique, een Core Outcome Set (COS) ontwikkeled voor het evalueren van power training bij ouderen. Deze COS omvat uitkomstmaten op het gebied van muscle power, fysieke prestaties in dagelijkse activiteiten en functionele zelfstandigheid. De totstandkoming van een gestandaardiseerde set draagt bij aan een verhoogde methodologische consistentie in zowel wetenschappelijk onderzoek als in praktijk. Tevens faciliteert het gebruikt van de COS onderlinge vergelijkbaarheid en synthese van onderzoeksresultaten, wat kennisverspreiding en-toepassingen ten goede komt.

Deel 2: "Van theorie naar praktijk: effectiviteit en klinische toepasbaarheid van power training bij ouderen"

Het tweede deel van het proefschrift richt zich op de effectiviteit en toepasbaarheid van power training in de praktijk en omvat de volgende hoofdstukken:

- **Hoofdstuk 5:** In dit hoofdstuk wordt een systematische review en meta-analyse gepresenteerd waarin de effectiviteit van power training werd vergeleken met die van met traditionele krachttraining bij ouderen. De resultaten tonen aan dat power training superieur is in het verbeteren van zowel muscle power als functionele prestaties waarbij de snelheid van krachtontwikkeling essentieel is, zoals bij traplopen en het verhogen van de loopsnelheid. Hoewel beide trainingsvormen gunstige effecten genereren, biedt power training aantoonbare voordelen ten aanzien van dynamische activiteiten die bepalend zijn voor het behoud van zelfstandigheid op oudere leeftijd.
- **Hoofdstuk 6:** In dit hoofdstuk wordt een pilot- en haalbaarheidsstudie beschreven waarin een power trainingsprogramma werd geïmplementeerd in een realistische setting met oudere deelnemers. De resultaten toonden aan dat het programma veilig en uitvoerbaar was, met een hoge mate van therapietrouw en positieve evaluaties door de deelnemers. Deze bevindingen ondersteunen de praktische toepasbaarheid van power training binnen zowel klinische als eerstelijns zorgsetting.
- **Hoofdstuk 7:** Dit hoofdstuk bevat een reeks casusbeschrijvingen waarin de effecten van power training op muscle power, fysieke prestaties en functionele zelfstandigheid bij ouderen worden geïllustreerd. De resultaten tonen concrete verbeteringen in balans, uitvoering van dagelijkse activiteiten en algehele fysieke capaciteit. Deze praktijkvoorbeelden onderstrepen de klinische relevantie van power training en leveren kwalitatieve onderbouwing voor de meerwaarde ervan binnen gepersonaliseerde interventies in de-ouderenzorg.

Algemene beschouwing, conclusies en implicaties

Dit proefschrift biedt een integrale en systematische verkenning van power training bij ouderen en overbrugt daarbij cruciale lacunes tussen theoretisch inzicht en praktische toepassing. Het werk behandelt de uitdagingen rondom de definitie, meting, effectiviteit en implementatie van power training, en onderstreept het potentieel van deze trainingsvorm om leeftijdsgebonden achteruitgang in fysiek functioneren tegen te gaan.

De ontwikkeling van een Core Outcome Set **(hoofdstuk 4)** vormt een belangrijke stap richting standaardisatie van onderzoeksmethoden en draagt bij aan de verbetering van de vergelijkbaarheid en synthese van wetenschappelijke bevindingen. De resultaten in **hoofdstuk 5** bevestigen dat power training effectiever is dan traditionele krachttraining, met name op dynamische functionele uitkomstmaten waarbij de snelheid van krachtontwikkeling centraal staat. De haalbaarheidsstudies in **hoofdstukken 6 en 7** tonen bovendien aan dat power training veilig, uitvoerbaar en positief ontvangen wordt binnen realistische zorgomgevingen, waarmee bezorgheden over de toepasbaarheid bij oudere populaties worden weerlegd.

Samenvattend pleit dit proefschrift nadrukkelijk voor een bredere en structurele integratie van power training in oefenrichtlijnen en revalidatieprogramma's voor ouderen. Om het volledige potentieel van deze interventie te benutten, is het van belang dat toekomstig onderzoek gebruikmaakt van gestandaardiseerde rapportagerichtlijnen en de voorgestelde Core Outcome Set implementeert. Zorgprofessionals worden hierbij aangemoedigd om power training te beschouwen als een centrale interventie voor het vergroten van muscle power, verbeteren van fysiek functioneren, en het versterken van autonomie en kwaliteit van leven bij ouderen.

Op deze wijze levert dit proefschrift een waardevolle bijdrage aan de verdere onderbouwing en implementatie van gerichte interventies ter ondersteuning van fysiek functioneren, zelfstandigheid en een actieve leefstijl in de ouder wordende populatie.

Dankwoord

Het voltooien van dit proefschrift markeert niet alleen het einde van een intensief en verrijkende academische traject, maar ook een persoonlijke reis van groei en ontwikkeling waarin ik oude gewoonten moest herzien, leerde loslaten en opnieuw naar mezelf en mijn werk heb leren kijken. In dit proces waren de ontmoetingen en samenwerkingen met anderen voor mij zowel een krachtige spiegel als een bron van groei.

Dit proefschrift is voor mij veel meer dan een verzameling studies en analyses; het is een reis van persoonlijke groei, gedragen door waardevolle ontmoetingen, onverwachte inzichten, tegenslagen en de steun die mij telkens weer vooruithielp. De filosoof Ricoeur benadrukt dat wij gevormd worden door onze ontmoetingen, de verhalen die wij delen en de ervaringen die wij samen beleven. Mijn verhaal is daarom vooral een verhaal van ontmoeting en dialoog: van gesprekken die mij tot het uiterste uitdagen, twijfels die mij scherper maakten en samenwerkingen die mij vooruitbrachten. Zoals Levinas het treffend verwoordde: *"je leert jezelf pas echt kennen via de ander"*. Precies dat vond zijn weerslag in de ontwikkeling van dit proefschrift.

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Conference Contribution

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About the Author

Mohamed el Hadouchi was born in Beni Touzine, Morocco, on January 2, 1970. He obtained his Bachelor's degree in Physiotherapy from the University of Applied Sciences Utrecht in 1999. He then specialized in Sports Physiotherapy at the IAS – International Academy for Sportscience, graduating as a sports physiotherapist in 2004. During this program, his interest in the relationship between physical performance, rehabilitation, and scientific evidence was further strengthened. In 2009, he completed a Master's degree in Clinical Health Sciences, with a specialization in Physiotherapy Science at Utrecht University, enhancing his clinical expertise with a scientific foundation in research methodology and knowledge development within the field of physiotherapy.

Throughout his career, Mohamed has worked in various clinical settings, focusing on the treatment and guidance of (elite) athletes, but primarily on individuals with load- and movement-related problems in primary care, including older adults and people with chronic conditions. In addition to his work as a sports physiotherapist, he has also been active as a performance coach and exercise physiologist, providing individualized performance optimization programs for (elite) athletes.

Alongside his clinical work, Mohamed has been active as a lecturer and curriculum developer in higher education, guiding students and professionals in their development within physiotherapy and sports rehabilitation. He combines teaching with practice-oriented research, with a specific focus on the role of muscle power and the effects of power training on physical performance across various populations.

In 2017, he was awarded a Doctoral Grant for Teachers by the Dutch Research Council (NWO). With this grant, he initiated a PhD project investigating the effects of muscle power and power training on physical functioning and performance capacity in older adults. This research was conducted in collaboration with the University of Applied Sciences Utrecht (HU) and Vrije Universiteit Amsterdam (VU), and serves as a bridge between scientific research, clinical practice, and educational innovation. During the PhD trajectory, he also completed a Master of Business Administration (MBA) in 2020, expanding his expertise in leadership, organizational development, and strategic management in healthcare.

In addition, Mohamed is co-owner of Health Research and Consultancy, an innovation-driven healthcare company focused on developing scientifically grounded treatment methods and interventions in physiotherapy and the broader field of health care. Through this company, he

works to translate scientific insights into practical applications, aiming to improve the quality and effectiveness of care.

The PhD trajectory culminating in this dissertation marks the culmination of his longstanding commitment to bridging science, practice, and education. His research contributes to a deeper understanding of the role of muscle power and power training in prevention and rehabilitation and offers new perspectives for more targeted and person-centered approaches to physical training and functional recovery in older adults.

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Amsterdam Movement Sciences conducts scientific research to optimize physical performance in health and disease based on a fundamental understanding of human movement in order to contribute to the fulfillment of a meaningful life.