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Review Article

What types of physical activities are effective in developing muscle and bone strength and balance?

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Abstract

The need to be fit, strong, fast and agile has been an evolutionary requirement since early history. In this paper we identify the effectiveness of different types of physical activity on muscle, bone and balance outcomes, and what types of physical activity contribute to the development and maintenance of these outcomes. We undertook a purposive search of PubMed, international evidence reviews of physical activity, and asked international experts to identify review level relevant literature on the effectiveness of muscle, bone and balance training and physical activity on health outcomes. We found consistent review level evidence that strength/resistance training as a single intervention or in combination with other activities, two/three occasions per week, were effective for muscular strength, with higher intensities of training producing greater gains. We found consistent review level evidence that strength training as a single intervention or in combination with high impact loading activities taken at least 3 times per week were effective for bone health. Physical activities with a high challenge to balance done in standing three times per week were beneficial for balance training and falls reduction. The current UK 2011 Chief Medical Officer's physical activity guidelines remain consistent with the most up to date review level evidence for muscle and balance health.

Keywords: Strength, Balance, Exercise, Bone, Physical Activity

Introduction

Why do muscle, bone strengthening and balance exercises matter?

Socrates (469-399 BC) the Ancient Greek philosopher outlined the innate potential that all adults possess to improve their physical selves via strength and balance training:

"No man has the right to be an amateur in the matter of physical training. It is a shame for a man to grow old without seeing the beauty and strength of which his body is capable".

However, these ancient philosophers also warned that there was a need for a healthy balance between physical and intellectual development for true health to be achieved[1]. This lack of balance between intellectual and physical health mirrors the challenge faced in physical activity promotion between unequal emphasis on the aerobic rather than the strength components of national physical activity guidelines for adults, neatly captured by Strain et al's (2016) "forgotten guideline" paper[2]. Muscle and bone health and the ability to balance are underpinning components of physical activity[3]. Each contributes independently to overall health and functional ability but, in combination, can offer lifelong benefits across the life course. Each contributes via mechanisms promoted by regular participation in physical activity and exercise and this participation can be characterised by the FITT principles (Frequency, Intensity, Time, and Type of activity).

The challenge of definition is critical in establishing what types of physical activity contribute to muscle, strength and balance health, and their relative effectiveness to develop and maintain health. This paper aims to review the evidence for what types of physical activity contribute to developing muscle and bone strength and balance, including the relative contribution of specific exercises/training and everyday non-exercise activities. This evidence is derived from

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Term	Definition
Muscle function	Muscle function is to permit movement and maintain posture. Sensory receptors in the muscles monitor the tension and length of the muscles and provide the nervous system with crucial information about the position of the body parts.
Bone Health	Bone health includes bone quality that refers to the capacity of bones to withstand a wide range of loading without breaking. Bone health includes also bone mineral, structure, geometry and strength.
Balance	A performance-related component of physical fitness that involves the maintenance of the body balance while stationary or moving. In addition agility can be seen as a component of dynamic balance. Agility is a performance-related component of physical fitness that is the ability to change position of the entire body in space with speed and accuracy.

Table 1. Definition of key terms for muscle function, balance and bone health (from Heinonen & Kujala, in Kokko et al 2011, p 32).

independent review level synthesis of two types of studies observational and experimental. Observational studies provide evidence to support the associations of specific FITT of physical activity in relation to health outcomes, reductions in mortality and morbidity. Experimental studies identify the evidence of causal effects (effectiveness and efficacy) for FITT of physical activity upon physiological outcomes and markers of chronic disease[4].

A brief history of muscle and bone strength and balance physical activity recommendations

Being strong, fit and moving with balance and agility were critical skills for our hunter-gatherer ancestors. These were the ultimate functional abilities, developed via the everyday challenges of survival. The transition to agriculture-based societies saw the transition from hunting and gathering to farming food and may be the first shift of lifestyle physical activity to become less active. The decline in health as one grows older has been noted since the ancient philosophers as reducing function and fitness. The advent of military and athletic training saw the focus on the benefits of strength. Early European and Nordic culture revered adults who could demonstrate prodigious feats of strength by lifting stones or logs. In the Far East (475-221 BC) the lifting of large ceremonial three legged cauldrons "dings" were central to worship and ceremony. The Greek wrestler, Milo of Croton, was credited with using progressive weight training by daily carrying a newborn calf. Women also participated in weight training as part of athletic sports preparation.

The function of weight training was to develop and maintain muscle mass primarily for military or athletic purposes. It was only in the Renaissance era that the physical body became as important as the spiritual and the works of Vittorino da Feltre, Christobel Mendez, and Mercurialis reconnected the works of the ancient cultures and philosophers with the new disciplines of anatomy, biology, health and physical education. For example, in 1553, in his book *El Libro del Ejercicio Corporal y Sus Provechos*, Mendez described classified exercises, games and sports from their health and medical benefits, offered different exercises as a means of injury recovery and prevention, and gave the first physical activity type guidelines of particular sports and exercises for children, women and the elderly. In the late 18th century, Europe saw the development of the culture of movement and gymnastics typified by physical education and gymnastics again emphasising strength, agility, fitness and balance activities. The work of Germans, Muths and Jahn, and the Swede Pehr Ling, developed four types of movements and exercises pedagogic, military, medical and aesthetic, with this final type of method being the first to emphasis physical activity for its own sake to promote general health and wellbeing. These new ideas spread rapidly across Europe (reflecting both military and social needs and fashions) and connected with traditional dances and cultural events to support the sense of personal and national identity.

The early 20th century saw the development of gyms, dedicated to muscular development, callisthenics movements, and the mechanisation of muscular training, exercise and activity through the new modern fitness industry. Public health recommendations for physical activity emerged in the early 1990s and were driven by the post 2nd World War occupational health studies of Morris and Paffenbarger on the impact of total physical activity upon mortality and morbidity. The 1960s saw this body of work shift from occupational physical activity to include leisure time physical activity, using data from all types of physical activity in order to identify the impact of intensity and volume on health outcomes. The 1990s saw the first recommendations for physical activity reflecting the aerobic/vigorous prescription for physical activity but strength training only appeared formally in 2007 with the inclusion of a muscle strength/endurance recommendation[5]. This recommendation also referred to physical activity including both resistance training and everyday activity like stair climbing. After 2007 strength training was joined by recommendations for older adults that included physical activity that developed balance training.

The challenge of definition is critical in establishing what types of physical activity contribute to muscle, strength and balance health, and their relative effectiveness to develop and maintain health. We have set out our definitions for

key terms in this paper in Table 1 (Heinonen A, Kujala U, in Kokko et al 2011), and present definitions for muscle function, balance and bone health[6].

What are muscle-strengthening activities?

The Health Survey for England lists badminton, canoeing, climbing, cycling, dancing, field athletics, football, horse riding, kayaking, rowing, rugby, running/jogging, sailing, squash, skiing/snowboarding, swimming, tai-chi, tennis, water-skiing and windsurfing as muscle strengthening activities when performed for bouts of at least 10 minutes[7]. They also include aqua aerobics/aquafit, aerobics, basketball, body boarding, bowls, exercise (press-ups, sit-ups etc.), cricket, curling, golf, hillwalking, hockey, ice skating, martial arts other than tai chi, netball, pilates, rambling, surfing, tenpin bowling, volleyball, workout at a gym (e.g. exercise bike, weight training), yoga when performed for bouts of at least 10 minutes if the effort of the activity made the participant's "muscles feel some tension, shake or feel warm".

What are bone strengthening activities?

The American College of Sports Medicine suggests that bone strengthening activities include weight-bearing endurance activities such as tennis, stair climbing, and jogging at least intermittently during walking; jumping activities e.g. volleyball or basketball; and resistance training e.g. weight lifting[8]. Howe et al suggest that interventions aimed at stimulating bone growth and bone mass preservation usually stress or mechanically load the bone. Specific examples that they include are: aerobics, weight bearing and resistance exercises[9].

What are balance activities?

The American College of Sports Medicine defines balance training as "a combination of activities designed to increase lower body strength and reduce the likelihood of falling"[10]. They cite a lack of evidence for not making specific type, frequency, and intensity recommendations for activities to improve balance. However, they suggest that activities including the following aspects should have a balance training benefit: activities which gradually progress postures to reduce the base of support, dynamic movements aimed at perturbing the centre of gravity, activities which stress postural support muscles, and activities which reduce sensory input. Exercise and Sports Science Australia suggest that activities which challenge balance include: graded reaching in standing, stepping in different directions, walking practice (e.g. changing base of support, changing step length and speed etc.), sit-to-stand, heel raises, forward and lateral step-ups, and half squats sliding down a wall[11]. The Health Survey for England list the following specific activities as improving balance and coordination: aerobics, aqua aerobics/aquafit, badminton, basketball, body boarding, bowls, canoeing, climbing, cricket, curling, cycling, dancing, field athletics, football, golf, hillwalking, hockey, horse riding, ice skating, kayaking, keep fit (workout at a gym), martial arts, netball, pilates, rambling, rugby, running/jogging, sailing, skiing/snowboarding, squash, surfing, table tennis, Tai-chi, tennis, tenpin bowling, volleyball, windsurfing, yoga, and water-skiing[7]. They also include exercise (e.g. press-ups, sit-ups) where participants are standing up and moving around.

This paper sets out to answer two questions:

1. What is the effectiveness of different types of physical activity on muscle, bone and balance outcomes?
2. What types of physical activity contribute to the development and maintenance of muscle, bone and balance outcomes?

Methods

We undertook a purposive search to identify review level relevant literature on the effectiveness of muscle, bone and balance training and physical activity on health outcomes. The search primarily focused on review level evidence for randomised controlled trials in order to identify from systematic review and meta analysis what types of physical activity were used in effectiveness studies. We searched PubMed using a tailored set of broad MeSH terms (Medical Subject Headings) to capture the most current studies published. For example, "resistance training", "muscle", "bone", "balance" AND "physical activity" AND "adults". We also searched for published international evidence reviews of physical activity, used to construct national physical activity guidelines and recommendations (published since 2010) using Google, targeting public health bodies (i.e. National Centre for Health and Clinical Excellence, Centre for Disease Control). We also contacted international experts to identify further examples of relevant reviews from Australia, Canada and The Netherlands. We identified the most relevant and up to date high quality reviews from these sources and made summations of the effectiveness of the evidence across the three areas muscle, bone and balance outcomes. We also identified (where possible) types of physical activities and their relative contribution to muscle, bone and balance outcomes.

Results

Evidence of the effectiveness of physical activity for muscle health

Muscle decline contributes to the development of frailty and functional impairment with aging, after a peak of muscle strength in mid to late 20s, decreasing in the next two/three decades and rapidly declining post 60 years plus. This condition of degenerative loss of skeletal muscle mass, sarcopenia (0.5-1% loss per year after the age of 50, 2-4% after 75 years), quality, and loss in strength, dynapenia, are both associated with aging[12,13]. Changes occur in both the neural (loss of alpha motoneurons) systems as well as the morphologiocal systems (reduced volume and number of type-II muscle fibres) increasing risks of falls, function

loss and impaired mobility[14]. However there is consistently strong evidence to support the efficacy of resistance training for increasing muscle strength and size, mitigating or even reversing the impacts of age related muscle decline[15].

Systematic reviews consistently show the efficacy of resistance training versus control in improving muscle strength in older adults, with larger effects on strength gained at increasing intensity of training[16]. Resistance training alone has also been examined for improvements in cardio-metabolic outcomes, including reduced systolic blood pressure, improved insulin sensitivity, and with participation in resistance training programmes, it lowered depressive symptoms in adults[17,18].

Reviews of interventions support the use of resistance training alone or in combination with endurance training, endurance/balance, or mixed regimes that involved a mixture of endurance/resistance/balance/coordination/ flexibility activities and exercises to increase strength, with one study reporting sustained effects at 24 months[19]. This review examined the effectiveness of resistance training and also attempted to identify what specific training variables were predictive of strength outcomes (volume, intensity and rest). Borde et al reported that resistance training improved muscle strength by 1.57 (weighted mean standardised mean difference, 25 studies) in healthy older adults and effects were similar for upper and lower extremities[19]. The length of programme (up to a year v 12 weeks) had differential effects on muscle strength impact, however gains from longer programmes were only slightly more effective than programmes of a shorter duration. Frequency of weekly training was between 2-3 sessions with higher intensity training producing the largest effects on muscle strength, with moderate intensity producing larger effects compared to light intensity sessions.

One of the characteristics and clearly recognisable signs of aging is slowing of habitual walking speed by as much as 16 % per decade starting at the age of 60 years[20]. A recent review by Hortobágyi et al assessed the effects of 42 RCTs on older adults' habitual and fast gait speed, examining the combined and individual effects of resistance, coordination and multimodal training studies[21]. The overall increase in gait speed was 0.10 m/s or 8.4 % with a large effect size of 0.84 in 2495 healthy old adults aged 74.2 years. All types of training produced similar increases in gait speed and they concluded that all types of training increase gait speed with no particular advantages of one mode over another. They also suggested that these results present the choices for older adults to use all types of physical activity and training based on their own preferences, context, social preferences and abilities. One recent meta-analysis reported that Nordic walking (with poles) produced significant gains in upper and lower limb body muscle strength compared to walking without poles, and in comparison to resistance training still produced similar significant muscle strength gains[22].

In summary, strength/resistance training as a single intervention or in combination with other activities, two/ three occasions per week, were effective for muscular strength. Higher intensities of training produced greater gains while the inclusion of walking did not increase overall effects on muscular strength but did improve gait speed in combination with resistance and other types of training. Walking with poles did increase muscle strength.

Evidence of the effectiveness of physical activity for bone health

Peak bone mass is reached from the mid to late 20s, with bone mineral density (BMD) decreasing by ~0.5% per year from age 40. Following menopause, women lose 2-3% BMD per year[23]. For an activity to be beneficial for bone health, overloading forces that stimulate an adaptive effect through physical deformation of bone cells must be applied to the bone, with progressive increases in overload for a continued adaptation[24]. As each bone remodelling cycle takes 3-4 months, a minimum of 6-8 months are required for bone to reach a new, measurable steady-state bone mass[24,25].

Systematic reviews have shown the efficacy of strength and weight training exercises for increasing, or at least slowing the rate of the age-related decline in bone mass[26,27]. Increases in BMD tend to be site-specific, requiring high loading 3-5 times per week. Exercise sessions should each be at least 45 minutes in length, over one-year duration[26].

Other types of activities shown to be effective for bone mass maintenance, especially in postmenopausal women, include multi-component exercise programmes consisting of strength, aerobic, high impact and/or weight-bearing training, or whole-body vibration as a single intervention[27]. While a popular activity in older adults, the modest increase on skeletal loads above gravity provided by walking are less effective than high impact training in the prevention of osteoporosis[27].

With respect to specific bone sites in postmenopausal women, non-weight bearing high-force exercises for the lower limbs e.g. progressive resistance strength training had the greatest effect on BMD at the neck of the femur, with 1.03% (MD 1.03; 95% confidence interval (CI) 0.24 to 1.82) less bone loss than non-exercisers. Those who took combination exercise programmes had on average 3.2% (MD 3.22; 95% CI 1.80 to 4.64) less bone loss than controls, at the spine[28]. There was no significant effect on the number of fractures between exercisers and non-exercisers (odds ratio (OR) 0.61; 95% CI 0.23 to 1.64)[28]. There is limited evidence to suggest that Tai Chi may be an effective, safe, and practical intervention for maintaining BMD in postmenopausal women[29].

There is less evidence on the efficacy of exercise interventions on BMD in middle-aged and older men. A synthesis of the evidence from trials in this population (8 studies) found that resistance training as a single intervention or in combination with high impact loading activities had

Type of Sport, Physical Activity or Exercise	Improvement in Muscle Function	Improvement in Bone Health	Improvement in Balance
Running	x	xx	x
Resistance training	xxx	xxx	xx
Aerobics, circuit training	xxx	xxx	xx
Ball Games	xx	xxx	xxx
Racquet Sports	xx	xxx	xxx
Yoga, Tai Chi	x	x	x
Dance	x	xx	x
Walking	x	x	O
Nordic Walking	xx	NK	xx
Cycling	x	x	x

xxx = Strong effect; xx = medium; x = low; O = no effect; NK = not known.

Table 2. Assessment of the positive impact of different types of sport, physical activity or exercise on muscle, bone and balance outcomes (adapted from Heinonen & Kujala, in Kokko et al 2011).

positive effects on BMD[30]. Walking trials were less effective and had a limited effect on BMD[30].

In summary, strength training as a single intervention or in combination with high aerobic, high impact and/weight weight-bearing training was beneficial for bone health. Effective strength training activities required high loading, 3-5 times per week.

Evidence for the effectiveness of physical activity for balance training and falls prevention

With ageing, there is a decline in the sensorimotor systems involved in maintaining postural control which in turn leads to an increased risk of falling[31]. A synthesis of 94 trials to improve balance found that the most effective programmes were generally those involving dynamic activity done in standing, which ran three times per week for three months. They concluded weak evidence of moderate improvement in clinical balance outcomes in older adults immediately post intervention for interventions involving gait, balance, co-ordination or functional tasks; strengthening exercises e.g. resistance or power training; or 3-dimensional exercises e.g. tai-chi, qui gong, dance and yoga. They reported insufficient evidence to conclude the efficacy of general physical activities such as walking or cycling, and exercise including computerised balance programmes or vibration plates, on clinical measures of balance[9]. A narrative systematic review considering dance on its own, showed a significant effect of dance on improvement in balance[32].

Gillespie et al found that both rate and risk of falls were effectively reduced through group and home-based exercise programmes containing multiple exercise categories, generally balance training and muscle strengthening[33]. Exercise interventions aimed at reducing falls were usually effective in reducing fractures. Tai-chi reduced the risk of falling, but interventions aimed at groups at high risk of falling were less effective. They found no evidence of the effectiveness of other single exercise interventions taken alone, such as balance retraining, muscle strengthening or walking programmes for reducing falls.

A recent meta-analysis found that overall, exercise programmes lowered the rate of falls by 21% (pooled rate ratio 0.79, 95%CI 0.73-0.85, p<0.001, I^2 47%, 69 comparisons) in community-dwelling older adults[34]. Meta-regression results suggested that exercise programmes containing both a high challenge to balance and more than three hours per week of exercise, reduced the rate of falls by 39%, where a high challenge to balance was defined as activities which moved the centre of mass, narrowed the base of support and minimised upper limb support[34]. Other trial-level characteristics such as inclusion of moderate or high-intensity strength training, inclusion of high intensity strength training, inclusion of walking training or practice, 2+ (but less than 3) hours per week of exercise, and better adherence to exercise, were not significant in meta-regression analyses. With respect to special populations, limited evidence suggested exercise may be an effective intervention for reducing falls among community-dwelling people suffering cognitive impairment and those with Parkinson's disease. Exercise as an individual intervention was not effective for reducing falls in residential care settings, those recently discharged from hospital, or stroke survivors[34].

Similar effects have been found when comparing the efficacy of exercise only interventions versus multifaceted interventions on fall prevention[33,35]. A synthesis of economic evaluations showing that effective single factor falls prevention interventions, especially those targeted at high

risk groups, prevent the largest number of falls at the lowest incremental costs[36]. Therefore, exercise interventions may provide the best solution at the population level.

In conclusion, dynamic activities with a high challenge to balance done in standing three times per week were beneficial for balance training and falls reduction. Specific activities that may be beneficial include: dynamic activities done in standing; gait, balance, co-ordination or functional tasks; strengthening exercises e.g. resistance or power training; or 3-dimensional exercises e.g. tai-chi, qui gong, dance and yoga. Walking was not found to be beneficial for balance and falls reduction.

What types of physical activity contribute to muscle, bone and balance health?

Any physical activity, sport or exercise that moves the body will deploy muscles and bones and their acute and chronic response to this movement will depend on the type of activity, duration of the activity, intensity and frequency. A recent review by Oja et al 2015 examined RCTs comparing the health impacts of participation in different types of sports but reported limited evidence for improvements in metabolic fitness, cardiac adaptation and muscular performance, in both genders, and in blood lipids and postural balance among men (from recreational football and running)[37]. Inconclusive evidence is shown for benefits in bone mineral density. The regular participation in sports and physical activity will clearly maintain muscle strength and support balance while some weight bearing might increase potential chronic risks to bone health. In 2011 The Finnish Sports Association convened an expert panel, to develop a health profile of sports and physical activities. Table 2 extends this work to also include data from systematic reviews that examined the specific health effects of more everyday physical activities, walking, dancing and cycling[22,38,39]. We offer this as a point of consideration for implementation of physical activity messages for muscle, bone and balance training. Clearly there are areas of further research needed particularly on the relative contribution of specific physical activities with muscle and balance benefits. However, it is important to note that housework or gardening are not considered a contributing physical activity to muscle, or balance activities in the Scottish and English Health Surveys[40].

Discussion

We aimed to answer two questions on the effectiveness of different types of physical activity on muscle, bone and balance outcomes, and what types of physical activity contribute to the development and maintenance of muscle, bone and balance outcomes. We found consistent review level evidence that strength/resistance training as a single intervention or in combination with other activities, two/three occasions per week, were effective for muscular strength, with higher intensities of training producing greater gains. We also found consistent review level evidence that strength training as a single intervention or in combination with high impact loading activities were effective for bone health. Increases in Bone Mass Density are site-specific, and can be achieved via high loading, 3-5 times per week. Physical activities with a high challenge to balance done in standing three times per week were beneficial for balance training and falls reduction. Walking was not found to be particularly beneficial for either bone health or balance and falls reduction with small gains in muscle strength reported, increasing to moderate gains for Nordic walking.

These results are consistent with the current 2011 CMO UK physical activity guidelines and with other recent national physical activity guidelines i.e. The Netherlands 2017, "Engage in activities that will strengthen your muscles and bones at least twice a week. Older people should combine these with balance training exercises"[41]. The presentation of the frequency of as "at least twice a week" appears less than the optimal recommendation (2/3 times per week) for both outcomes but their committee opted for the lower frequency (as did the UK in 2011). However, the Netherlands have also emphasised the contribution of everyday types of physical activities, "such as climbing stairs, repeated rising from your chair", and strength training, and for older adults, for muscle and bone outcomes, combining these with balance exercises[41].

These examples from the Netherlands show the challenge of creating a public facing response using examples of types of physical activities that people can understand and which move beyond the generic descriptions of "muscle strengthening exercises, resistance training, bone loading activities or balance training". This situation reflects the "inverse guidelines" law, a situation where most is known about the health benefits of sports and physical activities that are not undertaken by the majority of the population, and as a result are less relevant to their everyday lives (with the exception of walking). Indeed, UK national surveillance currently does not consistently define what are potentially key groups of behaviours that could contribute to muscle, bone and balance health. Table 1 presents a pragmatic application of up to date review level evidence across a broader range of physical activities, sports and exercises, however the absence of specific research for the contribution of these types of activities, at relative intensities, does need addressing. This is particularly important in light of the most recent Health Survey for England data that only 31% of men and 23% of women aged 16 and over met both the aerobic and muscle-strengthening guidelines.

The current UK 2011 CMO physical activity guidelines remain consistent with the most up to date review level evidence for muscle, bone and balance health. The recommendations on the frequency of undertaking of muscle strengthening, bone quality and, for older adults, balance training are also consistent with recent national reviews and guidelines. What is now needed are examples of everyday physical activities that are able to support the development of

MSB health, e.g. stair climbing, and their presentation to the population in messages that are accessible, understandable and effective.

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