TARGETED RESISTANCE TRAINING TO IMPROVE INDEPENDENCE AND REDUCE FALL RISK IN OLDER CLIENTS
by Joseph F. Signorile, Ph.D.

Learning Objectives

Readers will learn the multidimensional nature of resistance training. Information will be provided that will allow readers to modify common resistance training protocols and learn novel techniques to target goals inherent to the aging process. They also will learn how specific protocols can be structured to maximize benefits.

Key words: Resistance Training, Training Specificity, Translation, Exercise Prescription

Older persons (60 years of age and older) constitute the fastest growing segment of our population with an expected increase from 43.1 million in 2012 to a projected 83.7 million in 2050 (72). The loss of muscle and neuromuscular performance with age eventually leads to reduced physical independence, increased fall risk, and declining quality of life in older persons (49,62). Maintaining function and independence arguably is more important than increasing life expectancy (50). Given the increase in the elderly population, the social and economic burdens of declined physical function are a major public health concern. In recognition of this dilemma, an overriding goal of the U.S. Department of Health and Human Services’ Healthy People 2020 initiative is to reduce the proportion of older adults with moderate-to-severe functional limitations (47). Interventions that can successfully address these concerns are imperative to the well-being of older persons and society as a whole (46). Resistance training has proven to be an effective modality for addressing the needs of older individuals; however, the specific loading techniques, movement patterns, and protocols available to the clinician vary considerably. Careful manipulation of these training variables allows targeted prescriptive exercise designs that can address the particular needs of the individual and effectively reflect the American College of Sports Medicine’s (ACSM’s) Exercise is Medicine® initiative. This article will present protocols designed to address individual needs and explain the theories behind their design and implementation. Sidebar 1 presents definitions that may prove helpful as you read this article. In addition, although diagnostic testing is beyond the scope of this article, Sidebar 2 presents references for tests that you may use to track clients’ progress and recognize how to use the techniques included in this article to maximize clients’ progress.
Sidebar 1. Helpful Definitions.

**Agonist-Antagonist Coactivation**: The coordinated firing of the agonist (prime mover) and antagonist (opposing) muscles, presumably to maintain degree of joint stability.

**Classic Training Continuum**: The repetition training continuum (4) or repetition maximum continuum (39) states that the number of repetitions allowed by changing resistance results in specific training adaptations.

**Executive Function**: A diverse neuropsychological concept that includes the physical and cognitive skills necessary to initiate, implement, and maintain goal-specific activities and to modify activities as goals change (97). Therefore, executive function may be considered a multifaceted concept including factors such as selecting proper responses, blocking ineffective responses, improving motor capacity, and showing the cognitive flexibility to change goals (97).

**Isokinetic Training**: A specialized training system using a dynamometer that restricts movement speed (89,101).

**Motor Unit Recruitment**: Progressively activating motor neurons and their associated muscle fibers to increase force and potentially power output.

**Linear Periodization**: The classic periodization scheme that typically begins with high work volumes, low intensities, and low-skill work and progresses through targeted microcycles (approximately 1 wk) and mesocycles (multiple weeks) to low-volume, high-intensity work with increasing concentration on skill work.

**Lower Body Power Asymmetry**: Differences in power production between the lower limbs (92).

**Proprioception**: The perception of the relative positions of one’s body parts (88).

**Rate Coding**: Increases or decreases in the firing frequency of a motor unit to affect force production and/or movement speed of the motor fibers being innervated.

**Synchronization of Synergistic Muscles**: Matched motor unit discharges (firing patterns) across muscles that perform the same or similar actions with the intent of increasing strength or power.

**Surfing the Force-Velocity Curve**: As illustrated in Figure 4, some activities may require more strength for their successful completion, whereas others may be more dependent on speed of movement. I coined this phrase decades ago to indicate that you can target these activities by changing force-velocity relationships along the curve. The word surfing came to mind because the power and force-velocity curve both reminded me of ocean waves (87).

**Undulating Periodization**: A form of nonlinear periodization, the most popular being daily undulating periodization incorporating alternating days of hypertrophy, strength, and power/speed each week, whereas weekly undulating periodization uses this pattern across a 3-week repeating cycle (17).


**LOWER BODY STRENGTH**

**30-Second Chair Stand**


**UPPER BODY STRENGTH**

**30-Second Arm Curl**

James TW. The 30-second arm curl test as an indicator of upper body strength in older adults. 1999.

**Grip Strength Test**


**LOWER BODY POWER**

**30-Second Chair Stand**


**Ramp Power Test**


**UPPER BODY POWER**

**Gallon-Jug Shelf Transfer Test**


**Seated Medicine Ball Throw**


**LOWER BODY ENDURANCE**

**Two-Minute Walk Test**


**Static Half-Squat Test**

Sarcopenia and Dynapenia

Sarcopenia (sarco = muscle; penia = deficiency or lack) was traditionally defined as a decline in muscle mass. The classic definition was a sex-specific decline in muscle mass below two standard deviations of normal young men and women (Figure 1) (28). This definition encouraged concentration on increases in muscle mass rather than on muscle function (strength, power, endurance). Given this goal, and likely the dominant influence of bodybuilding on the design of resistance training workouts, most of the early work with older persons concentrated on hypertrophy-based protocols (22,41). The evolution of the definition, which incorporates functions such as walking speed and grip strength, and the prevalent use of the term dynapenia

**FUNCTIONAL PERFORMANCE/DAILY ACTIVITY BATTERIES**

**Short Physical Performance Battery (SPPB)**


**TEXTS**


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**Figure 1.** The classic sarcopenia curve. Note that the red portion of the curve is two standard deviations (97.6%) below the muscle cross-sectional area of sex-matched younger population.
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(dyna = power; penia = deficiency or lack), has redirected attention as it relates to this topic toward muscle function rather than size (24,28). Simply defined, dynapenia is a loss of strength, power, or endurance that can be expected to lead to an increased risk for functional loss and mortality in older persons (24,26). The distinction between sarcopenia and dynapenia is especially relevant to training prescription because muscle size has a progressively weaker relationship to neuromuscular function as we age.

HYPERTROPHY

In this section, we will concentrate on prescriptions addressing the classic definition of sarcopenia by examining protocols that maximize hypertrophy. Resistance training programs that target hypertrophy traditionally use high work volume by combining multiple sets and exercises with moderate to moderately heavy loading patterns (54,64). These patterns usually are coupled with intermediate-length recoveries to maximize total work during each session (54,64). Although there are a number of controlled studies that have demonstrated significant hypertrophic responses in older persons using standard strength training programs (22,41) and low training volumes, increases likely are not optimal when using protocols that fail to concentrate on maximizing total work (38). The relationship between work volume, with associated fatigue, and hypertrophy is supported in a recent meta-analysis by Csapo and Alegre (29) that reported significant gains in muscle mass were seen after moderate-intensity (approximately 50% one-repetition maximum (1 RM) and high-intensity (approximately 80% 1 RM) training as long as the volume of training is held high (8–11 reps for 2–4 sets) and sufficient recovery (approximately 1.5–3 min between sets and machines, respectively) is provided.

A final concept may be applicable when clinicians work with novice clients or those using daily undulating periodization during the early stages of training. There are data suggesting that when targeting increases in cross-sectional area in previously untrained, detrained, and to-some-extent-trained clients, low-repetition/high-load (4 sets, 3–5 reps; approximately 67%–93% 1 RM) and intermediate-repetition/moderate-load (3 sets, 9–11 reps; approximately 73%–77% 1 RM) training can produce similar levels of hypertrophy (19,84). This is not unexpected given the asymptotic nature of the training curve (13). In other words, improvements are greatest early in the training cycle (first 6–8 wks) and then show exponentially reduced levels of adaptation until a near-plateau is reached (Figure 2) (88).

STRENGTH

Of all the performance variables associated with resistance training, the most evident to the general public and most health professionals is strength. Although increases in strength are commonly associated with increases in muscle cross-sectional area, this relationship clearly is not absolute. In fact, the correlation between muscle size and strength becomes progressively less robust with age because it is influenced by the quality of muscle and connective tissue as well as reductions in voluntary muscle activation (24). For example, knee extensor isokinetic strength (see Sidebar 1 for definition) measured at 120 degrees/second versus hypertrophy in the time course of muscle strength gain. American Journal of Physical Medicine. 1979;58(3): 115–130. Used with permission) (13).

Figure 2. The asymptotic nature of training adaptations. (Adapted from: Moritani T, deVries HA, Neural factors versus hypertrophy in the time course of muscle strength gain. American Journal of Physical Medicine. 1979;58(3): 115–130. Used with permission) (13).

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and rate coding), 2) agonist-antagonist coactivation (5), and 3) synchronization of synergistic muscles (69) (see Sidebar 1). Although there is considerable support for increased activation and synchronization as controlling factors, the impact of agonist-antagonist coactivation remains undetermined (5). The greatest increases in neuromuscular activity in this older population were recorded at a resistance ranging from 70% to 80% 1RM using three sets of three repetitions three times per week (5).

Finally, there has been considerable dialogue during the past few decades concerning the optimum number of sets to be used to maximize strength gains. Despite earlier reviews supporting equal strength gains for single versus multiple sets (20,77), more recent meta-analyses support the use of multiple over single sets for strength development (79,80). However, single-set programs do seem feasible during the initial stage when working with previously untrained individuals or when maximizing strength is not the primary objective (102). Alternatively, it may be argued that the use of multiple sets allows the individual to improve skill and technique as long as intensity and volume are controlled carefully. Finally, results specific to older persons remain undetermined (43).

POWER

Power is the rate of doing work; therefore, it is the product of force and velocity of movement (87,88). The strong relationship between power and independence as we age is undeniable. Correlations have been reported between performance of activities of daily living (ADL), the ability to rise from a chair, stair climbing and gait speed and measures of leg extensor power (8,40,78,91). The relationship between reduced leg extensor, plantar flexor, and dorsiflexor power and falls also has been recognized for more than three decades (3,101) with special emphasis on increased risk due to lower limb power asymmetry (see Sidebar 1 for definition) (75,92).

With the onset of the new millennium, a number of studies have demonstrated the effectiveness of high-velocity training for power development and improved daily function in older persons (36,83,90). During the succeeding years, a great deal has been learned about the training methods that can maximize the development of mechanical power and its benefits to individuals as they age. The variables associated with maximizing power include optimal loading and the methods for providing training loads. Optimal loading can be defined as the percentage of maximal load that produces the highest power output. This concept may seem rather simple at first; however, there are a number of factors that can modulate this simple concept. The first is the mechanics of the joint being trained. We have demonstrated in a number of studies that the response of specific muscle groups to power training varies because of the bony levers associated with their structure (Figure 3) (42,89). Therefore, to maximize gains for each exercise, loading must be adjusted to reflect these biomechanical differences. We have established these loads for pneumatic (air pressure) training using Keiser machines, and we are currently establishing loads for standard selectorized Cybex machines.

The concept of optimal loading also must be adjusted to address what is arguably a more important factor: loading to address independence and fall reduction. Concerning independence let me harken back to a concept I presented more than a decade ago, “surfing the force-velocity curve” (see Sidebar 1 for definition) (87). This concept embodies a simple idea that ultimately dictates loading for functionality: the loads used to develop power should reflect the loads used during the activities being targeted by the training prescription applied. This concept is reflected in the work of Cuoco et al. (30). Succinctly, lower loads are used to train power at the velocity end of the curve when movement speed is the dominant goal, as when targeting gains in gait speed. In contrast, daily activities, such as rising from a chair or climbing stairs that require greater work against gravity, dictate training at the load end of the curve (Figure 4).

As a final caveat, given that many researchers recognize that power training with older persons is based primarily on the attempt to move at near-maximal speeds (36,83,90), the training modalities that can best support this type of training in a safe environment should be explored. Pneumatic resistance machines are the most common tools used because of their smooth force-angle curves and low levels of momentum. In addition, rubber tubing provides a practical, although somewhat limited, alternative. Free weights are another feasible option; however, their use should be approached with caution because they present a higher injury risk to the uninitiated or detrained individual with declining neuromuscular and connective tissue strength due to age. Finally, most research studies with older persons have incorporated dumbbells and weighted bags rather than barbells, leaving loading patterns across more classic lifts such as squats or bench press undetermined (15,91,92). Currently, our laboratory is comparing the use of selectorized and pneumatic machines to assess their relative effectiveness, safety, and acceptance with an older population.

MUSCULAR ENDURANCE

Before examining the importance of muscular endurance to older persons, it is first important to distinguish between muscular and cardiovascular endurance. Although these two concepts are not completely independent nor mutually exclusive, clear physiological and functional distinctions can be made when defining each. Cardiovascular endurance is “the ability of the circulatory and respiratory system to supply oxygen during sustained physical activity” (37) whereas muscular endurance can be defined as the ability of a skeletal muscle to maintain a specific power output (88).

Muscular endurance is a critical factor in maintaining independence (6,85) and reducing fall risk (85,94) in older persons. It also is associated with reduced proprioception (see Sidebar 1 for definition) (66). Because daily tasks each require their own critical absolute strength level for effective performance, older persons likely will require a greater proportion of their maximum
strength than younger individuals to perform each task, and their ability to perform these tasks for extended durations will be proportionally reduced (6,85).

Although increasing muscle strength may increase muscular endurance, specific protocols are available to target muscular endurance (15). For example, we have demonstrated the effectiveness of a high-repetition resistance training protocol based on ACSM guidelines at increasing muscular endurance. Subjects performed two sets of 15 to 25 repetitions for 11 exercises at 50% 1 RM, and high speeds were encouraged during the concentric phases of the lift to target the maintenance of a specific power output. They were allowed 1 to 2 minutes recovery between sets, with minimal recovery between machines. Upper and lower body exercises were alternated. Loading was increased as necessary to maintain resistance levels. Our results showed that this training protocol not only reduced power declines during 20-repetition leg and chest press tests; these improvements also were evident in ADL performance tests (Bailey et al., personal communication). Our results reflect the training continuum proposed by Campos et al. (19), who noted that muscle endurance could best be increased using two sets of high-repetition training (20–28 RM) with a 1-minute recovery between sets (see sidebar 1 for definition).

BIOMECHANICAL SPECIFICITY AND ACTIVITIES OF DAILY LIVING

In most of the resistance training studies done with older participants, the exercises were performed using standard weight training machines. These machines usually dictate that:
- The individual is seated;
- The movement of the handles follows a fixed, linear path;
- Isolated or limited kinetic chain patterns are used; and,
- Core muscles are rarely involved except as stabilizers.

Although, as noted above, resistance training enhances neuromuscular performance, these increases translate only modestly into improvements in daily activities (60,76). A feasible explanation for this low level of positive transfer is the lack of biomechanical specificity because the movement patterns used during machine-based training often fail to mirror those used during daily activities (21).

A number of researchers have addressed this issue by providing exercise programs that mimic or even replicate ADL (2,10, 11,32,63). Many of these exercises, however, fail to provide the external loading patterns that effectively improve neuromuscular capacity during resistance training.

This limitation can be addressed using exercises that allow more degrees of freedom such as free weights or cable machines,
with the latter providing a safer environment and less challenging learning curve. These modalities allow exercises to be performed in a standing position using movement patterns that provide transfer of forces from the lower to upper body through the core muscles in kinetic sequences common to many daily activities such as transfer tasks, house cleaning, and gardening (Figure 5 A-D). However, this does not negate the use of standard weight training machines, which can target daily activities that incorporate more linear or isolated movement patterns and can provide higher loads (Figure 6A, B). Furthermore, as illustrated in Figure 7A-H, band or tube resistance exercise may be used in lieu of weight training machines where this equipment is not available.

In addition to considering muscle use patterns as they relate to ADL, we also should consider muscle targeting as it relates to fall reduction. There are four muscle groups that receive minimal attention during training, yet are critical for improving balance and reducing fall risk. Perhaps the most ignored, and coincidentally the most important, are the dorsiflexors. A simple search of the literature will provide dozens of studies demonstrating the relationships of this muscle group to balance and falls (88). A second muscle group that receives minimal training is the hip flexors. If you doubt the importance of these groups to gait, simply put this article down and walk a few steps. Notice that every step is initiated by flexing the hip and dorsiflexing the foot. The inability to effectively perform these two movements reduces ground clearance and makes walking over a crack in the sidewalk equivalent to stepping over a curb. The other two muscle groups that are habitually ignored are the hip adductors and abductors. This predominantly sex-specific avoidance, with women as the predominant users, ignores the fact that there is a direct relationship between hip abductor and adductor function and fall risk (68) and related injury (23). In addition, as illustrated in Figure 8, weights can be used, in conjunction with postures that challenge center of gravity/base relationships, to improve balance.

**ENERGY EXPENDITURE AND BODY COMPOSITION**

Because of age-related declines in metabolic rate (34) and declining levels of physical activity (34), obesity is a common problem facing aging individuals. The implications of this condition range from reduced capacity to perform ADL to increased incidence of metabolic disease. When a body mass index of more than 30 kg/m$^2$ is combined with sarcopenia, a state known as sarcopenic obesity exists (56). Individuals with sarcopenic obesity are at greater risk for disability and loss of independence than those who are merely obese or sarcopenic (9,81). Although...
typical high-intensity interval programs have proven somewhat effective in addressing obesity and some aspects of metabolic syndrome in older (44) and younger populations (51,86), circuit resistance training programs have the capacity to elicit greater metabolic cost than typical steady state (25) or traditional-strength programs (82). They also can add the additional benefits of providing overloads capable of increasing muscle mass and neuromuscular function in older persons (7,82).

In addition to greater energy expenditure being generated by circuit resistance training compared with heavy resistance (71) or traditional treadmill training (25), it also can produce significantly higher excess postexercise oxygen consumption (EPOC) than steady state training (14,71). Research has demonstrated that explosive training at 60% 1 RM can produce greater energy expenditures than slow training at 60% 1 RM or explosive training at 80% 1 RM (64,65) and that minimizing recovery time between exercises and sets seems the most effective strategy for increasing EPOC (31). The following are other circuit training strategies that have shown the potential to positively address body composition and increase energy expenditure:

- Used a combination of resistance and aerobic exercise during the circuit (48,67,74,98);
Prescribed intensity based on heart rate (12); Used training frequencies higher than twice per week (1,45); and, Included dietary controls (55).

In summary, circuit-based resistance training, performed at moderate loads and high velocities at least three times per week, seems most effective, especially when combined with a calorie-restricted diet.

COGNITION

The link between cognitive function and exercise has generated significant interest within the scientific and clinical communities. To date, however, the predominant exercise interventions that have been linked to positive changes in cognitive function have concentrated on aerobic conditioning, and improvements have been hypothesized to be proportional to improved delivery of oxygen and nutrients to neural tissues (26,99). Reviews do suggest that improved cognition requires high-intensity aerobic exercise (26,99); however, improvements in aerobic capacity do not fully explain improvements in cognition (35). In addition, high-velocity circuit resistance training has been shown to improve cognition, psychiatric symptoms, and neuromuscular performance in overweight outpatients with schizophrenia and bipolar disorder (96). Four additional controlled trials support these results showing increases in cognition and executive function (for definition see Sidebar 1) with resistance training (16,52, 61,100). More recently, in a study of 324 healthy female twins aged 43 to 73 years, Steves et al. (95) demonstrated that leg power was a significant predictor of cognitive aging and changes in global brain structure even when controlling for genetics and developmental environment. And finally, a meta-analysis examining the effects of exercise on depression indicated that improvements were not mediated by increases in cardiovascular fitness (27). Therefore, improved cardiovascular fitness may be one facilitator of improved cognitive function, but increased motor capacity certainly is a major contributor.

The results of the study by Strassnig et al. (96) and a recently completed study comparing ballroom and hip-hop aerobic dance (Nicole et al., personal communication) add a further consideration when exploring resistance training designed to improve cognition. The Strassnig study used a translational recovery component where ADL-specific movements were practiced. The dance study showed that greater increases in executive function occurred with ballroom compared with aerobic hip-hop, even in the face of greater aerobic gains engendered by the latter. This was likely because of the need to work in coordinated patterns in response to changing auditory stimuli rather than the verbal cues and less complex imitative movements during the hip-hop class.

When the results of these studies are considered as indicators of the most effective resistance training protocol for improving cognition, two hypothetical protocols emerge. The first is a high-speed power-based circuit with recovery cycles that incorporate...
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ADL-specific translational cycles as recommended in my *Bending the Aging Curve* text (88) or high-speed power training using biomechanically specific movement patterns as previously described. Regardless of the method used, there is little doubt, given results of animal studies, that movement speed and complexity are each potent stimulators of cognitive capacity (53,59).

PERIODIZATION

Periodization can simply be defined as a method of cycling volume, intensity, and skill performance in a set pattern designed to maximize a specific goal while minimizing fatigue and the potential for overtraining. A comprehensive description of periodization as they may be applied to older individuals is beyond the scope of this article; however, I would like to conclude with some important considerations you should keep in mind:

- Recovery is as essential as overload for improving performance and related improvements in daily living.
- Both linear and undulating models can be effective methods for applying periodization (see Sidebar 1 for definitions);
- Taper periods during the periodization cycle are ideal times to add ADL-specific movements to allow increases in neuromuscular function to be translated into increased independence and reduced fall risk;
- After specific mesocycles, testing should be applied to provide direction and allow the evolution of the client’s/patient’s training program;
- A gradual tissue-adaptation period should be incorporated before beginning any program that will involve novice or deconditioned individuals; and,
- Proper structuring of targeted training cycles will allow the exercise physiologist to maximize benefits and reduce the potential for injury.

CONCLUSIONS

Resistance training is a potent tool for increasing independence and reducing falls and related injuries in aging individuals; however, to maximize the effectiveness of this tool, we must abandon the one-dimensional anorexic strength picture of resistance training and recognize that by changing the structure of the workouts and the methods by which loads are applied, we can truly realize the multidimensional nature of this intervention for successful aging. Therefore, the application of resistance training as an effective clinical intervention for sarcopenia and dynapenia should use concepts such as targeted loading, speed-specific power training, and biomechanical specificity to maximize improvement.


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