OSJ | OPEN SCIENCE JOURNAL

PRACTICE BRIDGE

Training Specificity and Ecological Validity: Challenging Reductionist Exercise Paradigms for Older Adults

Robert T Morrison[1,2]*

[1]Exercise Physiologist, Ireland
[2]Doctoral Candidate, Department of Physical Education and Sports Sciences, University of Limerick, Ireland

*Corresponding author: Robert T Morrison: rob@morrisonperformance.ie

OPEN ACCESS

Citation: Morrison R.T. (2024) Training Specificity and Ecological Validity: Challenging Reductionist Exercise Paradigms for Older Adults . Open Science Journal 9(2)

Received: 11th August 2023

Accepted: 4th August 2024

Published:19th August 2024

Funding: The author(s) received no specific funding for this work

Competing Interests: The authors have declared that no competing interests exists.

Abstract:

‘*Ageing is not lost youth but a new stage of opportunity and strength.*’ - Betty Friedan

This article challenges the prevalent approach in exercise science for improving functional performance in older adults. It argues that contemporary exercise research and practice adhere to an outdated paradigm that undermines the principle of specificity in training and assessment. The author supports this central critique by examining fundamental issues including conceptual imprecision, paradigmatic limitations, and misapplications of core theories of motor learning. Additional evidence from exercise science literature demonstrates how these issues compromise the effectiveness of interventions by violating the specificity principle. To address these limitations, the author proposes a preliminary framework titled 'The Emergence of Skilled Mobility in Ageing' (ESMA), which aligns training and evaluation with individual task-environment constraints. This framework recognises the critical role of adaptive variability and representative practice design in optimising coordination, skills, and mobility. The proposed preliminary framework has significant implications for interdisciplinary collaboration and knowledge translation through focused and ecologically valid assessments and interventions. Overall, this article identifies key gaps in the current exercise science paradigm for older adults and offers an integrated solution that promotes specificity and real-world functioning. Future research will focus on the development and validation of this framework.

Keywords: Exercise, Older adults, Functional performance, Specificity, Ecological dynamics

Introduction

The utilisation of first-principles reasoning is of the utmost importance in the quest for knowledge and advancement. As Rene Descartes stated, 'If you would be a real seeker after truth, it is necessary that at least once in your life you doubt, as far as possible, all things.' Reasoning from first principles involves breaking down complex concepts into fundamental truths and building a solid foundation from which to analyse and evaluate. In contemporary exercise science, this approach facilitates critical examination of current theories, methodologies, and paradigms. By questioning fundamental principles and challenging assumptions, and exploring the fundamental concepts of the field, one can stimulate innovation, challenge established beliefs, and enhance our understanding of human movement, performance, and health. This first-principles approach is particularly valuable when addressing the complex challenges at the intersection of exercise science and gerontology, where established paradigms may not fully capture the unique needs of older adults.

The global ageing population has led to an increased prevalence of frailty, a condition affecting approximately 10% of adults over 65, although estimates range from 4.0% to 59.1% [1]. Frailty is characterised by reduced physiological reserves, heightened vulnerability to adverse outcomes, and multi-system impairments. These factors contribute to difficulties in activities of daily living (ADL), loss of independence, and diminished health perceptions [2–9]. Given its widespread impact, frailty has become a focal point of significant research interest [10–13].

Exercise is a practical and powerful means of counteracting functional decline and preventing adverse health outcomes in the ageing population [14,15]. A wealth of evidence supports the efficacy of prescribed exercise, which involves strength, power, aerobic, and mobility activities, in compensating for age-related physical decline [16–18]. The goal of these exercise programmes is to improve overall functional performance and maintain a high quality of life. However, translating general fitness improvements into real-world functional gains remains a challenge [19–21].

This article presents a theoretical rationale for a novel approach to exercise prescription for older adults and introduces the initial formulation of the Emergence of Skilled Mobility in Ageing (ESMA) preliminary framework. The ESMA framework is grounded in the principles of ecological dynamics, an approach that views human movement and skill acquisition as emerging from the interaction between the individual, task, and environment. Ecological dynamics integrates concepts from dynamical systems theory and ecological psychology, offering a comprehensive perspective on how individuals adapt and function in real-world contexts [22]. This framework serves as the foundation for an ongoing research programme aimed at developing, refining, and validating this innovative approach. By critically examining current paradigms and proposing a new framework grounded in ecological dynamics, this article sets the stage for future empirical investigation. Readers should note that while the ESMA framework is presented here in its preliminary form, it is a work in progress, with detailed methodological guidance and empirical validation to be developed through subsequent research phases.

Scope

This article evaluates the current exercise approaches used to enhance functional capacity in older adults by examining conceptual clarity, motor theory, and paradigmatic constraints. The author presents relevant scientific exhibits in support.

Thesis

This article contends that current exercise approaches for functional performance in older adults adhere to a well-established paradigm rooted in the motor schema theory, which dilutes the principle of specificity. Owing to the misalignment between training methodologies and real-world functional outcomes, this article presents a novel framework based on ecological dynamics. This emphasises the placement of exercise and assessment in the context of daily living tasks and environments.

First principles: paradigmatic challenges

Philosophical perspectives

Despite its apparent clarity in terms of epistemological frameworks [23], rigorous methodologies [24], and emphasis on translational principles [25,26], it is important to consider exercise science from a paradigmatic perspective to uncover any inherent limitations and explore the potential for paradigm shifts. Karl Popper's philosophy provides valuable insights applicable to exercise science research [27]. His focus on hypothesis-driven investigations aligns with the work of exercise scientists in formulating hypotheses on training effects, interventions, and underlying mechanisms [28]. These hypotheses are then tested through controlled experiments and empirical observations, actively seeking evidence to challenge existing theories and assumptions. By adopting Popper's philosophy, exercise scientists engage in critical enquiry that propels scientific knowledge within the field.

On the other hand, there is an argument that exercise science can be viewed from a Kuhnian perspective [29]. Thomas Kuhn's philosophy of science introduced the concept of scientific paradigms and revolutions. According to Kuhn, scientific knowledge progresses through periods known as normal science, in which researchers work within a shared framework or paradigm [30]. As defined by Kuhn, a scientific paradigm represents an accepted achievement in science that provides model problems and solutions for a community of practitioners over a certain period [31]. However, revolutionary shifts in thinking occur when new theories or frameworks emerge, which significantly alter our understanding of science. This perspective becomes evident when considering various exercise science concepts like 'VO2 debt', 'lactic acidosis', or even the commonly used formula '220-age' which have been reinterpreted over time [32–35].

The evolving paradigms of exercise science

Concerns have been raised regarding the absence of distinct paradigms in the field of exercise science, from the lack of guiding principles connecting exercise science to its position within biological sciences [36]. Consequently, exercise science faces the challenge of clearly defining and measuring the key attributes required to advance its field [37]. Further complications arise regarding the instruments used because their objectivity or subjectivity depends on the perspectives of the individual researchers [38]. Constructs may become enduring paradigms if they are not challenged or refined by greater understanding. Therefore, accepting the status quo without further examination does not contribute to a good scientific discipline [38–41]. A synthesis of the above may better reflect the actual situation. Exercise science may operate as a 'normal science' in the sense put forward by Kuhn, but with shared inconsistencies in vague and malleable paradigms through which hypotheses are tested. However, the implications for exercise science are significant and should not be underestimated. The lack of a well-defined paradigm or the widespread acceptance of unchallenged constructs can hinder theory development, falsifiability, reproducibility, and progress in the field.

First Principles: The Issues of nomenclature and conceptual clarity

Concepts are essential for distinguishing between phenomena [40,41]. Without clear concepts, nomological validity is lost and scientific progress is hindered [42]. Conceptual changes from paradigm acceptance can lead to the misappropriation of terms. Researchers use terms that fit the accepted paradigm and create a standardised language among practitioners [43,44]. This lack of consistent terminology persists, as researchers accept theories that fit a given paradigm.

Exercise science has faced issues with nomenclature, causing considerable confusion [45–47]. For example, the polarising terms ‘aerobic’ and ‘anaerobic’ have been used to dichotomise exercise modalities when human movement relies on the integrated functioning of both anaerobic and aerobic energy systems [45]. Categorising exercise modalities as strictly ‘aerobic’ or ‘anaerobic’ is an oversimplification that fails to capture the complex interplay and coordination between two integrated systems. Similarly, the term 'power' is frequently touted as a generic neuromuscular or performance characteristic as opposed to its mechanical (SI) definition as ‘the rate of performing work’ [48]. This demonstrates the imprecision that can arise from the established nomenclature of exercise physiology.

Moreover, terms such as physical fitness, physical function, functional fitness, and functional capacity conflate capacity with ability and create confusion among researchers and practitioners (Table 1). For example, physical fitness is defined as the body's ability to perform tasks [49], whereas functional fitness refers to the capacity to meet the demands of daily life [50]. The lack of a universally accepted 'functional performance' definition further compounds matters. In this article, 'functional performance' is chosen as the most widely applicable term to describe an individual's ability to perform activities of daily living, encompassing both capacity and skill execution in real-world contexts

Table 1. Common terms used to conceptualize functional performance.

Common Terms	Sample Interpretation
Functional ability	Actual or potential capacity of an individual to perform normal activities and tasks [51].
Functional capacity	Ability to perform the activities and tasks necessary to live independently [52].
Functional fitness	Capacity to meet ordinary/unexpected demands of daily life safely and effectively [50].
Functional status	Ability to physically perform activities such as self-care, being mobile, and independence at home or in the community [53].
Physical ability	Actual skill; mental or physical; native or acquired. Ability to perform some physical act.
Physical capacity	Ability to learn a skill, usually mental; native, as opposed to acquired.
Physical fitness	Ability to carry out daily tasks with vigour and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits [49].
Physical function	Ability to carry out activities that require physical action, ranging from self-care to more complex activities that require a combination of skills, often with a social context [54].
Physical functional status	Level of activities performed by an individual to realise the needs of daily living in many aspects of life [55].
Physical performance	Objectively measured whole body function related with mobility [56].

The International Classification of Functioning, Disability, and Health (ICF) provides a valuable framework for understanding the complex nature of functional performance in older adults [57]. This model offers a biopsychosocial approach that considers the interplay between an individual's health condition, environmental factors, and personal factors. It helps to clarify the distinction between an individual's potential physical aptitude (capacity) and their demonstrated proficiency in activities of daily living (ADL) (ability) [58].

In the context of exercise for older adults, the ICF framework highlights several key points that support a more comprehensive approach to functional performance, including the multi-dimensional nature of functioning, environmental influences, personal factors, and interaction between body functions and activities. This perspective aligns with the present critique of reductionist approaches within exercise science. It suggests that effective exercise interventions for older adults should address not only physical capacity, but also the ability to perform in varied real-world contexts. Thus, the ICF provides theoretical support for the development of more ecologically valid approaches [58].

The principle of specific adaptation to imposed demands is fundamental to exercise science but is often misunderstood. This principle states that the human body adapts specifically to training demands and associated stressors [59], which is supported by studies on motor performance, muscle architecture, neural plasticity, and various cellular processes [60–67]. While some argue that the similarity in bioenergetics and biomechanics between training and task determines specificity [68], others claim that optimal gains come from training closely resembling the task [69], with some suggesting that specificity and learning transfer can coexist depending on the measures used [70]. These views underestimate the strict definition of specificity [71,72]. Specificity requires targeted task-specific training to elicit matched physiological adaptations. Attempts to define specificity as a continuum have undermined its definitive nature. Optimising performance necessitates embracing specificity as a dichotomous proposition, not a flexible guideline but an inviolable rule for human performance. Overall, the goal of optimising independence in ADL [73,74] and developing capacity for unpredictable daily environments highlights the need for clear, consistent terminology and concepts in exercise science for older adults [75].

Implications for the development and progress of theory

The lack of precision and agreement on conceptual definitions hinders cumulative knowledge building, impeding the incremental refinement of theories [39,76]. For example, the inconsistently defined concept of ‘fitness’ has faced criticism for obstructing the testing of falsifiable hypotheses and reproduction of findings [36]. Numerous constructs proposed for the ‘lactate threshold’, such as the onset of blood lactate accumulation and lactate turn point, exemplify this problem. With over 25 distinct proposed lactate threshold constructs, consensus and comparative analyses are hampered as researchers continue to propose new constructs without consolidating existing knowledge. [39]. This conceptual multiplicity enables 'reinventing the wheel' rather than building on established concepts. As Chalmers noted, 'in the absence of an accepted paradigm or some candidate for paradigm, all facts that could possibly pertain to the development of a given science are likely to seem equally relevant' [76]. Ultimately, inconsistent nomenclature and terminology impede the incremental refinement of theories. Establishing conceptual clarity by consolidating definitions and constructs is critical to scientific progress [40,42].

From principles to action: Insights from motor theory

Motor learning theory offers critical insights into exercise specificity and its link to functional performance [77]. This field examines how practice, training, and experience refine motor and movement skills. In 1950, Lashley proposed that learned motor skills are stored as ‘motor engrams’ or neural patterns in the brain [78]. Since then, motor control theory has progressed at an almost decadal pace (Fig. 1). As Table 2 outlines, research has progressed along two main avenues: motor programmes and dynamic systems theories. The contrast between these theories highlights the principles of variability and the representativeness of functional transfer. Implications for exercise science are discussed below.

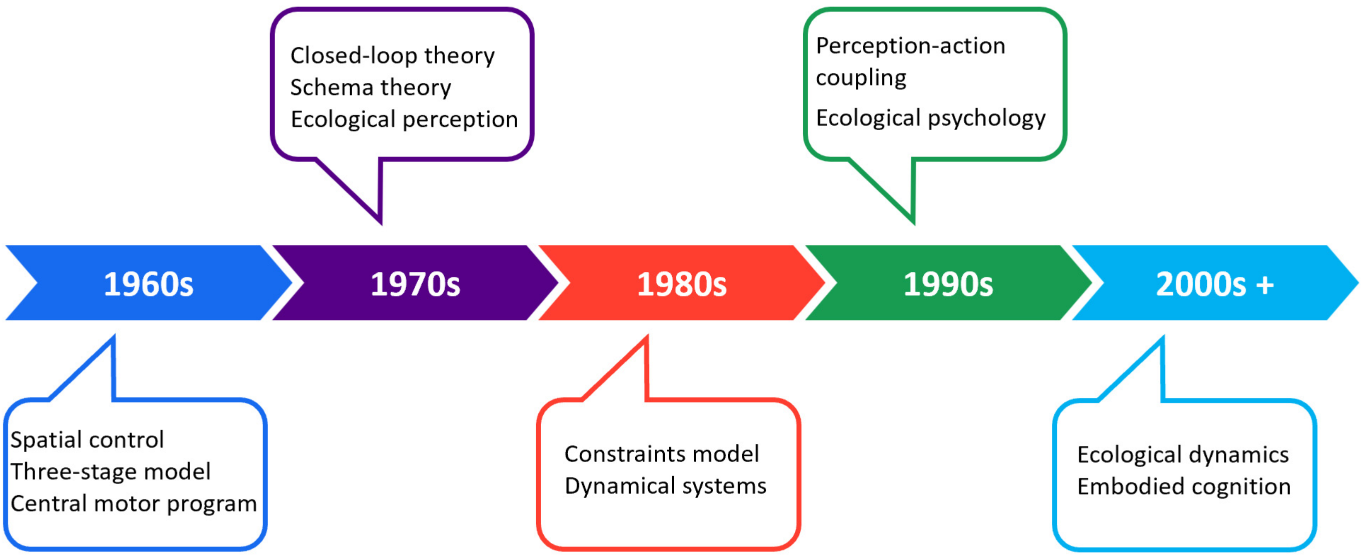

Figure. 1 Evolution of motor learning theory from the 1960s to the present.

Table 2. Synopsis of the progression of motor learning theory

Year	Author	Title	Approach	Synopsis
1967	Bernstein [79]	Degrees of freedom, aka 'spatial control'	Motor Programme	The nervous system simplifies movement control by organising and constraining degrees of freedom into functional synergies.
1967	Fitts & Posner [80]	Three-stage model	Motor Programme	Motor learning involves three stages: cognitive, associative, and autonomous, with increasing skill and decreasing effort.
1968	Keele [81]	Central Motor Programme Theory	Motor Programme	Movements are controlled by stored motor programmes in the brain, which dictate the sequence of muscle activations. Minimal flexibility.
1971	Adams [82]	Closed-Loop Theory	Dynamic	Motor learning relies on continuous feedback for movement adjustment, emphasising the role of sensory feedback.
1975	Schmidt [83]	Schema Theory	Motor Programme	Updated motor programme model. Motor learning involves developing generalised motor programmes (GMPs) and schemas to guide movement execution. Allows more adaptability than the Keele model.
1979	Gibson [84]	Ecological Perception	Dynamical	Real-time interactions between organisms and their meaningful surroundings as the basis for perception
1986	Newell [85]	Model of Constraints	Dynamical	Motor learning occurs through coordination from organismic, environmental, and task constraints interacting
1987	Kelso, Schöner [86]	Dynamical Systems	Dynamical	Motor learning is a self-organising process, with movement emerging from interactions between individual, task, and context.
1990	Warren [87]	Perception-action coupling	Dynamical	The perception and action processes are intrinsically linked and cannot be separated. Reciprocal real-time interactions between perception and action
1996	Reed [88]	Ecological psychology	Dynamical	Extends Gibson's work. Actions emerge from the real-time interplay between an actor and the environmental context.
2008	Davids [89]	Ecological Dynamics	Dynamical	Constraints Interaction in a Perception-Action Cycle
2009	Chemero [90]	Embodied cognition	Dynamical	Thinking and behaviour emerge from the bidirectional interactions between an organism's brain, its body, and the environment.

Schmidt's (1975) generalised motor programme theory has greatly influenced the exercise science field. It proposes that skills are controlled by motor schemas that specify invariant features while allowing for adjustable parameters, such as timing or force [83,91]. For instance, motor schemas contain a general stored movement pattern with modifiable force and timing to adapt to a skill. This implies that schemas may be transferred to similar tasks, as the motor programme can be adjusted [92,93]. Although schema theory includes parameterisation, this article focuses on critiques of the limited flexibility and transfer of programmed schema to new contexts. The motor schema theory was built on Bernstein's (1967) concept of degrees of freedom which refers to the extensive joint and movement possibilities in the musculoskeletal system. Bernstein proposed that the nervous system simplifies control by constraining degrees of freedom into functional units termed synergies [79]. However, schema theory emphasises central programming rather than emergent coordination.

Kelso and Schöner's dynamical systems theory (DST) has emerged as a parallel path [86]. DST, which evolved from constraints and closed-loop theories, proposes that movements and coordination arise from interactions between the individual, task, and environment under various constraints [94]. Constraints refer to the boundaries or features of a task, environment, or organism that shape the emergence of functional movement solutions [95,96]. The core principles of DST include:

- Self-organisation: The formation of movement patterns through self-organisation occurs due to spontaneous interactions between an organism and its environment, subject to certain constraints.
- Adaptability: Variability in movement patterns is essential for optimising movements to suit diverse situations.
- Perception-action coupling: The coupling between perception and action is ongoing and relies on continuous perceptual information to coordinate movement.

The motor schema theory proposes that generalised motor programmes guide movement [83]. In contrast, DST views movement emerging from interacting constraints [86]. DST recognises real-time perception-action coupling, the intrinsic link between how an individual perceives their environment and how they act within it, whereas schema theory focuses on central programming (Fig. 2). Although schema theory allows some adaptability, it underestimates the role of variability in functional transfer. As a later discussion shows, varied practices enhance flexibility and transfer [97]. However, DST better accounts for adaptable, context-specific solutions without depending on repetitive skill rehearsal. These contrasting perspectives highlight the shortcomings of schema theory when applied to real-world skills, laying the groundwork for the following critical analysis.

Generalised Motor Program Theory	vs	Dynamical Systems Theory
Generalisable programs	vs	Situation-specific emergence
Central structures	vs	Distributed control
Feedforward	vs	Feedback
Abstract computations	vs	Embodied cognition
Adapting stored ‘engrams’	vs	Perception-action coupling

Figure. 2 Contrast of the core principles of the two primary theories of motor learning

Relevance to exercise specificity and functional performance

While motor schema theory and DST present contrasting perspectives, they share common ground in the concept of practice variability, as exemplified by the 'variability of practice hypothesis’ [97]. This hypothesis proposes that exposure to varied practice is crucial for developing flexible cognitive patterns and strategies that enable the learning and transfer of skills. The variability-of-practice hypothesis applied to schema theory suggests that practicing a skill with parameter variations strengthens the underlying schema [83]. This somewhat aligns with Bernstein's (1967) concept of degrees of freedom, suggesting that practice involves learning to control movement variability [79].

However, variability in schema theory is limited to pre-planned parameter adjustments within the generalised motor programme (GMP) framework, maintaining an internal focus disconnected from the immediate environment. Critically, schema theory assumes that improved performance results from a more robust internal schema, rather than an enhanced alignment with environmental information. For instance, Newell (1991) argued that the schema concept does not capture the emergent nature of coordinated movements [98]. This limitation is particularly relevant in real-world contexts where adaptive and flexible responses to changing environments are crucial.

Empirical evidence on schema theory yields mixed results. While some findings align with the variability-of-practice hypothesis [99,100], discrepancies emerge, particularly in complex, real-world tasks [97,101], highlighting the theory's inadequacy in dynamic skill acquisition contexts. Furthermore, the focus of schema theory on central representations neglects perception-action coupling, as emphasised by ecological approaches [84,89]. For instance, Araújo and Davids (2011) suggested that skill acquisition involves developing the person-environment relationship rather than creating internal motor programmes [102].

By contrast, DST acknowledges that functional coordination and skills emerge from constrained interactions during representative practice [85,102]. Representative practice design aims to create training environments and tasks that closely reflect the perceptual and decision-making demands of real-world situations. Such a perspective aligns with research on motor control variability, which suggests that the nervous system selectively regulates movement variability to maintain stability in task-critical dimensions, while allowing flexibility in others [103]. This nuanced view of variability contrasts with the more rigid generalisation of schemas across contexts.

The limitations of schema theory indicate the need for alternative models that consider the context-dependent nature of skill development in practical situations, thus challenging its fundamental assumptions. The principles of DST have laid the groundwork for more comprehensive frameworks that place greater emphasis on the interplay between individuals and their environments. These emerging viewpoints offer ways to devise context-specific exercise training, drawing attention to the importance of adaptive variability in exercise specificity and functional transfer. Adaptive variability refers to flexibility in movement patterns that allows individuals to adjust their responses to changing environmental demands, thereby enhancing the transfer of skills to real-world situations.

One such concept, ecological dynamics, builds upon these principles to offer a more comprehensive approach for understanding skill acquisition and transfer. This perspective, which will be explored in greater detail later, is relevant for exercise interventions designed to enhance functional performance in real-world settings for older adults.

Perpetuation of the reductionist paradigm

Contemporary exercise research and practice continue to be guided by a reductionist paradigm rooted in Schmidt's motor schema theory [104–106]. To reiterate, this theory proposes that movements are controlled by generalised motor programmes that allow the transfer of skills between similar tasks [83,91]. The schema theory paradigm focuses on improving physical capacity in isolation through repetitive training. However, DST recognises functional coordination and skills emerging from constrained interactions during representative practice [85,107].

Fleishman’s taxonomy delineates various physical and perceptual proficiency abilities related to the ability to perform a task (Table 3) [108,109]. This taxonomy highlights the narrow range of attributes that are influenced by current exercise approaches. For example, strength, flexibility, and gross body coordination depend on broader perceptual-motor skills such as sensory processing, reaction time, and multi-limb coordination [110]. Performing a bicep curl is highly dependent on strength, but transferring that strength gain to washing dishes requires coordination of shoulder flexion with precise wrist and finger movements based on visual cues [111]. Consequently, it can be inferred that general strength or stamina training has a lesser effect on the overall functional competence in real-world tasks involving several integrated capacities.

Table 3. Fleishman's taxonomy of perceptual motor and physical proficiency abilities

Ability Type	Category	Operational Definition	Example
Perceptual motor	Arm-Hand Stability	Steadiness and control of the arm and hand.	Holding a paintbrush steady for detailed artwork.
	Control Precision	Accuracy and stability of controlled movements.	Operation of a surgical instrument during surgery.
	Finger Dexterity	Fine control and coordination of finger movements.	Playing a musical instrument like a piano.
	Manual Dexterity	Precise hand-eye coordination and fine motor skills.	Stringing beads on a necklace.
	Multi-limb coordination	Coordinating movements involving multiple limbs.	Dancing with complex arm and leg movements.
	Rate Control	Modulation of the speed or rate of movements or responses.	Adjusting the pace of walking on uneven terrain.
	Reaction Time	Speed of response to a stimulus.	Quick response to a red light turning red.
	Response Integration	Coordinating multiple actions into a single movement.	Playing a musical instrument with multiple limbs involved.
	Response Orientation	Adjusting motor response based on a stimulus cue.	Turning a steering wheel in response to road signs.
	Speed of Movement	The speed of performing a single movement.	Quick tapping on a keyboard.
	Wrist-Finger Speed	Quickness and accuracy of the wrist and fingers	Quick typing on a keyboard.
Physical proficiency	Dynamic Flexibility	Ability to perform smooth, controlled movements through a full range of motion.	
	Dynamic Strength	Ability to exert force repeatedly or sustainably over time during dynamic movements.	
	Extensive Flexibility	Range of motion around a joint, related to stretching and reaching movements.	
	Explosive Strength	Capability to produce a maximal force in a short time, commonly associated with rapid movements or jumps.	
	Gross Coordination	The skill of combining multiple parts of the body or muscle groups to perform complex movements efficiently.	
	Gross Equilibrium	Ability to maintain balance and stability during static or dynamic activities.	
	Stamina	Capacity to sustain prolonged physical or mental effort, often associated with endurance and resistance to fatigue.	
	Static Strength	The maximum force a muscle or muscle group can exert against an immovable object or resist without any visible change in muscle length.	
	Trunk Strength	Strength of the muscles in the torso or core region, which provides stability and support during various movements.	

Nevertheless, core textbooks perpetuate the reductionist paradigm in which isolated exercise training improves functional transfer [105,106]. One textbook on resistance training states that practicing general strength exercises produces direct functional carryover through increased force-generating capacity [104], citing evidence that resistance training improves ADL based on improved muscle strength and size [112,113]; and resistance training improves physical function in older adults by increasing muscle strength, power, and endurance [114]. This suggests a direct carryover effect on daily activities. Similarly, primary studies have demonstrated an inconsistent application of the specificity principle across training and assessment [115,116]. In one study, the authors argued that the benefits of traditional resistance training for improving muscle strength have limited transfer to the performance of activities of daily living (ADLs) in the elderly population [116]. They argued for 'functional training' using multiplanar, coordinated, and multijoint movements. However, their testing protocol was confined to isolated tests of trunk strength, rate of force development, and endurance, with participants confined to a machine, bearing no resemblance to true functional assessment.

A disconnect exists between targeted training of fitness capacities and changes in standard functional performance assessments. For example, older adults without specific deficits in strength or power may not exhibit improvements in common functional tests after isolated training of those attributes, as reported in meta-analytical studies [21,62]. This demonstrates the problem of assuming a functional carryover from general strength and power gains, especially when no initial impairment exists. Such individuals may be better served by specific task practice. Isolating fitness domains (strength, power) disregards the integration and coordination of multiple capacities needed for competence in variable, unpredictable ADL.

Research findings have shown considerable variability in the contribution of physical attributes to functional performance. Leg extensor muscle power accounts for 12-45% of the variance in functional performance, whereas strength contributes slightly less, accounting for 10-37% of the variance [117]. Other studies have suggested that leg press power and habitual physical activity account for approximately 40% of the variance in self-reported functional status [118]. This indicates that a range of attributes are likely to contribute to the remaining variance, including maximal strength, muscle endurance, aerobic capacity, and neuropsychological and health status factors, as expected from Fleishman's taxonomy. Therefore, task competence is multi-dimensional. Exercise prescription texts often rely on general assumptions rather than on promoting skill practices under various task-specific conditions [94,119]. These examples reflect the persistent influence of reductionist paradigms. This manifests itself in common assessments and training, as the upcoming exhibits demonstrate.

Exhibits: From evaluation to intervention.

The reductionist paradigm manifests in controlled assessments and generic training disconnected from ecological contexts. The key issues are insufficient variability, inappropriate progression, and dependence on equipment-altering movement. The following demonstrates these points across common assessment and training approaches.

Assessments that lack ecological validity

The reliance on reductionist, controlled assessments illustrate the misalignment with real-world specificity. There are numerous tests that measure functional performance (Table 4). However, these tests are purported to serve as proxies for both physical fitness domains and functional performance rather than competence in daily living [120]. It could be argued that they are neither ecologically valid nor domain-specific, as they do not directly quantify attributes, such as muscular strength or power. Hence, these tests fall within the grey area between the physical fitness domains (capacity) and functional performance (ability). This positioning is often cited as a compromise between accuracy and ecological validity, which refers to the degree to which they reflect real-life conditions [121–123]. However, this compromise comes with limitations. These tests are susceptible to floor and ceiling effects, which limit the detection of changes in low- and high-functioning groups [124–126]. Furthermore, these tests demonstrate only a weak-to-moderate correlation with ADL competence and insufficient responsiveness to change [125,127–129].

Table 4. Common tests of functional performance in exercise science

Test	Measures	Domain
10-Meter Walk [130]	Gait speed	Mobility
2-Minute Step [122]	Cardiovascular fitness with step-ups	Cardiovascular endurance
30-Second Arm Curl [131]	Upper body strength and endurance	Muscular Strength/Endurance
30-Second Chair Stand [132]	Lower body strength and endurance	Muscular Strength/Endurance
400-Meter Walk [133]	Endurance walking ability	Cardiovascular Endurance
4-Stage Balance [134]	Balance in varying conditions	Balance
5-Repetition sit-to-stand [135]	Lower body strength and power	Muscular Strength/Power
6-Minute Walk [136]	Cardiovascular endurance	Cardiovascular endurance
8-Foot Up-and-Go [137]	Agility and Dynamic Balance	Agility/Balance
Alternate Step [138]	Agility, coordination, cardiovascular fitness	Agility/Cardiovascular Endurance
Back Scratch [122]	Shoulder and upper body flexibility	Flexibility
Berg Balance Scale [139]	Balance and fall risk	Balance
Box and Block [140]	Manual dexterity/upper limb function	Fine motor skills
Chair sit-and-reach [141]	Hamstring and lower back flexibility	Flexibility
Figure-8 Walk [142]	Agility and coordination in walking	Agility / coordination
Four Square Steps [143]	Dynamic Balance and Functional Mobility	Balance/Agility
Functional Reach [144]	Dynamic balance and reach	Balance
Hand grip strength [145]	Overall grip strength	Muscular Strength
Finger tapping [146]	Manual Dexterity and Coordination	Fine motor skills
Lateral Reach [147]	Measure lateral trunk flexibility	Flexibility
Modified Push-Up [148]	Upper body strength and endurance	Muscular Strength/Endurance
One-Leg Stand [149]	Static Balance	Balance
One-Minute Sit-to-Stand [150]	Lower body strength and endurance	Muscular Strength/Endurance
Short physical performance battery [151]	Overall physical performance and mobility	Overall Physical Performance
Sit and Reach [152]	Flexibility of the lower back and hamstrings	Flexibility
Six-Minute Pegboard and Ring [153]	Manual dexterity and upper extremity coordination	Fine motor skills
Stair Climb [154]	Lower body strength and endurance	Muscular Strength/Endurance
Standing Long Jump [155]	Lower body power and explosiveness	Muscular Power
Tandem Walk [156]	Balance and coordination	Balance/Coordination
Timed Up-and-Go (TUG) [124]	Mobility, Balance, Agility	Balance/Agility
Zigzag Agility [157]	Agility, Quickness, and Directional Change	Agility

The most common functional assessments, such as the short physical performance battery (SPPB) and Timed Up-And-Go (TUG) tests, serve as surrogate measures of physical capacity rather than competency in daily living skills [127–129]. For example, the SPPB evaluates balance, gait speed, and lower body strength by using controlled self-paced tasks to deduce a composite score [151]. The TUG test measures the time to stand, walk three metres, turn around, and sit back down [124]. This dependence on reductionist instruments to quantify fitness supports the paradigmatic focus on physical capacities rather than abilities [121,123]. As discussed earlier, this conflates vague concepts, such as capacity and ability, undermining the principles of specificity and ecological validity.

In comparison, assessments deemed to have greater ecological validity, such as the assessment of motor and process skills (AMPS) and executive function performance tests (EFPT), may better evaluate proficiency in simulating daily activities [158,159] (Table 5). The AMPS uses detailed task evaluation to assess the quality of task performance based on effort, efficiency, safety, and independence. Studies have shown that the AMPS has high inter-rater and test-retest reliability for evaluating task function in older adults [160–162]. Meanwhile, the EFPT directly measures abilities such as communication and medication management through simulations of daily activities. The EFPT also shows good discriminatory ability for task competence across disparate populations along with sound psychometric properties [163–165]. Thus, ecological focused instruments, such as AMPS and EFPT, better measure real-world skill proficiency in accordance with the dynamical systems perspectives.

Table 5. Ecological assessments of activities of daily living (ADL)

Title	ADL included
Katz ADL Index [166]	Bathing, dressing, toileting, transferring, continence, feeding
Barthel Index [167]	Feeding, bathing, grooming, dressing, bowel and bladder control, toileting, chair transfer, ambulation
Lawton Instrumental ADL Scale [168]	Telephone use, shopping, food preparation, housekeeping, laundry, transportation, medication management
Functional Independence Measure (FIM) [169]	Eating, grooming, bathing, dressing, toileting, mobility, locomotion, stairs
Assessment of motor and process skills (AMPS) [170]	Varies, depends on the specific tasks assessed.
Performance Assessment of Self-Care (PASS) [171]	Bathing, dressing, grooming, feeding, toileting, functional mobility
Modified Barthel Index (MBI) [172]	Feeding, bathing, grooming, dressing, bowel and bladder control, toileting, chair transfer, ambulation
Functional Assessment Measure (FAM) [173]	Varies, depends on the specific tasks assessed.
Executive Function Performance Test (EFPT) [158]	Varies, depends on the specific tasks assessed.
Assessment of Living Skills and Resources (ALSAR) [174]	Varies, depends on the specific tasks assessed.
Canadian Occupational Performance Measure (COPM) [175]	Varies, depends on the specific tasks assessed.
Milwaukee Evaluation of Daily Living Skills (MEDLS) [176]	Varies, depends on the specific tasks assessed.
Nottingham Extended Activities of Daily Living Scale (NEADL) [177]	Varies, depends on the specific tasks assessed.
Routine Task Inventory (RTI) [178]	Varies, depends on the specific tasks assessed.
GARS = Groningen Activities Restriction Scale [179]	Varies, depends on the specific tasks assessed.
ADAP = Assessment of daily activity performance [180]	Varies, depends on the specific tasks assessed.

Generic training lacking specificity

Traditional exercise training approaches fail to consider the key principles of variability and representativeness, i.e. context specificity. Current modalities include strength, power, balance, and 'functional training', which place a narrow focus on improving general physical capacity rather than on developing adaptable competence in real-world tasks (Fig.3) [181–189].

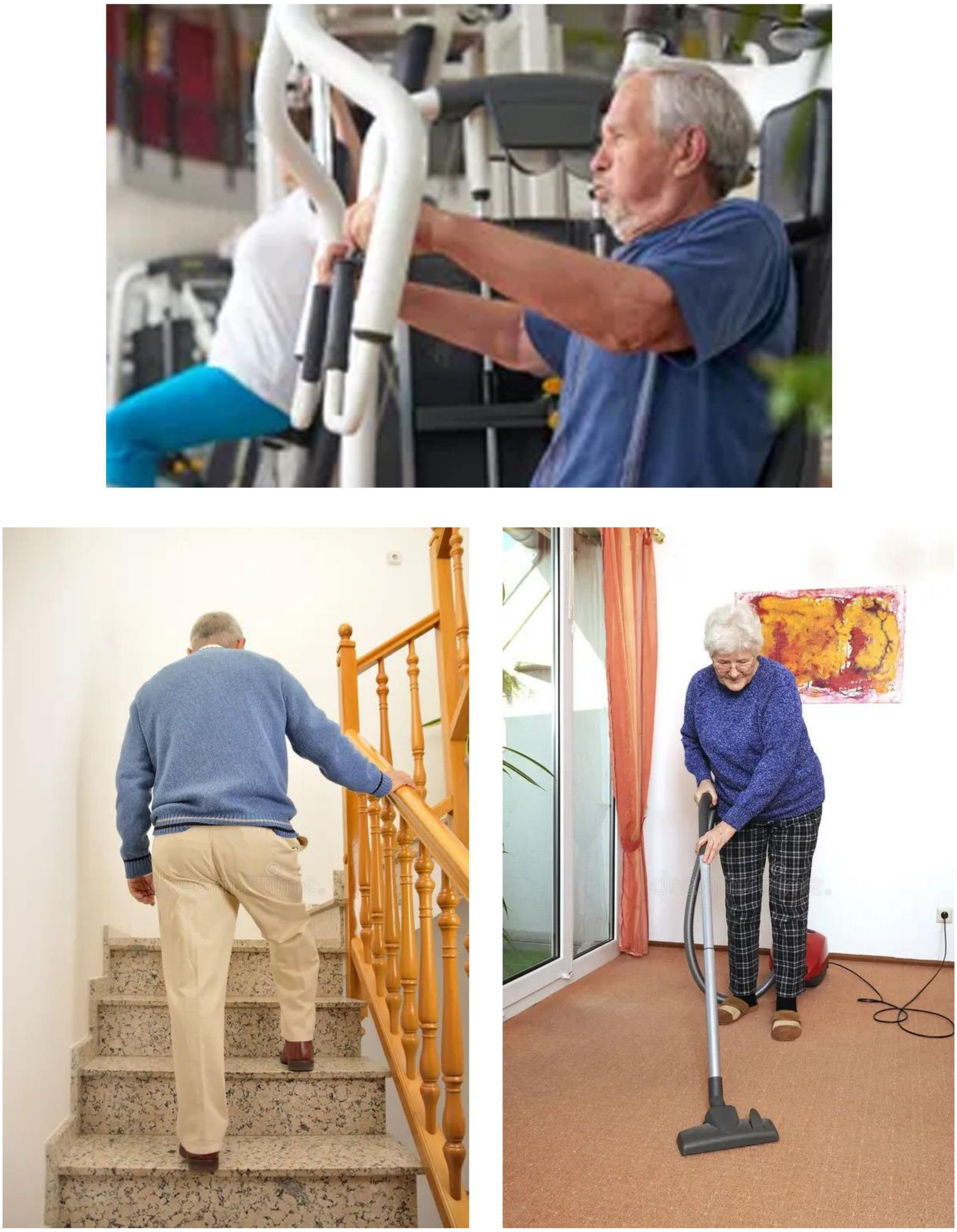

Figure. 3 Common exercise modalities lack variability, and context-specific practice aligned with real-world activities.

Controlled strength training is performed with the purpose of improving muscle force generation. Most movements are confined to isolated joint motions or external machines that disregard multijoint coordination, which is critical for ADL [181–184]. Motor learning research indicates that task specificity and adaptable variability are essential for functional transfer, which traditional strength training approaches lack [190–192]. Moreover, high-velocity power training, with the intention of performing the concentric part of a movement as quickly as possible, lacks both variability and contextual interference [193,194]. This restricts the development of flexible motor solutions necessary for changing the ADL demands. In contrast, ecological-based training has demonstrated improved skill acquisition and ADL competence with variable, multi-directional explosive movements patterned after real-world tasks [195,196].

Balance training emphasising static stance or seated exercises fails to meet real-world demands owing to the unpredictable nature of ADL mobility [189]. Balance control is highly task specific and multi-dimensional, encompassing static/dynamic steady-state balance, proactive balance, and reactive balance [93,197]. Consequently, isolated balance exercises show minimal transfer to untrained tasks [198]. Similarly, despite their intended aim to improve ADL competence through simulated skills, current ‘functional training’ methods demonstrate minimal ecological ADL improvements [199–202]. This lack of transfer in both traditional balance training and functional training approaches suggests issues such as insufficient variability in protocols and inappropriate progression, with an overemphasis on exercise load rather than applied skill practice [83,96,203–217].

Studies in which participants consistently practiced the actual outcome task over training sessions demonstrated significant task-specific performance improvements, emphasising the significance of a representative practice design and training specificity [21,194,218,219]. For example, Leizerowitz et al. (2023) reported that young adults who practiced the TUG test repetitively over one session showed significant retention and performance gains over a week and accrued more in subsequent practice [218]. Similarly, Bohannon et al. (2005) found that older adults who underwent consistent timed up-and-go practice over five weeks significantly improved their timed up-and-go performance over three training sessions [219].

In summary, traditional methods remain narrow in focus and target physical attributes over adaptable skill competence. This approach fails to address the complex and variable nature of real-world tasks faced by older adults in their daily lives. A more comprehensive approach that embraces task specificity and progressive variability may be necessary to optimise real-world functioning. This limitation of the current methods points to the need for a paradigm shift in how we approach exercise and functional performance in older adults.

A paradigm shift in exercise for older adults

True functional variability requires meaningful exploration of various real-world tasks, not just closed skills [220]. This concept aligns with DST, which recognises emergent, interactive behaviour based on task constraints, in contrast to motor schemas that imply top-down control of movement. This distinction has significant implications for skill transfer [221].

Older adults exhibit greater variability and inconsistency in their movement patterns, likely because of age-related neuromuscular changes [207,222,223]. Interestingly, uncontrolled manifold analysis suggests that older adults increase variability in irrelevant dimensions while controlling for relevant dimensions to maintain functioning [224]. From a DST perspective, this apparent randomness indicates that older individuals explore different movement solutions to find optimal coordination patterns that satisfy their changing constraints [225]. This variability, rather than detrimental, can be viewed as a compensatory factor reflecting adaptation to declining stability. The variability of practice hypothesis supports this view, demonstrating that varied training improves retention and transfer compared with repetitive skill rehearsal [99,100,226]. Thus, variability contributes positively to mobility, rather than introducing unwanted noise. This perspective reframes movement variability not as a system 'flaw', but as a functional aspect of motor learning and performance. In the context of older adults' mobility, such variability can be beneficial, allowing for the exploration and adaptation of movement strategies to meet changing environmental demands.

Embracing task variability: Insights from DST

As discussed in the overview of motor theories, DST recognises that movement emerges from individual-task-environment interactions rather than from pre-set programmes [85]. The provision of variability allows the exploration of specific solutions in various contexts [227]. DST explains how age-related increases in variability can aid mobility by exploring solutions across changing constraints [228]. Further, it offers insights into adaptation to injury or physiological decline, as constraints alter coordination and control processes [229]. Finally, DST characterises complex effects, such as fatigue, on neuromuscular control [230]. Consequently, it provides a valuable perspective for understanding how variability enables adaptable, context-specific solutions to motor challenges.

Ecological dynamics: Towards context-specific exercise

Building upon DST, ecological dynamics provides a more comprehensive framework for understanding human movement and skill acquisition [231]. While it shares DST's view of movement emerging from individual-task-environment interactions, ecological dynamics integrates additional concepts from ecological psychology [232]. Key concepts in ecological dynamics include:

- Affordances: Opportunities for action presented by the environment to an individual.
- Constraints: Boundaries or features that shape the emergence of functional movement solutions.
- Self-organisation: Spontaneous formation of functional movement patterns through the interaction of constraints.
- Perception-action coupling: The ongoing, reciprocal relationship between perception and action in coordinating movement.

Ecological dynamics emphasises representative practice design [232], addressing age-related mobility limitations and challenges by changing constraints on movement [188,233]. This approach highlights the significance of adaptive variability in exercise specificity and functional transfer, in contrast to the reductionist assumptions of traditional motor transfer theories. In the context of exercise for older adults, ecological dynamics suggest that training should simulate the variability and unpredictability of real-world tasks rather than focusing solely on improving isolated physical capacities.

Having examined the limitations of current approaches and the potential of ecological dynamics, the following section introduces the foundations of the Emergence of Skilled Mobility in Ageing (ESMA) framework, which aims to integrates the principles of ecological dynamics into a comprehensive approach for improving functional performance in older adults.

Emergence of skilled mobility in ageing: A preliminary framework

This section presents the ESMA framework as a potential solution to the challenges identified in the current exercise approaches for older adults. The key concepts of the framework are first outlined, followed by a discussion of its potential benefits and limitations, methodological guidance for its development, and illustrative examples of its application. Finally, strategies for facilitating wider adoption and future research directions are outlined.

Overview of the ESMA framework

Building on the principles of ecological dynamics, the author proposes the Emergence of Skilled Mobility in Ageing (ESMA) framework as an integrated approach to address concerns regarding exercise specificity and functional performance in older adults. The ESMA framework recognises that human movement and coordination emerge from the interaction between an individual, task, and environment under various constraints [109]. It focuses on open skills related to real-world demands rather than closed skill drills and adopts a bottom-up approach to the emergence of functional coordination patterns during meaningful interactions with various environments [238]. See the comparison with existing approaches in Table 6.

Table 6. Contrasting Current Approaches and the proposed 'Emergence of Skilled Mobility in Ageing (ESMA)

Limitations of Current Approaches	Benefits of Proposed Framework
Lack of variability in training	Emphasises adaptive variability
Progression focused primarily on load/volume	Progresses complexity of representative tasks
Isolated exercises disconnected from real-world skills	Integrates multiple capacities for coordination
Assessments measure narrow physical capacities	Incudes assessments based on real-world functioning
Focus on improving general physical fitness	Prioritises real-world skill competence
Repetitive closed skills	Open skills matching ADL demands
Fixed motor programmes	Emergent movement patterns

Overall, training should match real-world tasks in context and needs [231]. For instance, workouts that precisely replicate reaching, bending, and stepping movements that occur during daily activities. Compared to repetitive closed skills, this enhances functional transfer. Dual activities, different surroundings, and equipment that alter movement dynamics and coordination may be used in representative practice [232].

A periodised approach that combines physical conditioning and skill development may be optimal [234]. The initial assessment identifies capacity deficits to target in subsequent training (e.g., strength, balance, and coordination). Ongoing conditioning maintains physical fitness while skills progress in complexity. Periodic reassessment tracks changes in physical capacities to adjust training. Table 7 summarises the Emergence of Skilled Mobility in Ageing (ESMA) preliminary framework, which integrates key concepts from ecological dynamics into a comprehensive exercise approach for older adults. Furthermore, it supports emerging ideas regarding physical literacy throughout life [119,235].

Table 7. Emergence of skilled mobility in ageing (ESMA): A Preliminary framework

Principles	Application	Sample Training Protocol & Progression
Needs analysis with targeted conditioning.	-Diagnostic fitness tests [106] -Identify physical capacity deficits [114] -Targeted conditioning for individual needs [236] -Develop strength, power, endurance, mobility etc. [237]	**Phase 0: Initial Assessment and Conditioning** Resistance training 2-3x per week for strength Flexibility training 2-3x per week Aerobic conditioning 3-5x per week Neuromuscular coordination 1-2x per week - Agility drills, dance, tai chi etc.
Representative Practice Design	- Exercises mimic real-world demands [7] - Simulate variability in tasks [111] - Progressively increase contextual interference [238]	**Phase 1: Motor skill practice / Maintain targeted conditioning:** This early stage focuses on foundational perceptual-motor skills without added complexity. Potential manipulations could include altering base of support, removing visual cues, and changing surface stability. Simple repetitive exercises like sit-to-stands, stepping, and reaching motions facilitate exploration without equipment.
Perception-action coupling	- Emphasis on use of perceptual information during movements [239] - Minimise the reliance on internalised motor programmes [240] - Provide external feedback on skill execution [191]	**Phase 2: ADL training / Integrate conditioning activities:** Basic activities of daily living are practiced including kitchen tasks, laundry, and vacuuming. Constraints are imposed by introducing cognitive challenges such as remembering multi-step directions. Light loading in the form of bags or bottles carried during the activities alters the perceptual-motor demands.
Adaptive Variability	- Include variability in practice conditions [215] - Encourage exploration of different movement solutions [241] - Develop adaptable coordination patterns [231]	**Phase 3: Complex skill practice / Adjust conditioning as needed:** Individual coordination is challenged by increasing the unpredictability of movements through multi-directional perturbations and unstable surfaces during stepping and reaching. Varying visual cues, directions, and targets encourages perception-action coupling to adapt movements accordingly. **Phase 4: Integrated, adaptable skill / Maintain ongoing conditioning:** facilitated by embedding ADL practice into changing environments, introducing conflicting sensory information, and coupling activities with reactive balance challenges. Randomising the sequence of tasks, locations, and instructions enhances the representativeness.

The novel ESMA framework embraces evidence-based conditioning modalities including resistance training to enhance strength and power development. It does not assume that traditional training alone can produce task-specific adaptations; rather, it proposes that functional optimisation requires aligning conditioning methods with the demands of real-world tasks. This recognises the benefits of traditional training modalities in promoting general physical fitness while emphasising the importance of task-specificity through varied practice of open skills that match the requirements of ADL. By integrating these concepts, ESMA seeks to foster advancements in exercise science and functional training, translating research to practice.

Application limits and challenges of the ESMA framework

Despite this promising approach, the ESMA framework faces several potential challenges in its application. First, implementing ESMA may require more time, equipment, and expertise than traditional approaches. The need for individualised assessment and intervention design could strain resources in some clinical or community settings [242]. Second, the emphasis on individualisation and context-specificity may complicate standardising interventions for research purposes. This could impact the generalisability of findings and large-scale implementation [202]. Third, assessing outcomes within the ESMA framework may be more complex than traditional approaches because of the focus on real-world variable tasks. Developing valid, reliable, and sensitive measures of functional performance in ecologically valid contexts remains a challenge [243]. Fourth, the ESMA framework represents a significant paradigm shift from the traditional exercise prescription methods. Practitioners accustomed to more standardised capacity-focused approaches may face a learning curve when adopting this new methodology [119]. Lastly, while the emphasis on meaningful, context-specific tasks may enhance motivation for some older adults, others might find the increased complexity and variability challenging or overwhelming [69]. These challenges underscore the need for careful implementation strategies and ongoing refinement of the ESMA framework through rigorous research and practical application.

Methodological guidance and framework development

To address these potential challenges and further develop the ESMA framework, comprehensive methodological guidance is currently under development as part of ongoing doctoral research. The final framework will consider:

- Detailed guidelines for evaluating individual constraints, environmental factors, and task demands relevant to each older adult's functional objectives.
- Specific ways for creating exercise interventions that align with ecological dynamics principles, emphasising representative design and task-environment-individual interactions [232].
- Techniques for systematically increasing task complexity and variability while maintaining an appropriate challenge level for each individual [208].
- Approaches to integrating cognitive demands into physical tasks, reflecting the intricacy of real-world activities [244].
- Strategies for replicating or simulating real-world environments within training settings to enhance the transfer of skills [245].

These key components form the core of the methodological guidance of the ESMA framework, bridging theoretical concepts and practical applications. This comprehensive approach offers a structured yet flexible methodology that is adaptable to various settings and populations, while maintaining its grounding in ecological dynamics principles.

Illustrative examples and potential effects

While specific applications of the ESMA framework are still under development, the potential of ecological dynamics approaches can be illustrated through examples from sports contexts and hypothetical scenarios based on professional experience.

Sports application example

The underlying principles of ecological dynamics have been successfully applied to various sporting contexts, demonstrating the potential for transfer to functional performance in older populations. For instance, Browne et al. (2019) demonstrated improved tactical creativity and performance in elite rugby union players following an ecological dynamics training programme [246]. The intervention emphasised variability, constraint manipulation, and perception-action coupling, aligning with the key principles proposed in the ESMA framework for older adults. Similarly, Porter et al. (2020) investigated the effects of learner-adapted practice on skill transfer in adults learning basketball shots [247]. The study found that participants who engaged in learner-adapted practice, which allowed them to manipulate task constraints and select their own practice distances, showed superior skill transfer compared to those who followed a prescribed practice regimen. This finding supports the ESMA framework's emphasis on individualisation and context-specific practice.

Otte et al. (2020) explored the skill training approaches of expert goalkeeper coaches and revealed the importance of representative learning designs, constraint manipulation, and fostering adaptability [248]. Although the findings do not directly demonstrate enhanced performance outcomes, they highlight the value placed on ecological dynamics principles by practitioners in high-performance sports contexts.

These examples from sporting settings illustrate how principles of ecological dynamics may enhance skill acquisition, adaptability, and performance transfer. While specific tasks and populations differ from older adults performing daily activities, the underlying mechanisms of skill acquisition and transfer are likely similar. The success of these approaches in sports contexts provides promising support for the potential effectiveness of the ESMA framework in improving the functional performance of older adults.

It is important to note, however, that while these sporting examples are encouraging, the unique constraints and challenges faced by older adult populations warrant further investigation and tailoring the ESMA framework to their specific needs and contexts. Ongoing research aims to validate and refine these principles specifically for older adults performing daily living tasks.

Hypothetical application scenario

From Table 7, we can describe a hypothetical scenario to show how the framework may be implemented. Consider Sarah, aged 72, whose goal is to maintain independence in performing household chores, and reports difficulties with laundry tasks. An ESMA-based intervention may include the following.

1. Needs Analysis and Targeted Conditioning:
   - Assess Sarah's strength, balance, and cardiovascular endurance.
   - Identify specific physical capacity deficits.
   - Implement targeted conditioning: resistance training for upper body and core strength, specific balance exercises, and cardiovascular exercise.
2. Representative Practice Design:
   - Create a simulated environment with varying basket weights and machine heights.
   - Practice sorting, carrying, loading, and folding with real laundry items.
   - Increase task complexity - seated sorting to a top-loading washer.
3. Perception-Action Coupling:
   - Encourage decision making based on visual and tactile cues (e.g. determining water temperature).
   - Practice responding to machine sounds and visual indicators.
   - Incorporate external feedback on task execution and posture.
4. Adaptive Variability:
   - Vary laundry loads (weight and size) and environmental conditions (e.g. simulated wet floors).
   - Introduce dual-task scenarios (e.g. answering phone calls).
   - Add unexpected elements (e.g. dealing with an unbalanced load).
5. Progressive Challenge: Phase 1: Basic motor skills practice while maintaining conditioning. Phase 2: Integrate ADL training with conditioning activities. Phase 3: Increase complexity with multi-directional movements and unstable surfaces. Phase 4: Full task integration with changing environments and reactive challenges.
6. Outcome Measurement:
   - Assess performance using ecological assessments in both simulated and home environments.
   - Monitor fatigue, efficiency, and safety in task completion.
   - Evaluate improvements in strength, balance, and endurance.

This ESMA-based approach aims to develop functional capacity specifically for laundry tasks, enhancing the ability to perform these activities safely and efficiently in the home environment. By focusing on task-specific training with built-in variability and challenge progression, this integrated approach may result in more meaningful improvements in daily functioning compared to traditional isolated exercise interventions.

Facilitating wider adoption

The development of a novel framework through rigorous academic research is a critical first step, but equally important are its adoption and effective implementation [249]. This section explores strategies for facilitating the wider adoption of the ESMA framework, recognising that this process will evolve alongside the framework's development. The successful implementation and adoption of the ESMA framework requires a comprehensive strategy to address various stakeholder needs.

Interdisciplinary collaboration

The successful implementation of the ESMA framework across a heterogeneous older population with diverse functional capacities necessitates collaboration among allied health professionals. This includes exercise physiologists, who provide expertise in prescribing and implementing exercise, assessing fitness capacities, and analysing movement techniques and motor control [109,250]. They play a crucial role in identifying age-related physical decline, developing targeted interventions, and quantifying changes in musculoskeletal, cardiovascular, and neuromotor function [251,252]. Equally important are occupational therapists, who focus on optimising independence, safety, and quality of activities of daily living (ADL) meaningful to clients [252,253]. Their experience in task-oriented training and environmental adaptations is invaluable for informing exercise research on ADL. Physical therapists offer critical insights into improving mobility and function, with strong exercise prescription and movement analysis skills [254]. Their expertise in task-oriented training complements the ESMA framework's focus on real-world functionality. This interdisciplinary approach will ensure a comprehensive perspective on functional performance, bridging the gap between traditional exercise approaches and actual ADL performance [176].

Stakeholder engagement

A key component of the ongoing research is the planned stakeholder engagement process. This involves gathering input from practitioners, researchers, older adults, and healthcare administrators to ensure the relevance, feasibility, and adoptability of the framework across various settings.

Practitioner training

Successful implementation of ESMA necessitates comprehensive practitioner training, encompassing theoretical foundations of ecological dynamics and practical skills for framework application. This includes assessment techniques for individual-task-environment interactions, design of representative practice environments, and strategies for implementing adaptive variability and progressive challenges. Training programmes will balance depth of understanding with practical applicability, considering time and cost constraints. A centralised online portal can be developed to provide practitioners with accessible, up-to-date resources, including e-learning modules, webinars, and case studies. This digital platform will complement hands-on workshops and foster a community of practice, promoting proficiency and understanding.

Integration with existing systems

As a long-term objective, integrating ESMA into existing healthcare and community exercise programmes requires strategic planning that considers reimbursement structures, resources, and current practice guidelines. A phased implementation approach will be developed that focuses on identifying compatibility with established practices and addressing potential barriers. This involves collaborative efforts among healthcare administrators, policymakers, and community leaders to ensure integration. Pilot trials in diverse settings will inform best practices for scaling up ESMA implementation, while ongoing evaluation will guide refinements to maximise compatibility and minimise disruption to existing systems.

Communication and advocacy

Effective dissemination of ESMA benefits to older adults, healthcare providers, and policymakers is crucial for widespread adoption. A multi-faceted communication strategy will be developed, including targeted educational materials, an online portal, conference presentations, and engagement with professional organisations. Emphasis will be placed on demonstrating ESMA's potential to enhance functional outcomes and quality of life for older adults, while also highlighting its cost-effectiveness and alignment with person-centred care principles [14]. This comprehensive approach aims to create a framework that bridges theoretical advancements with real-world applicability, thereby fostering broad acceptance and implementation across diverse settings.

Having outlined the theoretical underpinnings and potential applications of the ESMA framework, it is crucial to consider how this approach can be effectively translated from research to practice. The following section explores the practical implications of implementing ESMA in real-world settings, highlighting the challenges of translating theoretical concepts to application in exercise interventions for older adults. Examining this transition from theory to practice may provide a better understanding of the potential impact of ESMA on current exercise paradigms and identify strategies for its successful integration into existing healthcare and community exercise programmes.

Consolidating research to practice

A Practitioner's perspective

A misalignment exists between research and practice in optimising the functional performance of older adults. Reductionist paradigms have led to fragmented assessments and training that lack real-world integration. This presents challenges for exercise professionals seeking to translate evidence into effective prescriptions that improve the integrated, variable competencies needed for daily living. Transitioning to the proposed framework can help resolve this divide through representative practice design and emphasis on adaptable capabilities.

A key aspect of implementing the framework is to understand the functional performance gap in exercise prescriptions for older adults. This gap spans capacity to ability, distinguishing between reductionist assessments and ecological and real-world skill competencies (Fig. 4)

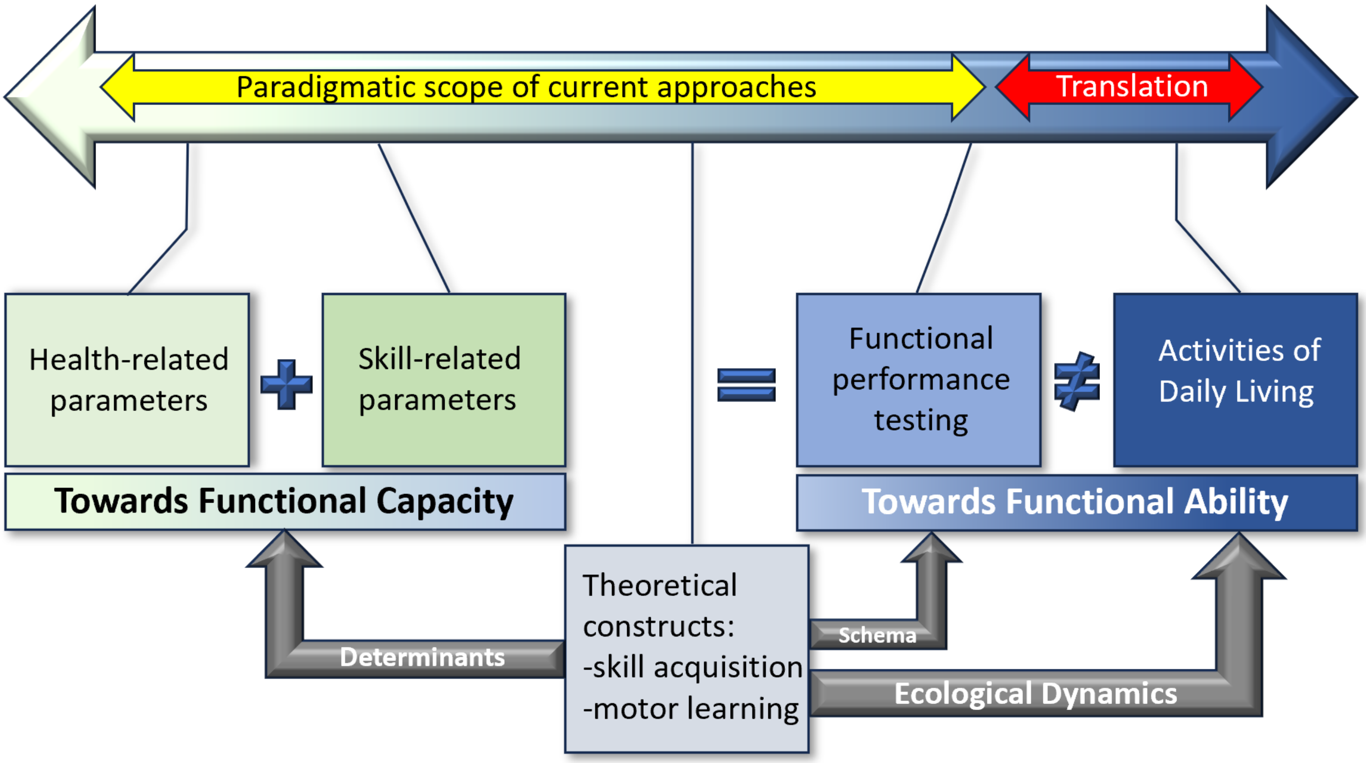

Figure. 4 The Functional Performance Gap in Exercise for Older adults.

To effectively apply the ESMA framework, practitioners must consider the following approaches that may call for departure from existing practices:

- Ecologically valid assessments, such as the Assessment of Motor and Process Skills (AMPS) and Executive Function Performance Test (EFPT), are used to evaluate real-world functional abilities. These assessments provide a more comprehensive and context-specific understanding of an individual's capabilities than traditional isolated capacity tests.
- Design periodised interventions that combine physical conditioning with skilled practice, progressively increasing the complexity and ecological validity of tasks. This approach ensures that improvements in physical capacity are directly transferable to activities of daily living.
- Focus on task-specific solutions while building general physical fitness, emphasising the exploration of task-specific solutions that directly relate to an individual's daily living requirements. This could involve practicing household tasks or simulating common activities in a controlled environment.
- Promote motor flexibility by incorporating various conditions and training activities to enhance adaptability to real-world scenarios. This could include the introduction of unexpected perturbations or changing environmental conditions during exercise.

Practical implementation considerations

Implementing the ESMA framework in real-world settings requires careful consideration of several factors. A thorough initial assessment, considering both physical capacities and functional abilities in context, is crucial for tailoring interventions to the unique challenges and capabilities of older adults [137]. The living environment plays a pivotal role, necessitating consideration of the home layout, community resources, and typical daily activities in exercise design [242]. While maintaining ecological validity, interventions should progressively challenge individuals through increased task complexity, altered environmental constraints, or dual-task scenarios [208]. Regular reassessment and feedback, combining objective measures with subjective reports of functional improvements, are essential for tracking progress [121,154]. Effective implementation may require interdisciplinary collaboration among allied health professionals, leveraging their unique insights [14]. Educating older adults on ESMA principles can enhance engagement and empower them to create their own movement solutions in daily life [255]. Where appropriate, integrating technologies such as wearable devices or virtual reality can enhance assessment and intervention strategies [256]. By addressing these aspects, practitioners can translate ESMA's theoretical underpinnings into meaningful interventions to directly benefit older adults' functional performance and quality of life.

Ongoing research objectives & future directions

The ESMA framework presented in this article represents the initial theoretical foundation of ongoing doctoral research. The subsequent phases of this research aim to refine, validate, and operationalise the framework through three interconnected studies. The first study is due to commence shortly and will entail a comprehensive review of exercise interventions for older adults, focusing on the application of fundamental exercise principles, ecological validity of outcomes, and alignment between interventions and functional performance measures. A subsequent concept mapping study will engage a diverse group of stakeholders to develop consensus and refine and operationalise the ESMA framework, ensuring its relevance and applicability across various contexts. Finally, a pilot study will be conducted to assess the framework's feasibility, acceptability, and preliminary effectiveness in a selected cohort of community-dwelling older adults. This phased approach will address the limitations of current approaches, provides empirical support for the framework's principles, and results in a comprehensive evidence-based guide for implementing ecologically valid exercise interventions for older adults.

The long-term goals include the following:

- Creating detailed guidelines for implementing the ESMA framework, including assessment protocols, intervention design principles, and progression strategies.
- Examining real-world perceptions, feasibility, and adoption of ecologically designed training approaches among exercise professionals.
- Designing and conducting trials to rigorously test the effectiveness of ESMA-based interventions compared to traditional approaches.
- Exploring the potential of wearable technology and virtual reality to enhance the assessment and implementation of ESMA-based interventions.
- Investigating the framework's applicability and effectiveness across different cultural contexts and healthcare systems.
- Assessment of the sustained impact of ESMA-based interventions on functional performance and quality of life in older adults over extended periods.

Through this research agenda, the objective is to transform the ESMA framework from a theoretical construct into a practical, evidence-based approach for enhancing functional performance in older adults. Ultimately, this work seeks to significantly advance the field, contributing to improved independence, well-being, and quality of life for older adults across diverse populations.

Conclusions

This article critically examines the current paradigm for exercise in older adults and introduces the Emergence of Skilled Mobility in Ageing (ESMA) framework as a potential solution to existing limitations. Challenging reductionist approaches highlights the misalignment between conventional exercise research and the functional needs of the older population.

The ESMA framework, grounded in ecological dynamics principles, offers a new perspective for enhancing functional performance in older adults. It addresses the limitations of traditional methods by emphasising representative design, task-environment-individual interactions, and adaptive variability. This approach better aligns training and evaluation with real-world demands, potentially improving the effectiveness of exercise interventions and enhancing quality of life for older adults.

Although promising, the ESMA framework is in its preliminary stages and requires further development, empirical validation, and refinement. Challenges include resource constraints, standardisation issues, and the need for practitioner adaptation. Ongoing research aims to address these challenges and provide comprehensive methodological guidance.

The ESMA framework has significant implications for collaborative research and practice, knowledge translation, and for improving the practicality of exercise research. By integrating physical conditioning, task variability, and representative practice design, ESMA offers a novel approach for enhancing coordination, skills, and mobility in older adults. Future research will focus on validating and refining this framework, potentially transforming exercise interventions for older adults and contributing to improved functional performance and independence in daily living.

References

1. Collard RM, Boter H, Schoevers RA, Oude Voshaar RC. Prevalence of frailty in community-dwelling older persons: a systematic review. J Am Geriatr Soc. 2012;60:1487–92.
2. Anton SD, Woods AJ, Ashizawa T, Barb D, Buford TW, Carter CS, et al. Successful aging: advancing the science of physical independence in older adults. Ageing Res Rev. 2015;24:304–27.
3. Ferreira OGL, Maciel SC, Costa SMG, Silva AO, Moreira MASP. Active aging and its relationship to functional independence. Texto Contexto-Enferm. 2012;21:513–8.
4. Forti P, Rietti E, Pisacane N, Olivelli V, Maltoni B, Ravaglia G. A comparison of frailty indexes for prediction of adverse health outcomes in an elderly cohort. Arch Gerontol Geriatr. 2012;54:16–20.
5. Hoogendijk EO, Afilalo J, Ensrud KE, Kowal P, Onder G, Fried LP. Frailty: implications for clinical practice and public health. The Lancet. 2019;394:1365–75.
6. Topinková E. Aging, disability and frailty. Ann Nutr Metab. 2008;52:6–11.
7. Sternberg SA, Schwartz AW, Karunananthan S, Bergman H, Mark Clarfield A. The identification of frailty: a systematic literature review. J Am Geriatr Soc. 2011;59:2129–38.
8. Pilotto A, Custodero C, Maggi S, Polidori MC, Veronese N, Ferrucci L. A multidimensional approach to frailty in older people. Ageing Res Rev. 2020;60:101047.
9. O'Caoimh R, Sezgin D, O'Donovan MR, Molloy DW, Clegg A, Rockwood K, et al. Prevalence of frailty in 62 countries across the world: a systematic review and meta-analysis of population-level studies. Age Ageing. 2020;50:96–104.
10. Arnadottir SA, Bruce J, Lall R, Withers EJ, Underwood M, Shaw F, et al. The importance of different frailty domains in a population based sample in England. BMC Geriatr. 2020;20:1–10.
11. Verver D, Merten H, de Blok C, Wagner C. A cross sectional study on the different domains of frailty for independent living older adults. BMC Geriatr. 2019;19:1–12.
12. Rothman MD, Leo-Summers L, Gill TM. Prognostic significance of potential frailty criteria. J Am Geriatr Soc. 2008;56:2211–6.
13. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci. 2001;56:M146–57.
14. Izquierdo M, Merchant R, Morley J, Anker S, Aprahamian I, Arai H, et al. International exercise recommendations in older adults (ICFSR): expert consensus guidelines. J Nutr Health Aging. 2021;25:824–53.
15. Beckwée D, Delaere A, Aelbrecht S, Baert V, Beaudart C, Bruyere O, et al. Exercise interventions for the prevention and treatment of sarcopenia. A systematic umbrella review. J Nutr Health Aging. 2019;23:494–502.
16. Amaral Gomes ES, Ramsey KA, Rojer AG, Reijnierse EM, Maier AB. The association of objectively measured physical activity and sedentary behavior with (instrumental) activities of daily living in community-dwelling older adults: a systematic review. Clin Interv Aging. 2021;1877–915.
17. Tak E, Kuiper R, Chorus A, Hopman-Rock M. Prevention of onset and progression of basic ADL disability by physical activity in community dwelling older adults: a meta-analysis. Ageing Res Rev. 2013;12:329–38.
18. Wang DX, Yao J, Zirek Y, Reijnierse EM, Maier AB. Muscle mass, strength, and physical performance predicting activities of daily living: a meta-analysis. J Cachexia Sarcopenia Muscle. 2020;11:3–25.
19. Brahms CM, Hortobágyi T, Kressig RW, Granacher U. The interaction between mobility status and exercise specificity in older adults. Exerc Sport Sci Rev. 2021;49:15–22.
20. McCrum C. Falls among older people: are intervention duration and specificity the keys to making a difference? BMJ E. 2018;361:k2213.
21. Morrison RT, Taylor S, Buckley J, Twist C, Kite C. High-velocity power training has similar effects to traditional resistance training for functional performance in older adults: a systematic review. J Physiother. 2023;69:148–59.
22. Button C, Seifert L, Chow JY, Davids K, Araujo D. Dynamics of skill acquisition: An ecological dynamics approach. Human Kinetics Publishers; 2020.
23. McFee G. Paradigms and possibilities: or, some concerns for the study of sport from the philosophy of science. Sport Ethics Philos. 2007;1:58–77.

24.Kent JA, Hayes KL. Exercise physiology from 1980 to 2020: Application of the natural sciences. Kinesiol Rev. 2021;10:238–47.
25.Estabrooks PA. Physical activity promotion and translational research. Transl Behav Med. 2017;7:1–2.
26.Verhagen E, Voogt N, Bruinsma A, Finch CF. A knowledge transfer scheme to bridge the gap between science and practice: an integration of existing research frameworks into a tool for practice. Br J Sports Med. 2014;48:698–701.
27.Freccia GW, de Carvalho T. A Reproducibility or an identity crisis in sports and exercise? A viewpoint on current challenges and solutions.
28.Caldwell AR, Vigotsky AD, Tenan MS, Radel R, Mellor DT, Kreutzer A, et al. Moving sport and exercise science forward: a call for the adoption of more transparent research practices. Sports Med. 2020;50:449–59.
29.Swann C, Piggott D, Schweickle M, Vella SA. A Review of Scientific Progress in Flow in Sport and Exercise: Normal Science, Crisis, and a Progressive Shift. J Appl Sport Psychol. 2018;30:249–71.
30.Kuhn TS. The structure of scientific revolutions. University of Chicago press; 2012.
31.Anand G, Larson EC, Mahoney JT. Thomas Kuhn on paradigms. Prod Oper Manag. 2020;29:1650–7.
32.Noakes T. How does a foundational myth become sacred scientific dogma? Philos Sci Exerc Health Sport. 2004;52.
33.Mann T. Sporting myths: the REAL role of lactate during exercise. South Afr J Sports Med. 2007;19:114–6.
34.Beneke R. Training at lactate threshold: science based concept or irrational myth. J Sports Med Doping Stud. 2012;2:2.
35.Robergs RA, Landwehr R. The surprising history of the" HRmax= 220-age" equation. J Exerc Physiol Online. 2002;5:1–10.
36.Kilgore JL, Baker J, Davies B. A consideration of the paradigm of exercise physiology. Res Sports Med. 2014;22:314–22.
37.Mood DP. Measurement in Exercise Science. Introd Exerc Sci. Routledge; 2017. p. 35–58.
38.Tesio L. Quality of life measurement: one size fits all. Rehabilitation medicine makes no exception. J Med Pers. 2009;7:5–9.
39.Faude O, Kindermann W, Meyer T. Lactate threshold concepts: how valid are they? Sports Med. 2009;39:469–90.
40.Sartori G, others. Guidelines for concept analysis. Soc Sci Concepts Syst Anal. 1984;15:85.
41.Goertz G. Social science concepts: A user's guide. Princeton University Press; 2006.
42.Popper K. The logic of scientific discovery. Routledge; 2005.
43.Barnes B, Bloor D, Henry J. Scientific knowledge: A sociological analysis. A&C Black; 1996.
44.Sparkes AC. The paradigms debate: An extended review and a celebration of difference. Res Phys Educ Sp. 2012;9–60.
45.Chamari K, Padulo J. 'Aerobic'and 'Anaerobic'terms used in exercise physiology: a critical terminology reflection. Sports Med-Open. 2015;1:1–4.
46.Winter EM, Knudson DV. Turning the Corner on the Correct Use of Terms and Nomenclature to Describe Performance in Sport and Exercise? 2016;
47.Winter EM, Abt G, Brookes FC, Challis JH, Fowler NE, Knudson DV, et al. Misuse of "power" and other mechanical terms in sport and exercise science research. J Strength Cond Res. 2016;30:292–300.
48.Rodgers MM, Cavanagh PR. Glossary of biomechanical terms, concepts, and units. Phys Ther. 1984;64:1886–902.
49.Utesch T, Bardid F, Büsch D, Strauss B. The relationship between motor competence and physical fitness from early childhood to early adulthood: a meta-analysis. Sports Med. 2019;49:541–51.
50.Osness WH, others. Functional Fitness Assessment for Adults Over 60 Years (A Field Based Assessment). ERIC; 1990.
51.Kirch W, editor. Functional AbilityFunctional ability. Encycl Public Health [Internet]. Dordrecht: Springer Netherlands; 2008 [cited 2023 Aug 2]. p. 466–466. Available from: https://doi.org/10.1007/978-1-4020-5614-7_1209
52.Sebastiano MDK. Functional Capacity, Disability, and Status. In: Gellman MD, editor. Encycl Behav Med [Internet]. Cham: Springer International Publishing; 2020 [cited 2023 Aug 2]. p. 903–5. Available from: https://doi.org/10.1007/978-3-030-39903-0_1133
53.Kalpakjian CZ, Forchheimer M, Tate DG. CHAPTER TWENTY-THREE - Quality of Life After Spinal Cord Injury. In: Sisto SA, Druin E, Sliwinski MM, editors. Spinal Cord Inj [Internet]. Saint Louis: Mosby; 2009. p. 537–52. Available from: https://www.sciencedirect.com/science/article/pii/B9780323006996100231
54.PROMIS. Dynamic tools to measure health outcomes from the patient perspective. [Internet]. [cited 2023 Aug 2]. Available from: http://www.nihpromis.org.
55.Wang T-J. Concept analysis of functional status. Int J Nurs Stud. 2004;41:457–62.
56.Beaudart C, Rolland Y, Cruz-Jentoft AJ, Bauer JM, Sieber C, Cooper C, et al. Assessment of muscle function and physical performance in daily clinical practice: a position paper endorsed by the European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Diseases (ESCEO). Calcif Tissue Int. 2019;105:1–14.
57.Üstün TB, Chatterji S, Bickenbach J, Kostanjsek N, Schneider M. The International Classification of Functioning, Disability and Health: a new tool for understanding disability and health. Disabil Rehabil. 2003;25:565–71.
58.Van Holle V, Van Cauwenberg J, Gheysen F, Van Dyck D, Deforche B, Van de Weghe N, et al. The association between Belgian older adults' physical functioning and physical activity: what is the moderating role of the physical environment? PLoS One. 2016;11:e0148398.
59 Pearson D, Faigenbaum A, Conley M, Kraemer WJ. The National Strength and Conditioning Association's Basic Guidelines for the Resistance Training of Athletes. Strength Cond J. 2000;22:14.
60.McCafferty WB, Horvath SM. Specificity of exercise and specificity of training: a subcellular review. Res Q Am Alliance Health Phys Educ Recreat. 1977;48:358–71.
61.Hong S-G, Shin J, Aldokhayyil M, Brown MD, Park J-Y. Mitochondrial and metabolic adaptations to exercise-induced fluid shear stress in endothelial cells. Exerc Sport Sci Rev. 2022;50:145–55.

62.Hortobágyi T, Granacher U, Fernandez-del-Olmo M, Howatson G, Manca A, Deriu F, et al. Functional relevance of resistance training-induced neuroplasticity in health and disease. Neurosci Biobehav Rev. 2021;122:79–91.
63 Blazevich AJ, Gill ND, Bronks R, Newton RU. Training-specific muscle architecture adaptation after 5-wk training in athletes. Med Sci Sports Exerc. 2003;35:2013–22.
64.Plotkin DL, Roberts MD, Haun CT, Schoenfeld BJ. Muscle fiber type transitions with exercise training: Shifting perspectives. Sports. 2021;9:127.
65.Behm D, Sale D. Velocity specificity of resistance training. Sports Med. 1993;15:374–88.
66.Hubbard IJ, Parsons MW, Neilson C, Carey LM. Task-specific training: evidence for and translation to clinical practice. Occup Ther Int. 2009;16:175–89.
67.Toigo M, Boutellier U. New fundamental resistance exercise determinants of molecular and cellular muscle adaptations. Eur J Appl Physiol. 2006;97:643–63.
68.Stone MH, Hornsby WG, Suarez DG, Duca M, Pierce KC. Training Specificity for Athletes: Emphasis on Strength-Power Training: A Narrative Review. J Funct Morphol Kinesiol. 2022;7:102.
69.Liu C, Shiroy DM, Jones LY, Clark DO. Systematic review of functional training on muscle strength, physical functioning, and activities of daily living in older adults. Eur Rev Aging Phys Act. 2014;11:95–106.
70.Healy AF, Wohldmann EL. Specificity and transfer of learning. Psychol Learn Motiv. Elsevier; 2012. p. 227–53.
71.specificity [Internet]. dictionary.cambridge.org. Cambridge University Press; [cited 2023 Aug 1]. Available from: https://dictionary.cambridge.org/dictionary/english/specificity
72.Brearley S, Bishop C. Transfer of training: how specific should we be? Strength Cond J. 2019;41:97–109.
73.Campbell E, Petermann-Rocha F, Welsh P, Celis-Morales C, Pell JP, Ho FK, et al. The effect of exercise on quality of life and activities of daily life in frail older adults: A systematic review of randomised control trials. Exp Gerontol. 2021;147:111287.
74.Paterson DH, Jones GR, Rice CL. Ageing and physical activity: evidence to develop exercise recommendations for older adults. Appl Physiol Nutr Metab. 2007;32:S69–108.
75.Thompson WR. Worldwide survey of fitness trends for 2018: the CREP edition. ACSMs Health Fit J. 2017;21:10–9.
76.Chalmers AF. What is this thing called science? Hackett Publishing; 2013.
77.Magill RA, Anderson DI. Motor learning and control: Concepts and applications (Eleventh). New York, NY: McGraw-Hill Education; 2017.
78.Lashley KS. In search of the engram. Physiol Mech Anim Behav Soc Symp IV. Oxford, England: Academic Press; 1950. p. 454–82.
79.Bernstein N. The co-ordination and regulation of movements. Pergamon, NY: Pergamon Press; 1966.
80.Fitts PM, Posner MI. Human performance. Oxford, England: Brooks/Cole; 1967.
81.Keele SW. Movement control in skilled motor performance. Psychol Bull. 1968;70:387.
82.Adams JA. A closed-loop theory of motor learning. J Mot Behav. 1971;3:111–50.
83.Schmidt RA. A schema theory of discrete motor skill learning. Psychol Rev. 1975;82:225.
84 Gibson JJ. The ecological approach to visual perception: classic edition. Psychology press; 2014.
85.Newell KM. Constraints on the development of coordination. Mot Dev Child Asp Coord Control. 1986;
86.Kelso J, Schöner G. Toward a physical (synergetic) theory of biological coordination. Lasers Synerg Colloq Coherence Self-Organ Nat. Springer; 1987. p. 224–37.
87.Warren Jr WH. The perception-action coupling. Sens-Mot Organ Dev Infancy Early Child Proc NATO Adv Res Workshop Sens-Mot Organ Dev Infancy Early Child Chateu Rosey Fr. Springer; 1990. p. 23–37.
88.Reed ES. Encountering the world: Toward an ecological psychology. Oxford University Press; 1996.
89.Davids K, Button C, Bennett S. Dynamics of skill acquisition: A constraints-led approach. Leeds: Human kinetics; 2008.
90.Chemero A. Radical embodied cognitive science. Cambridge/MA: Bradford. MIT; 2009.
91.Schmidt RA. Motor schema theory after 27 years: Reflections and implications for a new theory. Res Q Exerc Sport. 2003;74:366–75.
92 Shea CH, Kohl RM. Composition of practice: Influence on the retention of motor skills. Res Q Exerc Sport. 1991;62:187–95.
93.Shumway-Cook A, Woollacott MH, Rachwani J, Santamaria V. Motor control: translating research into clinical practice. Lippincott Williams & Wilkins; 2023.
94.Kamm K, Thelen E, Jensen JL. A dynamical systems approach to motor development. Phys Ther. 1990;70:763–75.
95.Latash ML, Scholz JP, Schöner G. Motor control strategies revealed in the structure of motor variability. Exerc Sport Sci Rev. 2002;30:26–31.
96 Porter JM, Magill RA. Systematically increasing contextual interference is beneficial for learning sport skills. J Sports Sci. 2010;28:1277–85.
97.Van Rossum JH. Schmidt's schema theory: The empirical base of the variability of practice hypothesis: A critical analysis. Hum Mov Sci. 1990;9:387–435.
98.Newell KM. Motor skill acquisition. Annu Rev Psychol. 1991;42:213–37.
99.Shea CH, Kohl RM. Specificity and variability of practice. Res Q Exerc Sport. 1990;61:169–77.
100.Brady F. Contextual interference and teaching golf skills. Percept Mot Skills. 1997;84:347–50.
101.Hall KG, Magill RA. Variability of practice and contextual interference in motor skill learning. J Mot Behav. 1995;27:299–309.
102.Ara'ujo D, Davids K. What exactly is acquired during skill acquisition? J Conscious Stud. 2011;18:7–23.
103.Scholz JP, Schöner G. Use of the uncontrolled manifold (UCM) approach to understand motor variability, motor equivalence, and self-motion. Prog Mot Control Ski Learn Perform Health Inj. 2014;91–100.
104.Fleck SJ, Kraemer W. Designing resistance training programs, 4E. Human Kinetics; 2014.
105.Howley E, Franks B. Health Fitness Instructor's Handbook. Champagne, IL: Human Kinetics; 2003.
106.Liguori G, Medicine AC of S, others. ACSM's guidelines for exercise testing and prescription. Lippincott Williams & Wilkins; 2020.

107.Araújo D, Davids K. What exactly is acquired during skill acquisition? J Conscious Stud. 2011;18:7–23.
108.Fleishman EA. Toward a taxonomy of human performance. Am Psychol. 1975;30:1127.
109.Fleishman EA, Quaintance MK, Broedling LA. Taxonomies of human performance: The description of human tasks. Academic Press; 1984.
110.Stodden D, Langendorfer S, Roberton MA. The association between motor skill competence and physical fitness in young adults. Res Q Exerc Sport. 2009;80:223–9.
111.Schmidt R, Lee T. Motor learning and performance 6th edition with web study guide-loose-leaf edition: From principles to application. Human Kinetics Publishers; 2019.
112.Latham NK, Bennett DA, Stretton CM, Anderson CS. Systematic review of progressive resistance strength training in older adults. J Gerontol A Biol Sci Med Sci. 2004;59:M48–61.
113.Latham N, Liu C. Strength training in older adults: the benefits for osteoarthritis. Clin Geriatr Med. 2010;26:445–59.
114.Gordon B, Medicine AC of S, others. ACSM's Resources for the Exercise Physiologist. Lippincott Williams & Wilkins; 2021.
115.Anderson K, Behm DG. The impact of instability resistance training on balance and stability. Sports Med. 2005;35:43–53.
116.Da Silva-Grigoletto ME, Mesquita MM, Aragão-Santos JC, Santos MS, Resende-Neto AG, de Santana JM, et al. Functional training induces greater variety and magnitude of training improvements than traditional resistance training in elderly women. J Sports Sci Med. 2019;18:789.
117.Byrne C, Faure C, Keene DJ, Lamb SE. Ageing, muscle power and physical function: a systematic review and implications for pragmatic training interventions. Sports Med. 2016;46:1311–32.
118.Foldvari M, Clark M, Laviolette LC, Bernstein MA, Kaliton D, Castaneda C, et al. Association of muscle power with functional status in community-dwelling elderly women. J Gerontol A Biol Sci Med Sci. 2000;55:M192–9.
119.Rudd JR, Pesce C, Strafford BW, Davids K. Physical literacy-A journey of individual enrichment: An ecological dynamics rationale for enhancing performance and physical activity in all. Front Psychol. 2020;11:1904.
120.Mijnarends DM, Schols JM, Meijers JM, Tan FE, Verlaan S, Luiking YC, et al. Instruments to assess sarcopenia and physical frailty in older people living in a community (care) setting: similarities and discrepancies. J Am Med Dir Assoc. 2015;16:301–8.
121 Freiberger E, De Vreede P, Schoene D, Rydwik E, Mueller V, Frändin K, et al. Performance-based physical function in older community-dwelling persons: a systematic review of instruments. Age Ageing. 2012;41:712–21.
122.Rikli RE, Jones CJ. Functional fitness normative scores for community-residing older adults, ages 60-94. J Aging Phys Act. 1999;7:162–81.
123.Mijnarends DM, Meijers JM, Halfens RJ, ter Borg S, Luiking YC, Verlaan S, et al. Validity and reliability of tools to measure muscle mass, strength, and physical performance in community-dwelling older people: a systematic review. J Am Med Dir Assoc. 2013;14:170–8.
124.Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc. 1991;39:142–8.
125.Rockwood K, Awalt E, Carver D, MacKnight C. Feasibility and measurement properties of the functional reach and the timed up and go tests in the Canadian study of health and aging. J Gerontol A Biol Sci Med Sci. 2000;55:M70-3.
126.O'Grady HK, Edbrooke L, Farley C, Berney S, Denehy L, Puthucheary Z, et al. The sit-to-stand test as a patient-centered functional outcome for critical care research: a pooled analysis of five international rehabilitation studies. Crit Care. 2022;26:1–11.
127.Volpato S, Cavalieri M, Guerra G, Sioulis F, Ranzini M, Maraldi C, et al. Performance-based functional assessment in older hospitalized patients: feasibility and clinical correlates. J Gerontol A Biol Sci Med Sci. 2008;63:1393–8.
128.Labata-Lezaun N, González-Rueda V, Rodríguez-Sanz J, López-de-Celis C, Llurda-Almuzara L, Rodríguez-Rubio PR, et al. Correlation between physical performance and stabilometric parameters in older adults. Medicina (Mex). 2022;58:1211.
129.Judge JO, Schechtman K, Cress E, Group F. The relationship between physical performance measures and independence in instrumental activities of daily living. J Am Geriatr Soc. 1996;44:1332–41.
130.Graham JE, Ostir GV, Fisher SR, Ottenbacher KJ. Assessing walking speed in clinical research: a systematic review. J Eval Clin Pract. 2008;14:552–62.
131.Rikli RE, Jones CJ. Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. The Gerontologist. 2013;53:255–67.
132.Jones CJ, Rikli RE, Beam WC. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. Res Q Exerc Sport. 1999;70:113–9.
133.Newman AB, Simonsick EM, Naydeck BL, Boudreau RM, Kritchevsky SB, Nevitt MC, et al. Association of long-distance corridor walk performance with mortality, cardiovascular disease, mobility limitation, and disability. Jama. 2006;295:2018–26.
134.Rossiter-Fornoff JE, Wolf SL, Wolfson LI, Buchner DM, Group F. A cross-sectional validation study of the FICSIT common data base static balance measures. J Gerontol A Biol Sci Med Sci. 1995;50:M291–7.
135 Bohannon RW. Reference values for the five-repetition sit-to-stand test: a descriptive meta-analysis of data from elders. Percept Mot Skills. 2006;103:215–22.
136.Brooks D, Davis AM, Naglie G. The feasibility of six-minute and two-minute walk tests in in-patient geriatric rehabilitation. Can J Aging Rev Can Vieil. 2007;26:159–62.
137.Rikli RE, Jones CJ. Development and validation of a functional fitness test for community-residing older adults. J Aging Phys Act. 1999;7:129–61.
138.Tiedemann A, Shimada H, Sherrington C, Murray S, Lord S. The comparative ability of eight functional mobility tests for predicting falls in community-dwelling older people. Age Ageing. 2008;37:430–5.

139.Berg K. Measuring balance in the elderly: Validation of an instrument (Dissertation). Montr Can McGill Univ. 1993;
140.Desrosiers J, Bravo G, Hébert R, Dutil É, Mercier L. Validation of the Box and Block Test as a measure of dexterity of elderly people: reliability, validity, and norms studies. Arch Phys Med Rehabil. 1994;75:751–5.
141 Jones CJ, Rikli RE, Max J, Noffal G. The reliability and validity of a chair sit-and-reach test as a measure of hamstring flexibility in older adults. Res Q Exerc Sport. 1998;69:338–43.
142.Hess RJ, Brach JS, Piva SR, VanSwearingen JM. Walking skill can be assessed in older adults: validity of the Figure-of-8 Walk Test. Phys Ther. 2010;90:89–99.
143.Dite W, Temple VA. A clinical test of stepping and change of direction to identify multiple falling older adults. Arch Phys Med Rehabil. 2002;83:1566–71.
144.Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: a new clinical measure of balance. J Gerontol. 1990;45:M192–7.
145 Bohannon RW, Peolsson A, Massy-Westropp N, Desrosiers J, Bear-Lehman J. Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. Physiotherapy. 2006;92:11–5.
146.Ashendorf L, Vanderslice-Barr JL, McCaffrey RJ. Motor tests and cognition in healthy older adults. Appl Neuropsychol. 2009;16:171–6.
147 Newton RA. Validity of the multi-directional reach test: a practical measure for limits of stability in older adults. J Gerontol A Biol Sci Med Sci. 2001;56:M248–52.
148.Miller J, Comfort P, McMahon J. Laboratory Manual for Strength and Conditioning. Taylor & Francis; 2023.
149.Vereeck L, Wuyts F, Truijen S, Van de Heyning P. Clinical assessment of balance: normative data, and gender and age effects. Int J Audiol. 2008;47:67–75.
150.Bohannon RW, Crouch R. 1-Minute sit-to-stand test: systematic review of procedures, performance, and clinimetric properties. J Cardiopulm Rehabil Prev. 2019;39:2–8.
151.Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol. 1994;49:M85–94.
152.Lemmink KA, Kemper HC, Greef MH, Rispens P, Stevens M. The validity of the sit-and-reach test and the modified sit-and-reach test in middle-aged to older men and women. Res Q Exerc Sport. 2003;74:331–6.
153.van Kan GA, Rolland Y, Houles M, Gillette-Guyonnet S, Soto M, Vellas B. The assessment of frailty in older adults. Clin Geriatr Med. 2010;26:275–86.
154.Bean JF, Kiely DK, LaRose S, O'Neill E, Goldstein R, Frontera WR. Increased velocity exercise specific to task training versus the National Institute on Aging's strength training program: changes in limb power and mobility. J Gerontol Ser Biomed Sci Med Sci. 2009;64:983–91.
155.Runge M, Rittweger J, Russo CR, Schiessl H, Felsenberg D. Is muscle power output a key factor in the age-related decline in physical performance? A comparison of muscle cross section, chair-rising test and jumping power. Clin Physiol Funct Imaging. 2004;24:335–40.
156.Steffen TM, Hacker TA, Mollinger L. Age-and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds. Phys Ther. 2002;82:128–37.
157.Abe T, Patterson KM, Stover CD, Geddam DA, Tribby AC, Lajza DG, et al. Site-specific thigh muscle loss as an independent phenomenon for age-related muscle loss in middle-aged and older men and women. Age. 2014;36:1353–8.
158.Baum CM, Connor LT, Morrison T, Hahn M, Dromerick AW, Edwards DF. Reliability, validity, and clinical utility of the Executive Function Performance Test: A measure of executive function in a sample of people with stroke. Am J Occup Ther. 2008;62:446–55.
159.Gary KW. Assessment of Motor Process Skills. In: Kreutzer JS, DeLuca J, Caplan B, editors. Encycl Clin Neuropsychol [Internet]. New York, NY: Springer New York; 2011. p. 263–4. Available from: https://doi.org/10.1007/978-0-387-79948-3_1794
160.Doble SE, Lewis N, Fisk JD, Rockwood K. Test-retest reliability of the assessment of motor and process skills in elderly adults. Occup Ther J Res. 1999;19:203–15.
161. Doble SE. Test-retest and inter-rater reliability of a process skills assessment. Occup Ther J Res. 1991;11:8–23.
162.Norberg E-B, Boman K, Löfgren B. Activities of daily living for old persons in primary health care with chronic heart failure. Scand J Caring Sci. 2008;22:203–10.
163.Goverover Y. Cognition and activities of daily living in multiple sclerosis. Cogn Behav Mult Scler. Washington, DC, US: American Psychological Association; 2018. p. 171–90.
164.Buchain PC, Harder J, Oliveira AM, Vizzotto A dias, Homem de Mello PC, Ferraz Alves TC. P1-511: FUNCIONALITY AND EXECUTIVE FUNCTION IN HEALTHY AND CARRIERS OF DEMENTIA IN ALZHEIMER'S DISEASE ELDERLIES: VALIDATION STUDY OF THE EXECUTIVE FUNCTION PERFORMANCE TEST-BR. Alzheimers Dement. 2019;15:P464–5.
165.Arieli M, Agmon M, Gil E, Kizony R. The contribution of functional cognition screening during acute illness hospitalization of older adults in predicting participation in daily life after discharge. BMC Geriatr. 2022;22:1–11.
166.Katz S. The index of ADL: a standardized measure of biological and psychosocial function. J Am Med Assoc. 1963;185:914–9.
167.Mahoney FI, Barthel DW. Functional evaluation: the Barthel Index: a simple index of independence useful in scoring improvement in the rehabilitation of the chronically ill. Md State Med J. 1965;
168.Graf C. The Lawton instrumental activities of daily living scale. AJN Am J Nurs. 2008;108:52–62.
169.RA K. The functional independence measure; a new tool for rehabilitation. Adv Clin Rehabil. 1987;1:6–18.
170.Fisher AG, Jones KB. Assessment of motor and process skills. Three Star Press Fort Collins, CO; 2003.
171.Holm MB, Rogers J, Hemphill-Pearson B. The performance assessment of self-care skills (PASS). Assess Occup Ther Ment Health. 2008;2:101–10.

172.Shah S, Vanclay F, Cooper B. Improving the sensitivity of the Barthel Index for stroke rehabilitation. J Clin Epidemiol. 1989;42:703–9.
173.Hall KM, Hamilton BB, Gordon WA, Zasler ND. Characteristics and comparisons of functional assessment indices: disability rating scale, functional independence measure, and functional assessment measure. J Head Trauma Rehabil. 1993;8:60–74.
174.Loewenstein DA, Amigo E, Duara R, Guterman A, Hurwitz D, Berkowitz N, et al. A new scale for the assessment of functional status in Alzheimer's disease and related disorders. J Gerontol. 1989;44:P114–21.
175.Carswell A, McColl MA, Baptiste S, Law M, Polatajko H, Pollock N. The Canadian Occupational Performance Measure: a research and clinical literature review. Can J Occup Ther. 2004;71:210–22.
176.Kuriansky JB, Gurland BJ, Fleiss JL, Cowan D. The assessment of self-care capacity in geriatric psychiatric patients by objective and subjective methods. J Clin Psychol. 1976;32:95–102.
177.Nouri F, Lincoln N. An extended activities of daily living scale for stroke patients. Clin Rehabil. 1987;1:301–5.
178.Heimann N, Allen C, Yerxa E. Reliability and validity of the Routine Task Inventory (RTI). Occup Ther Pract. 1989;1:67–74.
179.Kempen GI, Miedema I, Ormel J, Molenaar W. The assessment of disability with the Groningen Activity Restriction Scale. Conceptual framework and psychometric properties. Soc Sci Med. 1996;43:1601–10.
180.Schmitter-Edgecombe M, Parsey CM. Cognitive correlates of functional abilities in individuals with mild cognitive impairment: Comparison of questionnaire, direct observation, and performance-based measures. Clin Neuropsychol. 2014;28:726–46.
181.Loturco I, Contreras B, Kobal R, Fernandes V, Moura N, Siqueira F, et al. Vertically and horizontally directed muscle power exercises: Relationships with top-level sprint performance. PloS One. 2018;13:e0201475.
182.Kulmala J-P. The effects of locomotor pattern diversity and ageing on the lower limb joint mechanics and loading during human walking and running. Stud Sport Phys Educ Health. 2015;
183.Earles DR, Judge JO, Gunnarsson OT. Velocity training induces power-specific adaptations in highly functioning older adults. Arch Phys Med Rehabil. 2001;82:872–8.
184.Alexander N. Postural control in older adults. J Am Geriatr Soc. 1994;42:93–108.
185.Lesinski M, Hortobágyi T, Muehlbauer T, Gollhofer A, Granacher U. Effects of balance training on balance performance in healthy older adults: a systematic review and meta-analysis. Sports Med. 2015;45:1721–38.
186.Raymond MJ, Bramley-Tzerefos RE, Jeffs KJ, Winter A, Holland AE. Systematic review of high-intensity progressive resistance strength training of the lower limb compared with other intensities of strength training in older adults. Arch Phys Med Rehabil. 2013;94:1458–72.
187.Talar K, Hernandez-Belmonte A, Vetrovsky T, Steffl M, Ka\lamacka E, Courel-Ibáñez J. Benefits of resistance training in early and late stages of frailty and sarcopenia: a systematic review and meta-analysis of randomized controlled studies. J Clin Med. 2021;10:1630.
188.Davids K, Glazier P, Araújo D, Bartlett R. Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. Sports Med. 2003;33:245–60.
189.Schoene D, Valenzuela T, Lord SR, de Bruin ED. The effect of interactive cognitive-motor training in reducing fall risk in older people: a systematic review. BMC Geriatr. 2014;14:1–22.
190.Annett J, Kay H. Knowledge of results and'skilled performance'. Ergon Major Writ. 2004;31:91.
191.Lauber B, Keller M. Improving motor performance: Selected aspects of augmented feedback in exercise and health. Eur J Sport Sci. 2014;14:36–43.
192 Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. Med Educ. 2010;44:75–84.
193.Morrissey MC, Harman EA, JOHNSON MJ. Resistance training modes: specificity and effectiveness. Med Sci Sports Exerc. 1995;27:648–60.
194.Bean JF, Herman S, Kiely DK, Frey IC, Leveille SG, Fielding RA, et al. Increased Velocity Exercise Specific to Task (InVEST) training: a pilot study exploring effects on leg power, balance, and mobility in community-dwelling older women. J Am Geriatr Soc. 2004;52:799–804.
195.Faria AL, Andrade A, Soares L, others. Benefits of virtual reality based cognitive rehabilitation through simulated activities of daily living: a randomized controlled trial with stroke patients. J Neuroengineering Rehabil. 2016;13:1–12.
196.Dobek JC, White KN, Gunter KB. The effect of a novel ADL-based training program on performance of activities of daily living and physical fitness. J Aging Phys Act. 2007;15:13–25.
197.Granacher U, Muehlbaue T, Zahner L, Gollhofer A, Kressig RW. Comparison of traditional and recent approaches in the promotion of balance and strength in older adults. Sports Med. 2011;41:377–400.
198.Kümmel J, Kramer A, Giboin L-S, Gruber M. Specificity of balance training in healthy individuals: a systematic review and meta-analysis. Sports Med. 2016;46:1261–71.
199.Heinrich KM, Crawford DA, Langford CR, Kehler A, Andrews V. High-intensity functional training shows promise for improving physical functioning and activity in community-dwelling older adults: a pilot study. J Geriatr Phys Ther. 2021;44:9–17.
200.Giné-Garriga M, Guerra M, Pagès E, Manini TM, Jiménez R, Unnithan VB. The effect of functional circuit training on physical frailty in frail older adults: a randomized controlled trial. J Aging Phys Act. 2010;18:401–24.
201.Trombetti A, Hars M, Herrmann FR, Kressig RW, Ferrari S, Rizzoli R. Effect of music-based multitask training on gait, balance, and fall risk in elderly people: a randomized controlled trial. Arch Intern Med. 2011;171:525–33.
202.Okubo Y, Schoene D, Lord SR. Step training improves reaction time, gait and balance and reduces falls in older people: a systematic review and meta-analysis. Br J Sports Med. 2017;51:586–93.
203.Mian OS, Thom JM, Narici MV, Baltzopoulos V. Kinematics of stair descent in young and older adults and the impact of exercise training. Gait Posture. 2007;25:9–17.
204.Donath L, Kurz E, Roth R, Zahner L, Faude O. Leg and trunk muscle coordination and postural sway during increasingly difficult standing balance tasks in young and older adults. Maturitas. 2016;91:60–8.

205.Saeterbakken AH, Andersen V, Kolnes MK, Fimland MS. Effects of replacing free weights with elastic band resistance in squats on trunk muscle activation. J Strength Cond Res. 2014;28:3056–62.
206.Lee TD, Magill RA. Can forgetting facilitate skill acquisition? Adv Psychol. Elsevier; 1985. p. 3–22.
207.Lee TD, Swinnen SP, Serrien DJ. Cognitive effort and motor learning. Quest. 1994;46:328–44.
208.Guadagnoli MA, Lee TD. Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. J Mot Behav. 2004;36:212–24.
209.Liu C, Latham NK. Progressive resistance strength training for improving physical function in older adults. Cochrane Database Syst Rev. 2009;
210.Sherrington C, Tiedemann A. Physiotherapy in the prevention of falls in older people. J Physiother. 2015;61:54–60.
211.Cadore EL, Rodríguez-Mañas L, Sinclair A, Izquierdo M. Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: a systematic review. Rejuvenation Res. 2013;16:105–14.
212.Brady F. The contextual interference effect and sport skills. Percept Mot Skills. 2008;106:461–72.
213.Hall KG, Magill RA. Variability of practice and contextual interference in motor skill learning. J Mot Behav. 1995;27:299–309.
214.Graser JV, Bastiaenen C, van Hedel H. The Role Of The Practice Order: A Systematic Review About Contextual Interference. Context Interf. 2021;14:35.
215.Barreiros J, Figueiredo T, Godinho M. The contextual interference effect in applied settings. Eur Phys Educ Rev. 2007;13:195–208.
216.Kelso JS. Dynamic patterns: The self-organization of brain and behavior. MIT press; 1995.
217.Shea CH, Wulf G. Schema theory: A critical appraisal and reevaluation. J Mot Behav. 2005;37:85–102.
218.Leizerowitz GM, Gabai R, Plotnik M, Keren O, Karni A. Improving old tricks as new: Young adults learn from repeating everyday activities. Plos One. 2023;18:e0285469.
219.Bohannon RW, Schaubert K. Long-term reliability of the timed up-and-go test among community-dwelling elders. J Phys Ther Sci. 2005;17:93–6.
220.Koedijker JM, Poolton JM, Maxwell JP, Oudejans RR, Beek PJ, Masters RS. Attention and time constraints in perceptual-motor learning and performance: Instruction, analogy, and skill level. Conscious Cogn. 2011;20:245–56.
221.I Schollhorn W, Hegen P, Davids K. The nonlinear nature of learning-A differential learning approach. Open Sports Sci J. 2012;5.
222.Laidlaw DH, Bilodeau M, Enoka RM. Steadiness is reduced and motor unit discharge is more variable in old adults. Muscle Nerve Off J Am Assoc Electrodiagn Med. 2000;23:600–12.
223.Ketcham CJ, Dounskaia NV, Stelmach GE. Age-related differences in the control of multijoint movements. Motor Control. 2004;8:422–36.
224.Hsu W-L, Lin K-H, Yang R-S, Cheng C-H. Use of motor abundance in old adults in the regulation of a narrow-based stance. Eur J Appl Physiol. 2014;114:261–71.
225.Newell KM, Vaillancourt DE, Sosnoff JJ. Aging, complexity, and motor performance. Handb Psychol Aging. Elsevier; 2006. p. 163–82.
226.Magill RA, Hall KG. A review of the contextual interference effect in motor skill acquisition. Hum Mov Sci. 1990;9:241–89.
227.Wilson C, Simpson SE, Van Emmerik RE, Hamill J. Coordination variability and skill development in expert triple jumpers. Sports Biomech. 2008;7:2–9.
228.Stergiou N, Harbourne RT, Cavanaugh JT. Optimal movement variability: a new theoretical perspective for neurologic physical therapy. J Neurol Phys Ther. 2006;30:120–9.
229.Hamill J, van Emmerik RE, Heiderscheit BC, Li L. A dynamical systems approach to lower extremity running injuries. Clin Biomech. 1999;14:297–308.
230.Sparrow WA, Newell KM. Metabolic energy expenditure and the regulation of movement economy. Psychon Bull Rev. 1998;5:173–96.
231.Davids K, Araújo D, Vilar L, Renshaw I, Pinder R. An ecological dynamics approach to skill acquisition: Implications for development of talent in sport. Talent Dev Excell. 2013;5:21–34.
232.Pinder RA, Davids K, Renshaw I, Araújo D. Representative learning design and functionality of research and practice in sport. J Sport Exerc Psychol. 2011;33:146–55.
233.Brymer E, Renshaw I. An introduction to the constraints-led approach to learning in outdoor education. J Outdoor Environ Educ. 2010;14:33–41.
234.Turner A, Comfort P. Periodisation. Adv Strength Cond. Routledge; 2017. p. 116–36.
235.Savelsbergh GJ, Wormhoudt R. The athletic skills model: Enhancing physical literacy across the lifespan. Nonlinear Pedagogy Athl Ski Model. Routledge; 2021. p. 102–10.
236.Ehrman JK, Gordon PM, Visich PS, Keteyian SJ. Clinical Exercise Physiology: Exercise Management for Chronic Diseases and Special Populations. Human Kinetics; 2022.
237.Fragala MS, Cadore EL, Dorgo S, Izquierdo M, Kraemer WJ, Peterson MD, et al. Resistance training for older adults: position statement from the national strength and conditioning association. J Strength Cond Res. 2019;33.
238.Immink MA, Verwey WB, Wright DL. The neural basis of cognitive efficiency in motor skill performance from early learning to automatic stages. Neuroergonomics Princ Pract. Springer; 2020. p. 221–49.
239.Jacobs DM, Michaels CF. Direct learning. Ecol Psychol. 2007;19:321–49.
240.Vereijken B, Emmerik RE van, Whiting H, Newell KM. Free (z) ing degrees of freedom in skill acquisition. J Mot Behav. 1992;24:133–42.
241 Ferlinc A, Fabiani E, Velnar T, Gradisnik L. The importance and role of proprioception in the elderly: a short review. Mater Socio-Medica. 2019;31:219.
242.Clemson L, Singh MAF, Bundy A, Cumming RG, Manollaras K, O'Loughlin P, et al. Integration of balance and strength training into daily life activity to reduce rate of falls in older people (the LiFE study): randomised parallel trial. Bmj. 2012;345.

243.Bergquist R, Weber M, Schwenk M, Ulseth S, Helbostad JL, Vereijken B, et al. Performance-based clinical tests of balance and muscle strength used in young seniors: a systematic literature review. BMC Geriatr. 2019;19:1–14.
244.Wollesen B, Mattes K, Schulz S, Bischoff LL, Seydell L, Bell JW, et al. Effects of dual-task management and resistance training on gait performance in older individuals: a randomized controlled trial. Front Aging Neurosci. 2017;9:415.
245.Barnett CT, Vanicek N, Polman R. Postural responses during volitional and perturbed dynamic balance tasks in new lower limb amputees: A longitudinal study. Gait Posture. 2013;37:319–25.
246.Browne PR, Robertson S, Sweeting A, Davids K. Prevalence of interactions and influence of performance constraints on kick outcomes across Australian football tiers: Implications for representative practice designs. Hum Mov Sci. 2019;66:621–30.
247.Porter C, Greenwood D, Panchuk, D, Pepping G. Learner-adapted practice promotes skill transfer in unskilled adults learning the basketball set shot. Eur J Sport Sci. 2020;20:61–71.
248.Otte FW, Millar S-K, H"uttermann S. How does the modern football goalkeeper train?–An exploration of expert goalkeeper coaches' skill training approaches. J Sports Sci. 2020;38:1465–73.
249.Czosnek L, Rankin N, Zopf E, Richards J, Rosenbaum S, Cormie P. Implementing exercise in healthcare settings: the potential of implementation science. Sports Med. 2020;50:1–14.
250.Peterson MD, Gordon PM. Resistance exercise for the aging adult: clinical implications and prescription guidelines. Am J Med. 2011;124:194–8.
251.Buckley JP. Exercise physiology in special populations: Advances in sport and exercise science. Elsevier Health Sciences; 2008.
252.Mjøsund HL, Uhrenfeldt L, Burton E, Moe CF. Promotion of physical activity in older adults: facilitators and barriers experienced by healthcare personnel in the context of reablement. BMC Health Serv Res. 2022;22:956.
253.Hunter EG, Kearney PJ. Occupational therapy interventions to improve performance of instrumental activities of daily living for community-dwelling older adults: A systematic review. Am J Occup Ther. 2018;72:7204190050p1–9.
254.Falvey JR, Burke RE, Malone D, Ridgeway KJ, McManus BM, Stevens-Lapsley JE. Role of physical therapists in reducing hospital readmissions: optimizing outcomes for older adults during care transitions from hospital to community. Phys Ther. 2016;96:1125–34.
255.Schutzer KA, Graves BS. Barriers and motivations to exercise in older adults. Prev Med. 2004;39:1056–61.
256.Skjæret N, Nawaz A, Morat T, Schoene D, Helbostad JL, Vereijken B. Exercise and rehabilitation delivered through exergames in older adults: an integrative review of technologies, safety and efficacy. Int J Med Inf. 2016;85:1–16.