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THE GENERAL HEALTH-RELATED AND METABOLIC BENEFITS OF STRENGTH TRAINING

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Abstract

Lately, as our research group also previously showed, there is increased awareness in understanding if actually exercise performing could be somehow protective against most of the neuropsychiatric disorders such as dementia, Parkinson's disease, anxiety, depression, autism, schizophrenia or substance abuse disorder. Moreover, unlike cardio respiratory fitness, the effects of muscular strength training or resistive-type exercise on physiological and psychological outcomes have been largely overlooked in the research community. Thus, the main purpose of this article is to summarize what is currently known about the influence of strength training performed by adults on general mental health manifestations, as those encountered on the aforementioned disorders, by focusing this time on the specific physical movement aspects such as dose response, intensity, frequency and volume when performing these strength training exercises.

Key words: exercising, health, metabolic and neuropsychiatric disorders.

Introduction

Strength training is defined as the repeated muscle action against a resistance greater than those typically encountered during activities of daily living [1]. Muscle strengthening exercises are regularly performed as part of a progressive strength training program conducted with free weights, resistance training equipment, or elastic bands. Other examples of physical activities besides those listed above that may require a high resistance, depending on individual particularities such as a person's age, body size, strength, and fitness level, include gardening, carrying loads [2], water-based exercises [3], and activities that use the body weight for resistance, for example pull-ups, chin-ups and push-ups or body weight squats.

However lately, as our research group previously showed [4-8], there is increased awareness in understanding if actually exercise performing could be somehow protective against most of the neuropsychiatric disorders such as dementia, Parkinson's disease, anxiety, depression, autism, schizophrenia or substance abuse disorder.

In this way, for example it was previously demonstrated that an inverse relationship between cognitive impairment and cardiovascular fitness does seems to exist. Moreover, strength training was shown to be particularly effective for improving postural and motor functioning and reducing the risk of falling in demented subjects. In addition, the prevalence of obesity in children with autism was found to be 30.4% compared with 23.6% in age matched children without autism. The found data suggests that cardiovascular exercise interventions led to an improvement in overall symptomatology of autism, with significant results in behavioural and academic improvements, while also it was found to reduce the frequency of stereotypical behaviours, aggressive or self-injurious behaviours, and hyperactivity. Regarding Parkinson's disease, latest studies found that the risk of developing this disease appeared to be inversely associated with the amount of physical activity practiced throughout life. Also, strength training was found to have a positive effect on disease progression in people with Parkinson disease. In addition, studies on schizophrenia patients found a reduction in the severity of total symptoms of up to 9%. Moreover, other results suggested that patients with schizophrenia should use resistance training to improve their muscle strength and their physical, functional, and mental health [4-8].

Aerobic exercise is a necessary part of the treatment for patients suffering from these conditions, but aerobic exercise alone is probably not the best activity. Strength/power training, balance/coordination, and other types of physical exercises also contribute to reconditioning, maintaining, and improving the cognitive and motor functions these subjects.

As suggested above, unlike cardio respiratory fitness, the effects of muscular strength training or resistive-type exercise on physiological and psychological outcomes have been largely overlooked in the research community [9].
Typically, individuals commonly view strength training as a method to increase power and muscular size for athletic competition. But for the non-competitive athlete, resistance training, accomplished through a variety of equipment such as free weights or resistive machines, is an effective method for developing muscular-skeletal strength and has many prescriptive uses such as fitness, health, and prevention and rehabilitation of orthopedic injuries [10]. In addition, resistance training increases bone mineral density, promotes enhanced glucose metabolism, and increases basal metabolism that assists in weight management [11]. More so, a

cohort study of 8,762 men aged 20 to 80 years showed that maximum force is independently and inversely associated with all-cause mortality [12].

In this way, some demonstrated mental health benefits of resistance training could include a decrease in depression, an increase in self-esteem and physical self-concept, and it has been shown that strength training improves cognitive ability related to other neuropsychiatric disorders. Also, resistance training has been proven to reverse aging factors in skeletal muscle.

In addition, it is considered that a well-designed strength training program is context dependent and should take into consideration individual differences in a number of factors such as age, gender, the fitness goals or health outcomes, current fitness level, health status, any previous injuries or conditions, access to equipment, and the level experience with weight lifting of any kind.

For example, as a common guideline for general health, the US Department of Health and Human Services recommends that adults should strength train at least 2 times a week, should perform at least 1 set of 8 to 12 repetitions of muscle-strengthening activities of the major muscle groups (legs, back, chest, shoulders, arms, abdominals) [1]. It has been suggested that such a program, which can only take less than 30 minutes per week, will produce most of the health benefits of strength training [13].

However, a more rigorous program for healthy adults has been suggested by the American College of Sports Medicine for improving muscle strength and size [5]. The program should involve the use of both free weights and machines to perform preferably multiple-joint exercises (such as squats, bench press, leg press, shoulder press), but also single-joint exercises (such as leg extension, calf raise, arm curl). The program should involve 2 to 3 sets per exercise at an intensity that starts low (when individuals are learning the right technique) and then the intensity should increase to 60% to 80% of 1–repetition maximum (1-RM) for 8 to 12 repetitions, after the individuals have learned the correct motor pattern of the movement. It is recommended that the program should include 1 to 3 minutes of rest between sets and should be performed at a frequency of preferably 3 days per week. Each session in a program of this nature could be completed in approximately 40 to 80 minutes. This type of strength training program, performed for 8 to 52 weeks, which is considered typical strength training, is used in many studies.

Thus, the main purpose of this article is to summarize what is known about the influence of strength training performed by adults on general mental health manifestations, as those encountered on the aforementioned disorders, by focusing this time on the specific physical movement aspects such as dose response, intensity, frequency and volume when performing these strength training exercises.

General health benefits of strength training

Resistance training in general confers several health benefits, perhaps most notably for older adults, who often are characterized by reduced muscle mass, strength, and physical functional abilities [14]. As expected, evidence supports strength training effects on increased muscular strength [15], and power [16], bone density [17], and physical functional abilities such as improved balance and a reduction in the number of injurious falls among older adults [18,19]. Strength training can prevent sarcopenia (the degenerative loss of skeletal muscle mass quality, and strength associated with aging) and increase the ability to maintain muscle mass during a weight loss program [20]. Strength training also positively influences risk factors for diabetes and heart disease by improving insulin resistance and glycaemic control [21], as well as by lowering blood pressure [22]. The most important, muscular strength is inversely associated with all-cause mortality in men, independently of cardio respiratory fitness and other important confounders [23]. The mental health consequences of strength training are often disregarded, and are less frequently studied and consequently less well understood than, for example, the psychological effects of aerobic training.

Numerous studies have examined the beneficial effects of regular exercise across a variety of mental health measures. Thereby, as before mentioned, a big part of attention has been directed to the role of aerobic exercise, less is known about the role of resistance exercise in mental health outcomes.

Recent studies have documented the beneficial effects of resistance exercise on strength and performance-related outcomes, including increases in muscle mass, bone density and endurance [24, 25]. However, this research also indicates that the benefits of resistance exercise extend beyond muscle and tissue growth and include alterations in neurobiological systems relevant to mental health and anxiety-related outcomes [25]. These studies are helping in the understanding for the role of resistance exercise in mental health by showing that resistance exercise produces important alterations in the biological mediators of anxiety with potentially major implications for other important mental health outcomes.

In addition, strength training has become an essential integral component of the physical preparation for the enhancement of sports performance [26]. Moreover, while strength is defined as the integrated result of several force-producing muscles performing maximally, either isometrically or dynamically during a single voluntary effort of a defined task (e.g. power is the product of force and the inverse of time or such the ability to produce as much force as possible in the shortest possible time), although strength and power are not considered distinct entities, as power potential is directly influenced by training methods that maximizes strength [27, 28]. Therefore, the ability of a muscle to produce force and power is determined by the interplay of biomechanical and physiological factors, such as muscle mechanics (type of muscle action) and neural (motor unit recruitment) factors and morphological (muscle fiber type), and by the muscle environment itself (e.g. its biochemical composition) [29].

The mechanisms underlying strength/power adaptations are largely associated with an increase in muscle mass (hypertrophy) [30]. However, in some cases, muscular strength increase can be observed without noticeable hypertrophy and this is significant evidence for the importance of the neural involvement in the acquisition of muscular strength [30]. Also, despite the notion that hypertrophy and neural adaptations are the basis of muscle strength development [31], their respective mechanisms of adaptation in the neuromuscular system are distinct [32]. For that matter, to a certain extent, more strength does not necessarily mean an increase in muscle mass, because several distinct adaptations can lead to the same effect [31]. Thus, the effects of explosive and/or heavy-resistance strength training causing enhanced force and power production have been primarily attributed to neural adaptations, neural adaptations such as motor unit recruitment, synchronization and inter-muscular coordination [33,34].

The dose response for optimal health benefits

Despite the widespread acceptance among experts that strength training is necessary, even at an older age, many of the aspects of the dose-response relation have not been examined conclusively [35-37]. For example, activities of daily life are not sufficient as a training stimulus for the muscles. Elderly men and women which do not undergo additional training will lose body strength and the strength of the arms to a disproportionate extent [38].

Also, common training programs usually vary in terms of their intensity, the number of repetitions and sets, the progression of the weights, as well as the duration and frequency of the training days. Progressive muscle training requires precise instructions about the external load (the weight used as the resistance) and is mainly directed according to intensity. The external load is defined by traditional training equipment, free weights, resistance bands or the own body weight of the participant.

`In addition, depending on the intensity, physiological adaptation processes are being initiated either an increase in the cross-sectional muscle diameter or a higher acquisition of motor units, or most probably both.

Moreover, the correct execution of a strength training movement is very important because the way in which the exercises are performed contributes to transferring muscle force to activities of everyday life (e.g. getting up from a sitting position, holding one’s posture or carrying a heavy shopping bag).

Intensity

It is widespread the view that at an advanced age, load bearing intensity should be reduced in order to avoid injuries and chronic overuse. However, this idea is not supported by current evidence, and several studies have pointed out the need for higher intensities for elderly as well as young people.

Thus, n a meta-analysis of 29 randomized controlled studies including a total of 1313 subjects older than 65 years, Steib et al. showed a notable dependence of the improved strength capacity on the intensity of the weight training [39]. High-intensity strength training, performed at a higher than 75% of the maximal strength capacity, triggers higher increases in strength and hypertrophy than training at a medium or a low intensity.

Also, finding the right intensity and progression in a strength-training program may be the biggest challenge for a safe and effective exercise prescription for older adults, yet maybe the most important one. In a laboratory or highly supervised environment, it is relatively safe to have older adults exercising with a heavy weight (e.g. most often 70% to 80% of the one-repetition maximum). However, the vast majority of older adults will not be exercising in such a safe, supervised setting.

In this way, two methods for ensuring proper progression and intensity that are currently used when performing 1RMs are an option. These methods include the exercise intensity scale and repetition-based progression. Moreover, in some laboratories is has been successfully used a modified 10-point, Borg exercise-intensity scale for verbally assessing the intensity used [40, 41].

In addition, a verbal target of 7 to 8 out of 10 (hard) is considered to be ideal for ensuring a proper progression. This intensity is considered thus sufficiently challenging yet not too overwhelming or potentially injurious for older adults.

Another possible advantage of this method is the fact that it is a fairly simple concept in terms of application and explanation for older adults. For example, if the prescription is two sets of 10 repetitions, the load (or amount of weight being lifted) should be increased when more than 12 repetitions can be completed with proper form and speed [40].

Future studies should also examine the options for recommendations regarding intensity as part of a strength-training program. In the end, what is most important is that the individual progresses up to heavier weights over time, process known as progressive overload, always performing the exercises in good form and with good speed.

In addition, in a study by Ciolac et al. on women aged around 29 and 65, which lasted 13 week, with two groups, high intensity and low intensity strength training recorded an increase in strength in both groups, without any differences between groups. However, more importantly no adverse effects occurred in the high intensity training group [42].

In a follow-up study by the same authors, men (aged around 25, 65, and 72) also underwent 13 weeks of strength (resistance) training. They were also found to have relevant increases in strength as an adaptation to the training with heavy weights [43]. In elderly people, high-intensity progressive strength (resistance) training is therefore effective, and substantial adverse effects are not to be expected is the training is made with proper form.

In conclusion, the recommendation regarding a strength training program should not differ from that for young people, but a lower one-repetition-maximum can be assumed for elderly.

Typically, a strength training program aiming for hypertrophy is done at least 3 times a week for 8 to 12 weeks, while a longer training period increases a more sustained effect [44]. We should mentioned that a classic training program consists of 3 to 4 sets with about 10 repetitions per muscle group, at an intensity of about 80% of the one-repetition-maximum.

In addition, in order to maintain an adequate training stimulus, the intensity of the exercise will have to be ramped to the improved muscle force after some 6 to 8 weeks for muscle strength to increase progressively.

Besides the goal of muscular hypertrophy, strength training aims to increase muscle force by improving the acquisition, frequency and synchronization of motor units [36]. Such training of intramuscular coordination should be done in elderly people with higher (to maximum) weights with fewer repetitions per set, as a rule of thumb.

Current data clearly shows that training with fast movement speeds while using heavy weights is an effective and useful way to train for maximum benefits in everyday activities and general health [39].

Frequency

Studies have shown that there must be a careful balance between the progression of intensity and the utmost concern for safety and avoidance of injury when working with older adults. It could be argued that more than three sessions per week is burdensome and, as a result, some people would likely quit without supervision.

On the other hand, one session per week, while more prone to compliance goals, may not confer the maximum health benefits over time. As before mentioned, the current American College of Sports Medicine guidelines recommends at least 2 to preferably 3 days per week of strength training [45,46].

At the present time, this appears to be the perfect recommendation found in literature for strength-training recommendation for older adults, as it is manageable from a time perspective, allows certain flexibility in scheduling, and will deliver the desired physiologic and psychological benefits described in the literature.

Still, further research is needed to determine if 1 day per week of strength training can provide improvements in health outcomes over time in older adults.

Volume (Sets and repetitions)

Another important aspect of exercise programming that is still open for debate is the optimal number of repetitions and sets, as well as the total number of exercises, also known as the total volume of strength-training.

The studies are describing a range from two different exercises using three sets of eight repetitions to numerous exercises using one set of up to 20 repetitions. There are reasons to prescribe fewer exercises with multiple sets versus eight to ten exercises with only one or two sets depending on the study population. The main reason would be a faster learning of the correct motor pattern of the movement resulting in an easier and faster progression. Based on the majority of the evidence, it seems safe to use the following recommendations: when fewer than four exercises are used, prescribe two to three sets; when four to eight different exercises are used, prescribe one to two sets; when greater than eight exercises are used, prescribe one set. The general guidelines of 8 to 15 repetitions recommended by ACSM seem to be prudent advice when working with older adults [45,46].

Finally, future studies should examine the optimal design of the exercise program for maximum results in terms of the variation of intensity and volume (known as periodization) for older adults in studies lasting 12 weeks, as it was used in the studies made by Castaneda et al. [47] and Fielding et al. [48].

Equipment

In literature, there is also the question of what equipment is best suited to the needs and abilities of older adults. The primary options are single or multistation machines, body weight, free weights (barbells and dumbbells), exercise bands or a combination of all of the above. Probably the most important factor in this instance is access and availability. Where machines are available as is often true in a clinical or health and fitness centers the machines should be used. In general, achieving the desired intensity level, often times 70% to 80% 1RM, is easier using machines because the mechanics of the equipment allow a larger absolute load to be lifted. However, the machines are known to limit the natural range of motion, in which case one may argue that free weights are a better choice.

As a result, another important aspect, particularly in elderly population, is proper body positioning and range of motion for the prescribed exercises. In comparison to free weights, there is less room for misalignment of body positioning when using machines. Having said this, body weight, free weights and elastic bands have unique advantages for this population, especially in home-based or community settings. They are relatively inexpensive, transportable and take up minimal space. They may also confer additional benefits in terms of helping older adults maintain or increase kinaesthetic awareness, as well as dynamic movement and balance [49,50].

In addition, a study on 30 untrained subjects, with a mean age of 49, found a statistically significant difference for strength production in the group that trained only with free weights over the group that trained with fixed machines. The exercise groups were asked to exercise over a 16-week period, increasing resistance based on a standardized 8-12 repetition protocol. The same muscles were targeted in both exercise groups, all groups were instructed not to change their dietary habits. Major differences between the groups were found. Balance improved 49% in the fixed weights versus 245% in the free weights groups. The control group did not show significant improvement in either strength or balance. Results of this study indicate a greater improvement in free weight group over fixed machines group in strength (58%), and balance (196%). Most important, the subjects in the machines group reported increased pain levels while the free weights group reported lowered overall pain levels [51].

It should be noted that current research indicates that body weight exercises and free weights (barbells and dumbbells) elicit greater improvements in physiologic capacity (muscle strength and physical function) than elastic bands. Elastic bands are now being tested in larger-scale studies and may be a viable option when free weights are not available [52, 53].

Training environment

The concept of the training environment is an important one, and it should be assets on an individual differences. The literature indicates that important health improvements can be realized from both clinical and home-based strength-training programs. For some older adults, exercising at home is the most realistic and desirable option. No travel is required, and the older adult may feel most at ease. It can also be advantageous in terms of time and scheduling; individuals can exercise whenever they desire, without the constraints of a class schedule, and they can adapt their program as necessary to match daily schedule. However, for many older adults, the social network and social support of the exercise group increases program compliance, as well as their motivation and enjoyment of strength training.

Conclusions

There is a need for effective behaviour change interventions targeted at increasing the prevalence of resistance exercise behaviours. Health care practitioners are very important in assisting people in making the decision to adopt and maintain strength training as part of a healthy lifestyle, but these professionals often lack knowledge about strength training. Strength training should also be included when designing exercise programs for older adults (with the addition of balance training when indicated for frailer elders). Physical and psychological benefits have been clearly demonstrated using strength-training prescriptions that have varied in terms of frequency, intensity, duration and specific exercises. One area that research must now investigate is whether the addition of strength training to exercise prescriptions for older adults will actually delay the onset of disability in terms of occupation, socialization and the ability to remain living independently.

References

1. Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report, 2008. Washington, DC: US Department of Health and Human Services; 2008.
2. Bean J, Herman S, Kiely DK, et al. Weight stair climbing in mobility-limited older people: a pilot study. J Am Geriatrics Soc. 2002;50:663-670.
3. Takeshima N, Rogers ME, Wantanabe E, et al. Water-based exercise improves health-related aspects of fitness in older women. Med Sci Sports Exerc. 2002;34:544-551.
4. Ciobica A, Honceriu C, Ciobica A, Dobrin R, Trofin F, Timofte D. Is exercising relevant for some therapeutical approaches in anxiety and depression? Bulletin of Integrative Psychiatry. 2016; 71: 4.
5. Ciobica A, Honceriu C, Ciobica A, Dobrin R, Trofin F, Timofte D. The importance of exercising in the pathological manifestations of some psychiatric disorders such as autism or schizophrenia. Romanian Journal of Psychopharmacology. 2016; 22.
6. Ciobica A, Honceriu C, Ciobica A, Dobrin R, Trofin F, Timofte D. A mini-review on the effects of exercising on Parkinson’s disease. Rev. Med. Chir. Soc. Med. Nat., Iasi. 2017.
7. Andrei Ciobica, Cezar Honceriu, Alin Ciobica, Romeo Dobrin, Florin Trofin, Iulia Antioch, Daniel Timofte, Is exercising beneficial in relation with substance abuse disorder, quality of sleep, self-esteem and chronic pain? Bulletin of Integrative Psychiatry. 2017.

8. Andrei Ciobica, Cezar Honceriu, Alin Ciobica, Romeo Dobrin, Florin Trofin, Ioana Miruna- Balmus, Daniel Timofte, Possible relevance of physical exercising in Alzheimer's disease and other dementias. Mini-review, Romanian Journal of Psychopharmacology. 2017.

9. American College of Sports Medicine. Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2009;41:687-708.

10. Seguin R, Nelson ME. The benefits of strength training for older adults. Am J Prev Med. 2003;25 (suppl 2):141-149.

11. 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;59:48-61.

12. Chodzko-Zajko WJ, Proctor DN, Fiatarone-Singh MA, et al. Exercise and physical activity for older adults: ACSM position stand. Med Sci Sports Exerc. 2009;41:1510-1530.

13. Winett RA, Carpinelli RN. Potential health-related benefits of resistance training. Prevent Med. 2001;33:503-513.

14. Seguin R, Nelson ME. The benefits of strength training for older adults. Am J Prev Med. 2003;25 (suppl 2):141-149.

15. 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;59:48-61.

16. Chodzko-Zajko WJ, Proctor DN, Fiatarone-Singh MA, et al. Exercise and physical activity for older adults: ACSM position stand. Med Sci Sports Exerc. 2009;41:1510-1530.

17. Martyn-St James M, Carroll S. High-intensity resistance training and postmenopausal bone loss: a meta-analysis. Osteoporos Int. 2006;17:1225-1240.

18. Liu CJ, Latham NK. Progressive resistance strength training for improving physical function in older adults. Cochrane Database Syst Rev. 2009;8(3):CD002759.

19. Robertson MC, Campbell AJ, Gardner MM, Devlin N. Preventing injuries in older people by preventing falls: a meta-analysis of individual-level data. J Am Geriatr Soc. 2002;50:905-911.

20. Fielding RA. The role of progressive resistance training and nutrition in the preservation of lean body mass in the elderly. J Am Coll Nutr. 1995;14:587-594.

21. Gordon B, Benson A, Bird S, Fraser S. Resistance training improves metabolic health in type 2 diabetes: a systematic review. Diabetes Res Clin Pract. 2008;83:157-175.

22. Cornelissen VA, Fagard RH. Effect of resistance training on resting blood pressure: a meta-analysis of randomized controlled trials. J Hypertens. 2005;23:251-259.

23. Ruiz JR, Sui X, Lobelo F, et al. Association between muscular strength and mortality in men: prospective cohort study. BMJ. 2008;337:a439.
24. Crewther B., Keogh J., Cronin J., Cook C. (2006). Possible stimuli for strength and power adaptation. Sports Med. 36 215–238
25. Crewther B. T., Cook C., Cardinale M., Weatherby R. P., Lowe T. (2011). Two emerging concepts for elite athletes: the short-term effects of testosterone and cortisol on the neuromuscular system and the dose-response training role of these endogenous hormones. *Sports Med.* 41 103–123
26. Young W. Transfer of strength and power training to sports performance. Int J Sports Physiol Perform. 2006;1:74–83.
27. Hoff J, Helgerud J. Endurance and strength training for soccer players: physiological considerations. Sports Med. 2004;34(3):165–80.
28. Schmidtbleicher D. Training for power events. In: Chem PV, editor. Strength and Power in Sports. Boston: Blackwell Scientific; 1992. p. 381-95
29. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 1–biological basis of maximal power production. Sports Med. 2011;41(1):17–38.
30. Gabriel DA, Kamen G, Frost G. Neural adaptations to resistive exercise: mechanisms and recommendations for training practices. Sports Med. 2006;36(2):133–49.
31. Toigo M, Boutellier U. New fundamental resistance exercise determinants of molecular and cellular muscle adaptations. Eur J Appl Physiol. 2006;97(6):643–63.
32. Hakkinen K, Alen M, Kraemer WJ, Gorostiaga E, Izquierdo M, Rusko H, et al. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. Eur J Appl Physiol. 2003;89(1):42–52.
33. Hakkinen K, Komi PV, Alen M. Effect of explosive type strength training on isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. Acta Physiol Scand. 1985;125(4):587–600.
34. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. J Appl Physiol. 2002;93(4):1318–26.
35. Aagaard P, Suetta C, Caserotti P, Magnusson SP, Kjaer M. Role of the nervous system in sarcopenia and muscle atrophy with aging: strength training as a countermeasure. Scand J Med Sci Sports. 2010;20:49–64.
36. Petrella RJ, Chudyk A. Exercise prescription in the older athlete as it applies to muscle, tendon, and arthroplasty. Clin J Sport Med. 2008;18:522–530.
37. Ratamess NA, Alvar BA, Evetoch TK, Housh TJ, Kibler WB, Kraemer WJ, Triplett NT. ACSM Position Stand: Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2009;41:687–708.

38. Graef FI, Pinto RS, Alberton CL, de Lima WC, Kruel LF. The effects of resistance training performed in water on muscle strength in the elderly. J Strength Cond Res.2010;24:3150–3156.
39. Steib S, Schoene D, Pfeifer K. Dose-response relationship of resistance training in older adults: a meta-analysis. Med Sci Sports Exerc. 2010;42:902–914.
40. Baker K, Nelson M, Felson D, Layne J, Sarno R, Roubenoff R. The efficacy of home based progressive strength training in older adults with knee osteoarthritis: a randomized controlled trial. J Rheumatol 2001;28:1655– 65.
41. Borg G, Linderholm H. Perceived exertion and pulse rate during graded exercise in various age groups. Acta Med Scand 1967:194–206.
42. Ciolac EG, Brech GC, Greve JM. Age does not affect exercise intensity progression among women. J Strength Cond Res. 2010;24:3023–3031.
43. Ciolac EG, Garcez-Leme LE, Greve JM. Resistance exercise intensity progression in older men. Int J Sports Med. 2010;31:433–438.
44. Petrella RJ, Chudyk A. Exercise prescription in the older athlete as it applies to muscle, tendon, and arthroplasty. Clin J Sport Med. 2008;18:522–530.
45. American College of Sports Medicine. Position stand: the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sport Exerc 1998;30:975–91.
46. American College of Sports Medicine. Position stand: progression models in resistance training for healthy adults. Med Sci Sport Exerc 2002;34:364–80.
47. Castaneda C, Layne J, Munoz-Orians L, et al. A randomized control trial of progressive resistance exercise training in older adults with type-2 diabetes. Diabetes Care 2002;25:235–41.
48. Fielding R, LeBrasseur N, Cuoco A, Bean J, Mizer K, Fiatarone Singh M. High-velocity resistance training increases skeletal muscle peak power in older women. J Am Geriatr Soc 2002;50:655–62.
49. Campbell A, Robertson C, Gardner M, Norton R, Buchner D. Falls prevention over 2 years: a randomized controlled trial in women 80 years and older. Age Ageing 1999;28:513–28
50. Campbell A, Robertson M, Gardner M, Norton R, Tilyard M, Buchner D. Randomized controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. BMJ 1997;315:1065–9.
51. Spennewyn KC. Strength outcomes in fixed versus free-form resistance equipment. J Strength Cond Res. 2008 Jan;22(1):75-81.
52. Thomas K, Muir K, Doherty M, Jones A, O'Reilly S, Bassey E. Home based exercise programme for knee pain and knee osteoarthritis: randomised controlled trial. BMJ 2002;325:752.
53. Jette A, Lachman M, Giorgetti M, et al. Exercise—it's never too late: the Strong for Life program. Am J Public Health 1999;89:66–72.