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PERSPECTIVE FOR PROGRESS

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The Interaction between Mobility Status and Exercise Specificity in Older Adults

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BRAHMS, C.M., T. HORTOBÁGYI, R.W. KRESSIG, and U. GRANACHER. The interaction between mobility status and exercise specificity in older adults. *Exerc. Sport Sci. Rev.*, Vol. 49, No. 1, pp. 15–22, 2021. *Many adults older than 60 yr experience mobility limitations. Although physical exercise improves older adults' mobility, differences in baseline mobility produce large variations in individual responses to interventions, and these responses could further vary by the type and dose of exercise. Here, we propose an exercise prescription model for older adults based on their current mobility status.* **Key Words:** exercise prescription, training intervention, walking speed, activities of daily living, elderly

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Key Points

- Exercise dose and type interact with mobility status in older adults.
- Walking speed is a simple, valid, and reliable biomarker of mobility status.
- Mobility-limited older adults (walking speed, $<0.8\ \text{m}\cdot\text{s}^{-1}$) should exercise independent of type and dose, as long as recommendations for daily physical activity are met.
- Older adults with normal mobility (walking speed, $0.8\text{–}1.4\ \text{m}\cdot\text{s}^{-1}$) should perform higher volumes of specific balance and resistance training.
- Highly mobile older adults (habitual walking speeds of $>1.4\ \text{m}\cdot\text{s}^{-1}$) benefit most from task-specific balance, strength, and power training at high doses performed in a periodized fashion.

INTRODUCTION

Mobility is associated with health and quality of life in old age. Although it has been broadly defined as the ability to move independently or with the use of assistive devices within one's environment, mobility is inherently linked to walking (1,2). Mobility depends on an individual's physical, cognitive, and psychosocial resources and is influenced by environmental, biographical, and cultural factors (3,4). Natural aging and sedentariness favor the evolution of mobility limitations, and consequently many older adults have difficulties walking and performing other activities of daily living (5). Prevalence rates of mobility limitations vary with definition. For example, 59% and 43% of adults aged 60–74 yr in the United States and Europe, respectively, and as much as 75% of individuals 80 yr or older have mobility limitations, that is, difficulties walking for longer distances or climbing steps without resting (3,6–8). Moreover, 40% of adults aged 60–74 yr and 65% of people aged 75 yr have at least one chronic disease such as heart disease, diabetes, or osteoarthritis, which increases the risk for future mobility limitations (5). For the purpose of this narrative review, we will define mobility as the ability to walk independently within one's environment. We will further discuss mobility in the context of walking speed, as it correlates with or predicts other dimensions of mobility, such as static and dynamic balance, chair rise time, timed up and go test performance, and stair ascent and descent (9–12). Furthermore, training-induced increases in walking speed are often accompanied by concomitant increases in other measures of mobility, and several large-cohort studies have demonstrated its predictive nature with respect to future health status, mobility limitations, and mortality (13–17). Moreover, we define mobility limitations as objective difficulties to move oneself around by walking or as the need of equipment or personal assistance for walking (2).

Physical activity, defined as movement generated by contracting skeletal muscle that leads to an increase in energy expenditure, can reduce common risk factors for mobility limitations, such as

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obesity, hypertension, and diabetes (18,19). Similarly, exercise, a subset of physical activity characterized by planned, structured, and repetitive movement, can preserve or improve physical determinants of mobility, such as muscle strength, balance, and flexibility (20). In light of this evidence, the World Health Organization (WHO) has recognized physical activity and exercise as fundamental strategies to improve older adults' mobility and health. To facilitate the translation of scientific results into practice, guidelines have been established for specific age groups. Accordingly, international health organizations such as the WHO and the American College of Sports Medicine recommend that all adults 65 yr or older perform either 75 min of vigorous-intensity physical activity (4.8–6.8 metabolic equivalent of task [MET], 76%–96% of maximum heart rate [HR_{max}]), 150 min of moderate-intensity physical activity (3.2–4.8 MET, 64%–76% HR_{max}) per week, or an equivalent combination thereof, as well as strength exercises on two or more days per week (21,22). The guidelines further loosely address older adults with "poor mobility" and recommend that these individuals additionally perform balance exercises on three or more days per week (21). Despite their effectiveness, universal exercise guidelines suggest that older individuals represent a homogeneous group of inactive yet "healthy" individuals. However, it is often overlooked that older adults' mobility varies greatly and overall diversity generally increases with age (23).

In a landmark article based on his J.B. Wolffe Memorial Lecture, Haskell (24) proposed a model that assumes the magnitude of exercise-related health benefits changes as a function of baseline activity status. The model predicts that for any given increase in activity, larger effects will be observed in inactive individuals. In accordance with the law of diminishing returns, the effects will be blunted in moderately active individuals and barely detectable in highly active individuals. However, despite its relevance, the model is vague with respect to predictors as well as outcome measures, and it also does not discuss dose-response relations in the context of training specificity. We, therefore, adapted the model to address the hypothesis that differences in baseline mobility status cause substantial variation in the responsiveness to training, and these responses further vary by exercise type and dose (Fig. 1). That is, the effects of resistance and aerobic training on mobility are inversely related to the severity of mobility limitations: the greater the mobility limitation, the greater the training-induced improvements in mobility (25). In these low-baseline individuals, the interventions produced a dominant overall conditioning effect, which masks specific training adaptations. For example, even a specific gait retraining intervention originally designed for stroke patients may result in improved cardiovascular function in sedentary adults if their baseline function is low enough. Hortobágyi *et al.* (26) expressed this idea by stating that interventions intended to reduce specific dysfunctions will produce a general effect in healthy but sedentary individuals.

A reinterpretation of Haskell's model within a mobility framework further indicates that exercise programs with the main goal to promote physical activity will fail to generate an appropriate adaptive response in older adults with high baseline mobility status. In contrast, older adults with low mobility status benefit from these unspecific interventions and may even improve their mobility at least during the early stages of training (27). To test these assumptions, accurate and meaningful information about an individual's current mobility status must be obtained. Since walking speed represents the integrative output of multiple body systems and functions, such as postural control, muscle strength, and aerobic capacity, its assessment could serve as a first step in the process of designing and implementing targeted exercise intervention for older adults (28). As indicated in Figure 2, walking speed can predict future mobility limitations and overall health in aging adults and even outperforms more complex, multicomponent mobility scales, such as the Short Physical Performance Battery (30). The literature has established cutoff values to cluster subpopulations of older adults according to their mobility status. For example, individuals with habitual walking speeds of >1.0 $m \cdot s^{-1}$ are generally at a low risk of experiencing future mobility limitations, whereas older adults who habitually walk at speeds of 0.6 $m \cdot s^{-1}$ represent a high-risk population (13). Furthermore, a threshold of 0.8 $m \cdot s^{-1}$ has been successful in identifying older adults at increased risk for mobility limitations, frailty, hospitalization, and death (31–33). Based on the white paper of Fritz and Lusardi (28), we propose that older adults with walking speeds of <0.8 $m \cdot s^{-1}$ be classified as having low mobility status, whereas those with habitual walking speeds ranging from 0.8 to 1.4 $m \cdot s^{-1}$ and walking speeds of >1.4 $m \cdot s^{-1}$ be classified as having normal and high mobility status, respectively.

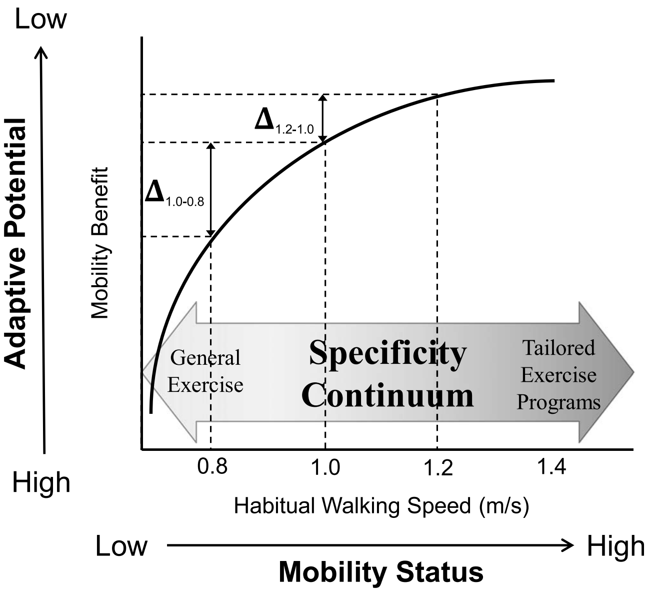

Figure 1. Conceptual model of the principle of diminishing returns in a mobility context. The logarithmic growth of training adaptations is a function of improved mobility status. Δ represents the magnitude of exercise-induced mobility benefits as walking speed improves from 0.8 to 1.0 $m \cdot s^{-1}$ and from 1.0 to 1.2 $m \cdot s^{-1}$, respectively. Individuals with high mobility status have to invest more time to induce adaptations compared with individuals with low mobility status. Based on information from (24).

This Perspective for Progress paper provides a synopsis of the efficacy of balance, strength, and power training to improve mobility in subpopulations of older adults that differ with respect to baseline mobility. We also propose a conceptual model that illustrates the adaptive potential to improve mobility as a function of an individual's baseline mobility status and argue that optimal exercise dose-response relations vary according to exercise type and baseline mobility. First, we discuss the general effects of exercise on mobility and its underlying physiological mechanisms.

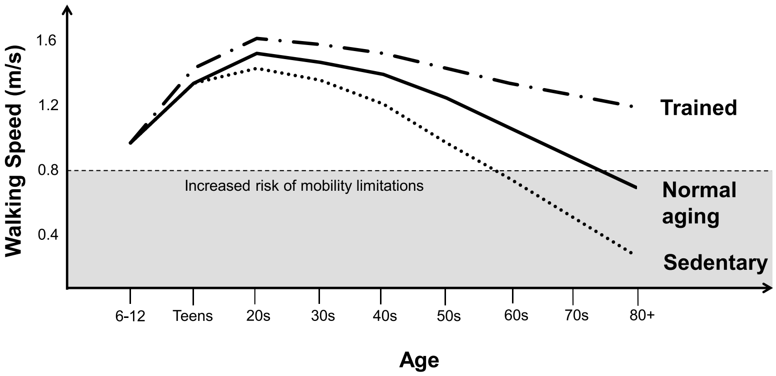

Figure 2. Mobility throughout the lifespan. Visual representation demonstrating the effects of exercise on walking speed and its implications for mobility status. Based on information from (29).

GENERAL EFFECTS OF EXERCISE ON MOBILITY AND ITS PHYSIOLOGICAL CORRELATES

Exercise interventions (*e.g.*, resistance training, aerobic training) can reduce the risk of developing mobility limitations and improve mobility-limited older adults' walking capacity. For example, high-intensity agility exergaming and stationary cycling at identical cardiovascular load were both similarly effective in improving perceived mobility limitations and walking capacity in mobility-limited older adults (27). A recent large cohort study showed that mobility-limited older adults were able to improve walking speed and delay the onset of mobility disability after completing two training sessions per week (amounting to 150 min of moderate-intensity exercise), each of which consisted of aerobic walking followed by 10 min of resistance exercise, as well as a brief flexibility and a set of balance training (34). In these individuals, diverse interventions mitigated the age-related muscular, skeletal, nervous, and cognitive decline underlying mobility limitations. For example, exercise programs involving aerobics, dancing, strength, and balance training were all shown to reduce the risk of dementia, a condition that has been associated with mobility impairment (35). Older adults who reported deterioration of their memory over the past years were able to improve cognition and mobility after participating in dual-task gait training and aerobic exercise three times per week for a period of 6 months (36).

Diverse weight-bearing exercises, such as resistance and jump training, can improve bone health, which is particularly relevant for sedentary and mobility-impaired older individuals who are at a high risk for mobility limitations through fractures and osteoporosis (37,38). Furthermore, exercise can ameliorate the progressive, age-related decline in skeletal muscle strength and mass that begins in the fourth decade of life (39,40). This condition called sarcopenia is a critical risk factor for frailty and mobility limitations in older adults (41). Fortunately, skeletal muscle retains its trainability throughout the lifespan and responds well to exercise, even in individuals 90 yr and older (42). Randomized controlled trials demonstrated that high-velocity training with low loads as well as high-intensity resistance training improved muscle power and physical performance in mobility-limited older adults (43). Likewise, high-intensity resistance training as well as low-load blood flow-restricted resistance training improved muscle size and strength in older adults who were classified as being at risk of mobility limitations due to low levels of leg muscle strength (44). In sum, clinical evidence suggests that exercise helps to maintain mobility in older adults, independent of type, dose, and intensity.

SPECIFICITY AND DOSE-RESPONSE RELATIONS OF STRENGTH, POWER, AND BALANCE TRAINING

The mobility benefits produced by diverse interventions in aging adults support the validity of different exercise types to prevent and treat mobility limitations. However, studies have reported significant interindividual variability in responsiveness to exercise training, which has been assumed to result from poor compliance with established training principles and in particular from a lack of training specificity (45,46). Accordingly, musculoskeletal adaptations occur only in the muscles, tendons, and bones that have been exposed to a stimulus and are determined by the type, frequency, intensity, and duration of exercise (47). For instance, adaptations in skeletal muscle are specific to the type of contraction, the speed at which a movement is executed, as well as the range of motion or position at which an exercise is performed. Likewise, metabolic adaptations occur only in energy systems that are stressed during exercise. The principle of training specificity further predicts that exercises, which mimic the demands of a discrete movement task, will result in better outcomes compared with less specific training interventions (47).

Elite athletes intuitively train according to the principles of training specificity: marathon runners train with high volumes and intensities that are specific to the demands of their competition, whereas Olympic weightlifters develop muscle strength and power by high-intensity resistance exercises. Evidence from studies involving elite athletes further suggests that in trained individuals, progression in the form of an increase in task-specific training volume and intensity is needed to produce further physiological adaptations (48). This phenomenon previously has been denoted as the principle of diminishing returns: as physical function improves relative to baseline, the magnitude of training-induced adaptations in response to identical training loads decrease over time (Fig. 1). This principle also applies to highly mobile older adults, that is, those with walking speed above 1.4 m·s^{-1}, because they will have to scale up task-specific exercise volume and intensity to provide continuous overload on their system. In other words, an individual with high mobility status has to invest more training time, use higher training loads, and perform more specific exercises to elicit additional performance improvements compared with a person with low mobility status.

Specificity of Balance Training

Walking requires dynamic control of the body's center of mass over a narrow base of support, making dynamic balance a critical determinant of mobility. Interventions aimed at improving balance can also improve mobility. As expected, tai chi, dancing, multicomponent individual and group exercises, and resistance training can all improve dynamic balance and reduce the risks of developing mobility limitations (49–51). There is evidence, however, that the effects of balance training are task specific: even small differences between a balance test and a training exercise can make tests insensitive to changes produced by balance training (52). By increasing the complexity of the training stimulus, balance training involving mechanical perturbations of the center of mass and motor-cognitive multitasking seem to improve mobility and reduce fall risks more effectively than traditional balance training, which consists of static and dynamic exercises performed on various surfaces in a single- or two-legged stance (53).

A thorough analysis of the optimal dose-response relations of balance training in healthy older adults indicated that the period, frequency, and volume of training can significantly affect balance improvements and that the greatest effects on balance are observed when training three times per week over a period of 11–12 wk for a total number of 36–40 training sessions, a duration of 31–45 min of a single training session, and a total duration of 91–120 min of balance training per week (54). Supervision-related eedback to participants increases movement quality and balance training intensity, thus improving balance outcomes more than unsupervised balance training (55).

In the context of training specificity, exercise types that can be performed at a relatively low intensity and require balance, cognitive control, coordination, strength, and endurance, such as group dancing or tai chi, improve balance and mobility in older adults with low mobility status (51). These intervention programs represent gentle, low-intensity aerobic exercise types, particularly when performed by sedentary individuals. More importantly, they likely improve balance in untrained or mobility-impaired individuals via a general training effect, as its execution simultaneously poses demands on musculoskeletal, cardiovascular, and cognitive and postural control systems. Dancing is an exercise type that affords multitasking (*i.e.*, listening to music and moving to the rhythm of the music most often with a partner). In addition, these activities appeal to former inactive adults because of its social dimension and accessibility (50). As a result, these activities have gathered attention in the geriatric community and are increasingly used for the prevention of falls and maintenance in individuals with limited mobility. For instance, Trombetti *et al.* (56) have shown that a 6-month music-based training (Jaques-Dalcroze eurhythmics) has positive effects on gait, balance, and fall risk in frail older adults. In contrast, balance-training interventions with high task specificity, that is, those that use reactive, anticipatory, or multitask balance exercises, are well suited for highly mobile older adults because these individuals possess the physical capacity to handle these stimuli and adapt to them.

Specificity of Strength and Power Training

Rapid force generation is fundamental in fall risk situations, for example, when tripping over an obstacle, because there is limited time to stabilize the body's center of mass and recover from loss of balance. Consequently, both muscle strength and power are important determinants of mobility, and resistance training is an effective means to induce specific neuromuscular adaptations that translate into improved mobility in healthy older adults. It is assumed that increases in muscle-tendon properties underlie improvements in healthy older adults' mobility (57). In particular, high-intensity resistance training improves maximal voluntary muscle strength, and lower-intensity, high-volume training is effective for improving muscle morphology (58). Meta-analytical evidence identified the optimal resistance training dose parameters for improving healthy older adults' lower extremity muscle mass and strength (59). Accordingly, optimal benefits for increasing muscle strength are achieved by training twice per week over a period of 50–53 wk, using 7–9 repetitions per set and 2–3 sets per exercise, contracting muscles for 6 s per repetition, as well as resting 4 s between repetitions and 60 s between sets. The optimal training intensity for increasing muscle strength ranges from 70% to 79% of the one-repetition maximum (1RM). The largest effects on muscle cross-sectional area, muscle volume, and thickness were reported when exercising three times per week for a total period of 50–53 wk, with 2–3 sets per exercise and 7–9 repetitions per set at intensities ranging from 51% to 69% of the 1RM. Here, the optimal time under tension is 6 s per repetition, whereas rest should amount to 120 and 2.5 s between sets and repetitions, respectively (59).

In healthy older adults without mobility limitations, muscle power increases in response to resistance training performed with either high loads (80% of the 1RM) or lighter loads (40% of the 1RM) that are moved at a high velocity (60,61). Meta-analytical evidence further recommends jump training as a safe and effective way of increasing muscular power in this population (62). High-velocity resistance training seems to be particularly effective to improve balance, walking speed, and other measures of physical function in older adults with normal to high mobility status (63–65). Although the exact mechanism of how training-improved muscle power increases walking speed remains unclear, 10 wk of lower extremity power training modified the gait mechanics of healthy older adults so that knee extensor, plantar flexor, and hip extensor joint powers increased significantly at fast but not habitual walking speeds after training (66). The same intervention improved walking speed via increased cadence, a greater reliance on hip muscle function, and a heightened activation of knee extensors (Fig. 3) (66–68). However, the optimal dose of power training to improve healthy older adults' mobility has not yet been identified.

The evidence from resistance and power training studies suggests that healthy older adults with low baseline mobility, as indicated by habitual walking speeds of $<0.8\ \mathrm{m{\cdot}s^{-1}}$, could accrue substantial mobility benefits from resistance training regardless of dose parameters and with a minimal risk for injury especially after low-intensity resistance training (60). In contrast, older adults with high baseline mobility, that is, those with fast walking speeds above $1.4\ \mathrm{m{\cdot}s^{-1}}$, will need to execute resistance training at a high intensity and volume to maintain or improve the high-level function further.

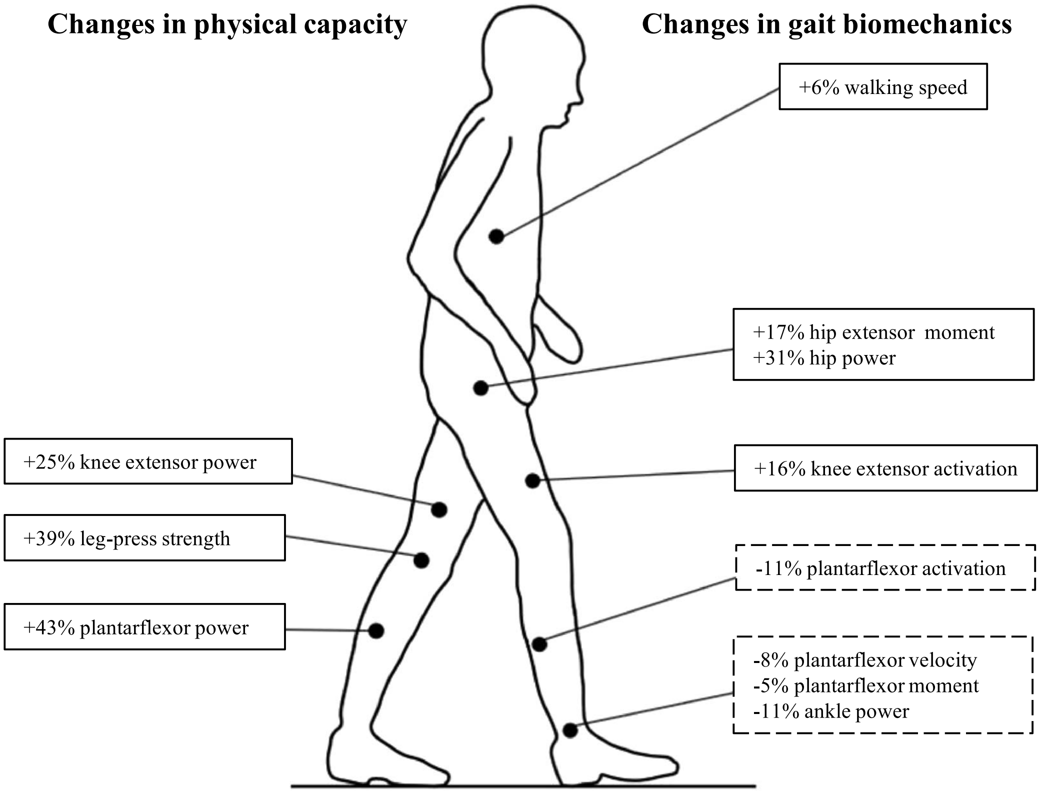

Figure 3. Effects of 10 wk of lower extremity power training on physical capacity and gait mechanics in healthy older adults (as detailed in [66–68]).

THE WALKING SPEED EXERCISE PRESCRIPTION MODEL

Sedentary older adults with low baseline mobility have a high adaptive potential regardless of the exercise stimulus. This is because subclinical mobility limitations (slow gait, low stability, obesity, arthritis) are randomly distributed among older adults (26) and adaptations produced by specific mobility interventions produce general and heterogeneous effects on these older adults' mobility outcomes. The random distribution of subclinical mobility limitations across this cohort may be related to a lack of selective effects of exercise interventions on walking speed, a key marker of mobility (57).

With respect to the type and volume of recommended exercise, we propose that older adults with slow habitual walking speeds participate in multimodal or combined exercise interventions, because for these individuals, the type of exercise is of minor importance and adherence to age-specific exercise guidelines will result in broad and general benefits on mobility outcomes. The aim for these patients is to start the exercise program as soon as possible after the diagnosis of mobility limitation and prevent or slow further loss of mobility, balance, muscle strength, muscle mass, and bone mass. For older adults who have managed to reduce their initial mobility limitation with exercise and for older adults with high mobility status at the time of mobility testing, the aim is to maintain or perhaps further improve the current level of mobility. Health care professionals should, however, carefully select the type and dose of exercise because improvements in mobility may be small, may not be even necessary, and could increase risk for musculoskeletal injuries. Interventions for mobile older adults should include balance and resistance training with higher volumes of specific task loads, such as perturbation and dual-task exercises. In addition, these individuals should adhere to the dose-response relations on measures of balance training, as well as resistance training for muscle and bone mass and mobility outcomes. The Table summarizes the model of exercise prescription.

Adjustment of training interventions in compliance with established principles of exercise physiology must occur as individuals progress along the mobility continuum. Changes in walking speed between 0.05 and 0.10 $m \cdot s^{-1}$ were shown to be clinically relevant, and significant walking speed improvements have been observed after interventions lasting 8 wk (64,69–71). For healthy older adults, it is, therefore, advisable to reassess walking speed every 6–8 wk to track potential changes in mobility status. In mobility-limited older adults, walking speed increases after

TABLE. Summary of the walking speed exercise prescription model: suggested categories of mobility status based on walking speed and their respective exercise implications

Walking Speed	Mobility Status	Exercise Implications
<0.8 ($m \cdot s^{-1}$)	Low	• Adherence to general, mostly untargeted interventions according to age-related exercise guidelines
0.8–1.4 ($m \cdot s^{-1}$)	Normal	• High degree of specificity • Larger doses of task-specific balance and strength training, such as perturbation and dual-task balance training • Evidence-based dose-response relations should be considered
>1.4 ($m \cdot s^{-1}$)	High	• High volumes of task-specific balance, strength, and power training embedded in a periodization model

short-term interventions lasting only 4 to 6 wk, which suggests that shorter testing intervals, for example, every 4 wk, may be advantageous for these individuals (72–74). Notably, walking speed assessment does not render potentially more detailed assessments obsolete. Rather, it should be regarded as a regular screening tool whose results serve as a starting point for more detailed assessment (57). However, further studies are required to verify the proposed model based on data and to investigate the mechanisms responsible for the heterogeneity of adaptive responses.

FUTURE PERSPECTIVES

The reviewed research suggests an interaction between mobility status and exercise dose and type in older adults across the mobility spectrum. Existing exercise guidelines are valid for a large part of the aging population, and sustained adherence will cause notable benefits in sedentary older adults. In these individuals, diverse exercise types cause great improvements in terms of mobility, even if administered in small doses. However, because the training response to unspecific intervention programs seems blunted in individuals with higher mobility status, it is imperative to endorse the need of tailored strategies to produce optimal mobility benefits for all of the aging population. This approach requires a screening tool that is capable of quickly and reliably assessing the mobility status of an individual. The prognostic capabilities of walking speed in terms of mobility limitations, frailty, falls, cognitive decline, and mortality as well as established cut-off values make a strong case for its use in the exercise prescription process for older adults (28,75). We propose that older adults with habitual walking speeds of $<0.8\ \mathrm{m{\cdot}s^{-1}}$ should focus on meeting the recommended activity requirements for their age group, whereas individuals who have progressed along the mobility continuum and have habitual walking speeds ranging from 0.8 to $1.4\ \mathrm{m{\cdot}s^{-1}}$ should perform balance and resistance training with increasing volumes of specific task loads, such as perturbation and dual-task exercises. Because older adults with habitual walking speeds of $>1.4\ \mathrm{m{\cdot}s^{-1}}$ do not need to further improve their mobility, they should exercise with high volumes of specific strength, power, and balance training in a periodized fashion to prevent the decline of mobility. Strategic resistance, power, and plyometric training with high intensities significantly increased muscle strength, power, lean body mass, and functional capacity in high-functioning older individuals and recreational senior athletes, which suggests that these programs provide sufficient stimuli to increase their functional capacity (76–78). In conclusion, the examined data suggest that the optimal exercise type and dose for older adults depend on an individual's current mobility status. Physicians and other health care professionals are encouraged to leverage evidence of these interactions to improve exercise prescription for older adults.

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