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11

Do the benefits of participation in sport and exercise outweigh the negatives? An academic review

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A B S T R A C T

Public health campaigns promote regular exercise and physical activity. These campaigns are founded on global recommendations that a combination of aerobic and resistance exercise is required, on a weekly basis, to maximise physical and mental health. However, participation in all forms of sports and physical activity has inherent risks that need to be considered by both health practitioners making activity recommendations and the people participating. This review examines biological, psychological and social benefits and harms of the three highest participation physical activities: walking/running, multidirectional sports and resistance exercise. While the remaining evidence indicates that the positives do outweigh the negatives, it demonstrates that moderate amounts of exercise provide the most optimal balance and that potential harms are typically associated with low or high participation.

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Introduction

One of the overwhelming public health messages in recent years has been participation in regular exercise and physical activity. We are encouraged to move more, in whatever way we can. For some, this might be increasing incidental exercise such as taking the stairs rather than the elevator. Others may elect to participate in more organised exercise or sports activities, such as gym-based classes or team sports. A widely accepted opinion is that personal preference regarding choice of exercise activity is essential for both enjoyment and long-term adherence with an active lifestyle. The American College of Sports Medicine recommends that individuals engage in at least 150 min of moderate intensity exercise each week, along with two to three resistance training sessions [1].

However, despite the emphasis on the importance of regular participation in exercise and physical activity, statistics from several developed nations indicate that people are not active enough. National surveys collected for the past five years demonstrate a universal trend, whereby only 50–60% of adults meet the guidelines for aerobic exercise and approximately 30% meet both the aerobic and resistance training guidelines [2]. Recent estimates indicate that not meeting physical activity recommendations is responsible for more than 3.2 million deaths globally each year, making physical inactivity the fourth leading risk factor for global mortality [3].

For the general population, as well as those with specific health conditions, exercise is thought to have a variety of health and social benefits. Dose-responsive positive changes in musculoskeletal, cardiovascular, respiratory, endocrine, immune and metabolic health markers have all been reported [4–6]. Similarly, psychological benefits such as dopamine and serotonin regulation, pain modulation, academic performance, general wellbeing and mental health are reported for the general population, as well as in at-risk populations such as those with anxiety, depression or chronic pain.

However, it remains unclear whether the risks associated with exercise and sport participation are worth these benefits. Individuals who regularly participate in competitive sports are aware of the heightened risk of acute physical injury, which may have consequences for future joint health. For example, acute ligamentous injury in the knee is not only common but also associated with the development of early osteoarthritis in young individuals [7]. There are also perceived risks associated with non-organised sports and physical activities. A recent Canadian study reported that 13.1% of the general population believe that regular running hurts the knee joint, while 29.5% were uncertain [8]. While regular (7.6%) and long distance (15.5%) running were believed to lead to knee osteoarthritis, there was a large degree of uncertainty (34–42%) [8]. This is despite evidence suggesting that recreational runners have a lower risk of knee or hip osteoarthritis than sedentary individuals and elite runners [9].

To be able to advise patients and the general public regarding appropriate exercise and sport choices, health professionals must understand the benefits and negatives associated with different activities. Each type of sport and exercise has unique characteristics that appeal to different interests and abilities [10]. Moreover, there are vastly different demands placed on the individual, such as levels of exertion and involvement of different body systems. Importantly, all forms of sport and physical activity carry different levels of risk and health-related rewards and are associated with different attitudes towards different levels of participation and social interaction.

This narrative review provides an overview of available evidence regarding the benefits and negatives associated with the highest participation sports and exercise activities, as identified through national surveys from Australia, the UK and the USA. We chose to take a holistic view of the individual rather than limiting to specific rheumatology outcomes. Within each sport and exercise, we focus on biological benefits and negatives across multiple body systems, including musculoskeletal, cardiovascular, respiratory, metabolic and endocrine and immune systems. We also discuss the benefits and negatives of sport and exercise participation in a broader psychological and social context. Studies relating to the benefits and negatives of sport and exercise during childhood, and their effects on growth and development, are beyond the scope of this review. Literature presented in this review was sourced through searches up to September 2018 using PubMed, Scopus and Cinahl databases (limited to English-language studies). We also hand-searched sports policy and frameworks from Australia, the UK, the USA and countries of the European Union.

Biological benefits and negatives of participation in sport and exercise (Fig. 1)

Walking and running

Walking and running are fundamental gross motor skills. They are critical requirements for almost all self-propelled land-based sporting activities, as well as for basic transport. Walking is the most popular form of physical activity [11] and has been identified as one of the primary ways by which individuals get to work and school [12]. Both walking and running offer simple, accessible forms of exercise across a variety of populations.

Musculoskeletal system

Walking and running are both impact activities, with high ground reaction forces occurring with fast speeds. The influence of impact loading on bone mineral density, muscle power generation and the degradation of cartilage extracellular matrix has been widely studied [5,13]. It appears that walking, even uphill, does not produce sufficient acceleration frequencies to have a positive effect on bone density [13]. Endurance and cross-country running have been associated with a high prevalence of low bone mineral density in women [14]. In contrast, compared with age-matched peers, sprint and middle-distance (i.e. up to approximately 1500 m) runners have greater bone mineral density in high-risk stress fracture sites, including the hips and lumbar spine [15]. This association remains significant even when adjusted for body mass [16]. This suggests that a balance between speed and distance is required to maximise effects on bone health.

Cartilage in load-bearing joints may also benefit from both walking and running. A recent systematic review and meta-analysis demonstrated that, in healthy animals, a moderate daily exercise dose has positive effects on the composition of the cartilage matrix [17]. In rat models, mRNA levels in cartilage are upregulated in animals assigned to running groups compared with controls, indicating that the intermittent cartilage overload experienced by running followed by a rest period initiates a

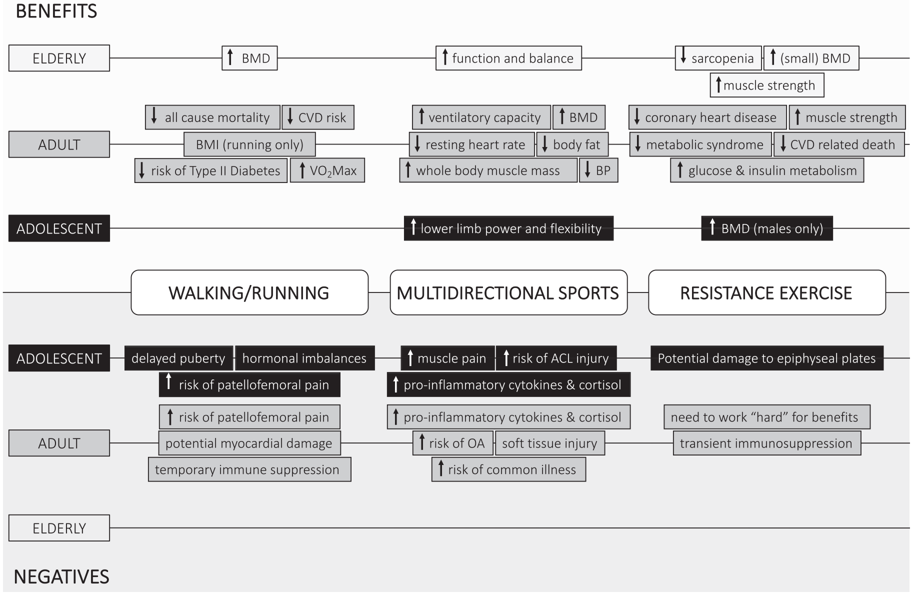

Fig. 1. Summary of biological benefits and harms of sports and exercise. Black = adolescent, white = adult and grey = elderly individuals typically over the age of 65 years. ACL = anterior cruciate ligament, BMD = bone mineral density, BMI = body mass index, BP = Blood pressure (both systolic and diastolic), CVD = cardiovascular disease, OA = osteoarthritis. The figure does not include topics where evidence is equivocal or controversial between benefits and harms.

"self-repair" and possible resistance to further damage [18]. The concept of running-related cartilage resistance to impact loading has been supported by a study in humans. Celik et al. [5] measured serum levels of a biomarker of cartilage degeneration (COMP). They found that, after participants completed a 12-week running program, serum levels no longer increased during activities that previously triggered an increase in COMP. This highlights the potential for running to mediate cartilage health. However, it is likely that the benefits of walking and running on cartilage health are dose dependent. Bricca et al. [17] highlighted the non-linear relationship between dose and cartilage composition in animal studies, with low and high exercise doses demonstrating negative effects on cartilage matrix composition.

Even with these proposed musculoskeletal benefits, injuries related to running are common, more so than walking. While the exact incidence and prevalence of running-related injuries are difficult to quantify, it is estimated that up to 33 injuries occur per 1000 h of running [19]. The knee is the most prevalent site of pain and injury in walkers and runners. Particularly, patellofemoral pain accounts for up to 40% of knee injuries [20]. The contributors to patellofemoral pain are multifactorial and consist of both intrinsic and extrinsic factors. This makes it a difficult condition to prevent and manage, with more than 50% of individuals reporting persistent pain years after their initial diagnosis [21]. A recent study found that one-quarter of adults aged 26–50 years with persistent patellofemoral pain have radiographic signs of patellofemoral osteoarthritis (OA) [22]. A further 43% had early signs of radiographic OA, which has been shown to be one of the strongest predictors of future development of established OA in people with knee pain [23].

Despite evidence associating patellofemoral pain with OA, a causative link between walking or running and OA has not been established. Animal and theoretical models demonstrate that mechanical loading can deform cartilage, which results in an altered signalling response of the chondrocytes that control the maintenance and adaption of joint surface tissue [24]. However, Abusara et al. [24] used a recently developed *in vivo* mouse model to demonstrate that relatively high muscular forces (approximately 1.3 x body mass) are required to deform cartilage during dynamic cyclical loading, and even higher amounts of dynamic cyclical compressive forces are required to change protein concentration in synovial fluid. While the actual compressive load placed on the knee during running is unknown, there is little to no evidence that running initiates OA [9]. However, it cannot be assumed that running protects the knee from structural OA damage. Runners exhibit a higher proportion of knee lesions that may lead to OA in runners than active controls [25]. It is important to highlight that, in knees where joint lesions are present, there is no evidence that running makes them worse in the short term [25]. However, long-term prognosis is unknown.

Cardiovascular and respiratory systems

The cardiovascular and respiratory benefits associated with walking and running have been well established. Both walking and running have been associated with low risk factors for cardiovascular and respiratory diseases such as hypertension, hypercholesterolaemia, dislipidemia, pneumonia and asthma [13]. Runners have a 45% lower risk for cardiovascular-related mortality and three years greater life expectancy than non-runners, even after adjustment for other mortality predictors [26].

The potential harms associated with walking and running have primarily been investigated in the context of endurance running, such as half marathons, marathons and ultra-events. The first evidence of potential myocardial damage after prolonged vigorous exercise was published in the 1980s. Since then, U-shaped [27] and J-shaped [26] curve relationships have been proposed between the intensity of running and mortality, highlighting greater risk of mortality with either too little or too much intensity. However, the mechanisms underlying this mortality rate remain unclear. While some studies have reported increased prevalence of high blood pressure and atherosclerotic plaques in individuals who self-report high intensities of running [28], the remaining literature reports no increase in risk factors. A significantly lower number of coronary artery plaques were found in marathon running women than in sedentary controls [29]. Similarly, arterial stiffness and endothelial dysfunction, both early predictors of vascular impairment, were within normal ranges in 97 marathon runners [30]. While Schwarz et al. [31] reported findings in contrast to this in their study of 110 marathon runners, they reported that the circulating microparticles indicative of endothelial dysfunction were transient and resolved within 2 days of marathon completion. Combined, these data suggest that if there is a cardiovascular risk associated with running, it is transient and only associated with endurance running.

Metabolic and endocrine systems

Walking and running have been shown to have lifelong benefits to metabolic health [32]. Data from the national runners and walkers health studies demonstrate that runners are at 71% lower risk of developing diabetes mellitus than walkers [33]. This is largely due to runners having lower body mass and travelling further distance in the same time periods [33]. When matched for distance, walking and running were associated with equivocal reductions in new-onset hypercholesterolaemia and diabetes mellitus. However, these activities are not matched for energy expenditure. It is not surprising that the energy expended by walking is less than half that reported for running [34]. This difference has been associated with significantly less gain in BMI and smaller waist circumference over a six-year period [34].

There are detrimental consequences of low body mass associated with running, particularly endurance running. Hormonal imbalances and low energy availability are frequently observed among women in sports where leanness is seen as beneficial to optimise performance [32]. Frequently, the hypothalamic–pituitary–gonadal axis is disrupted, which causes a decrease in oestrogen [35]. This can result in amenorrhoea and delayed puberty in women and girls. Other hormonal disturbances include increased cortisol, low leptin, and low insulin-like growth factor-1 concentrations. The latter is an important bone anabolic hormone, and detrimental changes in bone metabolism can result when levels are low [35]. Little research has been conducted into testosterone levels in male runners. There is some older evidence indicating a depression in serum testosterone concentrations in male runners undergoing strenuous training [36]. However, testosterone levels appear to remain stable in men who maintain a habitual training load [36].

Immune system

Immune responses to walking and running may follow a more j-shaped curve than metabolic responses, whereby there is an 'optimal' level of intensity or duration with more detrimental effects associated with levels above or below this. This 'optimal' level has not been systematically quantified and appears to be individual specific. Importantly, prolonged or unaccustomed bouts of running, during periods of overtraining and competition, have been associated with increases in inflammatory markers such as natural killer cells, cytokines, chemokines and free radicals [37,38]. This process may result in an immunosuppressive cascade. However, this process is transient, lasting between 3 and 72 h [38], and proteomic research suggests that there is a simultaneous expression of proteins associated with detoxifying processes and immune responses [37]. A similar antioxidant response was observed in blood samples of walkers 2 and 4 h after vigorous walking [37]. This suggests that, while there may be an increased risk of immune suppression immediately after walking and running, there may also be upregulation of systems designed to combat this.

Summary: benefits and negatives of walking and running

Taken together, it is apparent that the benefits of walking and running for the musculoskeletal, cardiovascular, respiratory, metabolic, endocrine and immune systems outweigh the risks of harm. However, on the basis of available evidence, individuals should respect dose-response relationships regarding their exercise load, being mindful that too little exercise may be detrimental across body systems, while too much load may have significant consequences for their musculoskeletal, cardiovascular and immune health.

Multidirectional sports (court and field sports)

Multidirectional sports such as soccer, basketball, volleyball, football and hockey are intermittent sports. In both training and competition, they exhibit alternating exercise intensity, and multi-limb and cross-body movements such as kicking, jumping and throwing. These movements are often performed while running at high intensity or changing direction, followed by relatively short recovery periods [39,40]. Multidirectional sports and exercise typically require equipment such as balls, helmets and sticks and are performed by two teams in competition with each other. This places additional demands on the individual beyond that of walking and running.

Musculoskeletal system

The high-intensity and whole-body movements associated with multidirectional sports place high demands on the musculoskeletal system [39]. These demands can generate significant adaptations, which are both positive and negative, across the lifespan. In a study of individuals aged more than 70 years, Pedersen et al. [41] found that weekly ball sport competitions resulted in significant improvements in weighted arms curls and the number of 30-s chair-stand repetitions, suggesting an improvement in both upper and lower limb function and balance. Similarly, in a group of untrained women aged 20–30 years, a 17-week handball training intervention resulted in significant improvements in both whole-body muscle mass and bone mineral density [42]. In overweight 11- to 13-year-old boys, recreational football training for 12 weeks was associated with moderate increases in lower body power and flexibility [43].

Improvements in physical and mechanical properties of soft and bone tissue are well documented in a variety of multidirectional sports such as soccer, basketball, volleyball, rugby and hockey [44,45]. Bone mineral density in people who primarily play these sports has been found to be greater than that in those who only run [46]. This is likely due to the greater mechanical loads associated with multidirectional sports, which arise from both ground impact and high muscular contractions [45]. A narrative review also hypothesised that the uneven distribution of load may have higher potential for increasing osteogenesis than habitual loading patterns associated with running or walking [47]. Cumulatively, these data support participation in multidirectional sports, at all ages, for bone and muscle health.

Conversely, participation in multidirectional sports has been associated with increased rates of traumatic injuries, immediate microtrauma and long-term impairments. These can include muscle imbalances [48] and structural changes [49] that have been associated with on-going pain and risk of long-term joint damage. A systematic review of injury incidence in women playing sports involving a bat or stick reported soft tissue injuries and ligament sprains to be the most common form of injury. The ankle, hand, knees and head were the most common injury sites [50]. This is similar to injury epidemiological studies in soccer [51], basketball and American football [52].

While most traumatic injuries are the result of contact with another player [52], anterior cruciate ligament (ACL) injuries are arguably of greatest concern. Multidirectional sports people, particularly adolescents, are a high-risk group for ACL tears [53]. ACL injury is more likely to occur as a non-contact injury during a deceleration or a change in direction, both of which are common in multidirectional sports [54]. When combined with large degrees of knee valgus and hip internal rotation, the strain on the ACL is maximised [55]. As female adolescents mature, neuromuscular control around the knee reduces, potentially explaining higher rates of ACL injury in female than in male athletes, when matched for sport [56]. Approximately 50% of people who have tear in their ACL proceed to develop OA, with changes to the joint occurring as early as one year post-injury [57], and worsening over the first five years [58]. These rates appear the same regardless of whether or not an individual undergoes surgical repair of the ligament [59].

Cardiovascular and respiratory systems

While there is a considerable amount of evidence regarding the general benefits of participating in multidirectional sport, specific cardiovascular and respiratory benefits have not been widely investigated. A systematic review of health benefits associated with participation in different types of sport and exercise reported, on average, one published study for each field and court sport [60]. The exception is soccer, where meta-analysis of five studies demonstrated a systematic increase in ventilatory capacity (VO_{2max}) and decrease in resting heart rate after 6–12 weeks of soccer participation [60]. More recent data have supported this finding, with improvements also being noted in diastolic blood pressure [43]. However, changes in VO_{2max} and endurance were not as great as those observed after running interventions of similar duration [39].

Recent studies have demonstrated that participation in other multidirectional sports such as basketball results in decreased heart rate and blood pressure, as well as improved VO_{2max} [6]. Interestingly, basketball-based data suggest that cardiovascular benefits may be optimised when playing over the full court. When comparing full- and half-court basketball interventions, y individuals who played full court experienced decreases in systolic blood pressure, heart rate, total cholesterol and triglycerides, as well as increases in VO_{2max} [6]. In contrast, no changes in these markers were observed after a small-sided 12-week handball intervention [42]. The intervention period in both studies was 12 weeks and targeted 'untrained' people of the same age group (20–40 years). In both studies, individuals participating in modified versions of the sport experienced little cardiovascular benefit. This finding may indicate that non-modified sports are optimal for cardiovascular health. However, another important difference between the studies is that the basketball cohort was male and the handball cohort was female. While no study has compared cardiovascular variables of men and women participating in the same multidirectional sport, a comparison of the studies of Randers et al. [6] and Hornstrup et al. [42] suggests that women may not derive the same cardiovascular benefits as men. Given that the number of women living and dying from cardiovascular disease exceeds that of men [61] and that the highest participation sports for women are court-based sports [11], this is an area where more research would be valuable.

Metabolic and endocrine systems

The stop–start nature of multidirectional sports and exercise requires brief but maximal efforts during both training and competition. Consequently, these sports are considered to rely predominantly on anaerobic metabolism using high-energy phosphates and anaerobic glycolysis [44]. This can result in short-term increases in blood lactate concentrations, even in highly trained athletes [62].

Blood lactate concentrations are one of several detrimental influences on muscle function. Oxidative stress, proinflammatory cytokines, depleted glycogen stores and changes in plasma concentrations of several hormones including cortisol are metabolic and endocrinological changes associated with participation in multidirectional sports [40,62,63]. In adults, these changes appear to be at their most pronounced after a game [40,62]. However, in adolescents, the elevation is present for seven days and is correlated with the presence of muscle pain [63]. These data indicate that recovery periods are needed, particularly after intense bouts of multidirectional sport. A period of up to four days is recommended for adults, while one week may be appropriate for those under 17 years of age [62,63].

Importantly, multidirectional sports have been reported to have little long-term effect on testosterone and oestrogen levels [63]. While testosterone/cortisol ratio decreases substantially immediately after competition in both soccer [64] and rugby [65], it increases to levels above baseline within 48 h [65]. This is important for the maintenance of performance, bone density and muscle mass, while decreasing body fat. Basketball and soccer have both been demonstrated to reduce body fat percentage, but the effect appears to be greater in people who began playing within a healthy weight range [6,43]. This may be due to the ability to play at a higher intensity. Reaching and maintaining a high intensity of exercise can be difficult for overweight people [66] and may explain why there is little research into the association between weight loss, diabetes risk and multidirectional sport.

Immune system

The literature pertaining to immune function and multidirectional sports is focused on elite or highly competitive athletes. This literature reports globally similar findings: that salivary immunoglobulin A, which populates mucosal surfaces for protection against pathogens, decreases after prolonged and strenuous competition [64,65]. This is coupled with reports of increased white blood cell counts [62], plasma levels of interleukin-6 [62,67] and several other blood markers of systematic immune suppression [64]. These changes are transient, exposing athletes to a small increase in risk of common illness such as upper respiratory tract infections [67]. It is unlikely that the general population would compete at the levels of intensity and duration required to experience immunosuppression from multidirectional sports. Further, it is possible that participation alone is not enough to trigger such responses. Gleeson [67] notes that the athletes under investigation in studies of immune function and multidirectional sports are typically also experiencing dietary energy deficiency, sleep deprivation and psychological stressors associated with competition. These stressors are likely to primarily contribute to altered immune and endocrine responses [67].

Summary: benefits and negatives of multidirectional sports

The substantial risks of sustaining an acute musculoskeletal injury during participation in multidirectional sports cannot be ignored. However, the more widespread biological benefits of multidirectional sport, especially in sub-elite populations, taken together with positive effects of injury prevention programs when implemented effectively, mean that the benefits of participation in multidirectional sport do appear to outweigh negatives.

Resistance exercise

Resistance exercise, also known as strength training, fundamentally differs from aerobic exercise. Whereas aerobic exercises use whole-body movements, resistance exercise typically focuses on building strength and neuromuscular control in specific muscle groups using discrete tasks, often against some resisting force [68]. Muscle contractions can be concentric, eccentric, isometric and isotonic; frequently, a combination of contractions is utilised within a single exercise. However, when undertaking these exercises, multiple training variables need to be considered, including intensity, rest intervals and duration, as these variables all appear to influence the type and magnitude of the biological effect [69]. Intensity for strength building is traditionally set as a percentage of a 1 repetition maximum (RM), or the maximum amount of resistance that can be overcome during a single effort. In the current literature, a range of intensities is used, from body weight [70] up to 80% of 1RM [71]. As such, it is not surprising that there is considerable variability in the outcomes measured.

Musculoskeletal system

Despite substantial variation in resistance exercise interventions, level 1 evidence from systematic reviews indicates that resistance training has the potential to increase muscle strength [71,72]. These benefits appear to occur regardless of the age of the participants. In healthy, recreationally active men, 12 weeks of strength training resulted in large improvements in both 1RM and multiple repetition strength parameters [73]. Even low frequency of resistance exercise may confer benefits. A meta-analysis of 47 studies showed that two sessions per week consisting of two-to-three sets of 7 repetitions can improve muscle strength by up to 33% in adults over 70 years, regardless of their sex [72].

Multiple systematic reviews have demonstrated that a minimum intensity of 60% 1RM is essential to gain strength benefits in untrained people, and 80% 1RM is required for trained individuals. A cross-sectional study of trained women asked them to self-select their desired intensity and rating of perceived exertion (RPE) for both upper and lower limb resistance exercise. Participants selected an average of 57% 1RM and an RPE of 'somewhat hard' [69]. Findings of this study suggest that, in the real world, people may not be working at appropriate intensities to reap the potential strength benefits of resistance exercises.

The benefits of resistance exercise on bone and joints are not clear. In children and adolescents, resistance training has not been widely recommended due to speculated negative effects of high forces on growth plates [74]. While no recent study has supported this theory, it may be that osseous changes in adolescents associated with resistance exercise are influenced by sex. Multiple studies in adolescent girls have found that resistance exercise performed three times weekly for up to 15 months had no effect on bone mineral density [75,76]. In age-matched boys who underwent a similar training program, significant improvements in bone mineral density were observed [75]. However, resistance training may not have the same effects on increasing bone mineral density in older adults. Two systematic reviews have reported that progressive lower limb strength training, in isolation or combined with high-impact exercise, has small but significant positive effects on bone mineral density in post-menopausal women [77,78]. In men and women aged over 65 years participating in a randomised clinical trial, 26 weeks of resistance training did not significantly change bone mineral density [68]. Because groups were stratified for sex, it was not possible to draw conclusions from this study regarding the influence of sex on bone health. However, taken together, these findings suggest that resistance training at least maintains bone density in at-risk populations.

Very few soft tissue injuries, specific to resistance training interventions, have been reported in the literature. A systematic review of 27 studies reported that a total of 3 injuries occurred across all of the studies, which ranged over a 20 year period [79]. Data of presentation to emergency rooms due to injuries occurred during resistance training indicate that when injuries do occur, they are primarily lower back injuries, regardless of the age and sex of the population [80,81]. While this is concerning, Myer et al. [81] also demonstrated that the number and severity of soft-tissue injuries associated with resistance exercise significantly decreases with age. Further, modifiable factors such as supervision, technique and resistance load are the primary contributors to injuries, and addressing these factors may significantly reduce injury risk.

Cardiovascular and respiratory systems

Resistance exercise is not specifically designed to target cardiovascular fitness. For people with hypertension, resistance exercise was once contraindicated due to acute disruption to the cardiovascular system. The acute increase in blood flow, blood pressure, cardiac sympathetic modulation and arterial stiffness was thought to facilitate atherosclerotic plaques and aneurysm rupture, increasing the risk of sudden cardiac death [82]. However, large longitudinal studies, involving several thousand people, have demonstrated that resistance exercise is associated with a 23% reduction in coronary heart disease in men [83] and a significant quadratic association for cardiovascular-related death in women [84,85]. Women with moderate amounts of self-reported resistance exercise exhibited significantly low levels of risk factors such as cholesterol and triglycerides [84] and low rates of mortality [85]. However, women reporting more than 150 min of strength training per week did not have low mortality risks [85]. These findings have resulted in resistance exercise being proposed as an important addition, and a potential alternative, to aerobic exercise for the prevention and management of cardiovascular disease.

The most studied cardiovascular variable in resistance exercise literature has been blood pressure. Level 1 evidence demonstrates that both systolic and diastolic blood pressures decrease in hypertensive and normotensive individuals after resistance exercise interventions [4]. The blood pressure-lowering effect appears to be enhanced by exercising larger, rather than smaller, muscle groups [4], and by performing bilateral exercises [86]. Further, a repeated-measures study on normotensive men, who were experienced with resistance exercise, found that the magnitude and duration of the post-exercise hypotension were dependent on training volume. In particular, a higher number of sets resulted in the greatest effect [87].

Metabolic and endocrine systems

Resistance exercise has gained attention over the past two decades for its capacity to increase lean body mass, glucose tolerance and insulin sensitivity, as well as modulate other metabolic and hormonal characteristics [88]. Large epidemiological studies from the United States have shown that meeting the World Health Organization's guidelines for weekly resistance exercise is associated with a 25% reduction in the odds of having metabolic syndrome [89]. Further, Bakker et al. [89] found that the total time required for resistance exercise was less than 1 h per week. Higher volumes of exercise were not found to provide a further reduction in odds. A potential criticism of these studies is that they were based on self-reported data. However, as individuals tend to over-report physical activity [90], the implication is that even less frequent resistance exercise is required to confer metabolic benefit.

In search of potential mechanisms to explain why resistance exercise lowers metabolic syndrome risk, epidemiological studies from Australian cohorts have found that resistance exercise, performed a minimum of once per week, was associated with significantly low odds of impaired glucose metabolism [91] and insulin resistance [92]. Further, independent of insulin sensitivity, increased muscle mass and strength are important protective factors of metabolic syndrome [92]. In their systematic review, Hurley et al. [88] proposed that this is likely due to qualitative changes in the muscle and stimulation of hepatic lipid metabolism due to repetitive muscle loading. However, the type of loading may be an important consideration, as eccentric muscle activation and concentric muscle activation have been demonstrated to result in different endocrine responses in men [93]. While testosterone and cortisol responses appear to be similar regardless of contraction type, less growth hormone is produced during the eccentric phase of many exercises [93].

Immune system

There is a developing body of research describing the effects of resistance exercise on the immune system. There is general agreement that an acute bout of resistance exercise induces short-lived but significant increases in total leukocytes, monocytes, cytokines, immunoglobulin and neutrophils [70,94,95]. The response appears to be greater with higher exercise intensities [94] and with shorter rest intervals between exercises [95]. The immunosuppression does not appear to extend beyond 24 h [94]. Interestingly, long-term resistance exercise programs have recently been associated with decreased expression of Toll-like receptors [67]. These receptors play an important role in the detection of microbial pathogens. Over the long term, decreased Toll-like receptor expression may also decrease the inflammatory capacity of leukocytes and potentially reduce the risk of developing chronic disease [67]. As such, while there may be short-term higher susceptibility to infection after a resistance exercise session, there may be long-term benefits for overall health.

Summary: benefits and negatives of resistance exercise

It is clear that resistance exercise is essential for maintaining musculoskeletal health, particularly in at-risk populations such as post-menopausal women and the elderly. The benefits of resistance exercise extend beyond the musculoskeletal system, with evidence of improvements in cardiovascular, respiratory, metabolic, endocrine and immune systems. However, it appears that many of these benefits are not realised if individuals are not working hard enough or if they participate too frequently. Further, while there is a small risk of musculoskeletal injuries, particularly in the lower back, this is primarily due to inadequate professional supervision and poor technique. As long as individuals are well instructed and do not exceed recommendations for resistance training load, it appears that benefits far outweigh potential harms.

Psychosocial benefits and negatives of participation in sport and exercise

This section provides an overview of the benefits and negatives of sport and exercise on psychosocial constructs. Considering the smaller volume of literature, we have considered all forms of increased participation sport and exercise together. Furthermore, in interpreting the evidence on psychosocial benefits and negatives, it is important to consider that the majority of studies focus on a broad definition of physical activity. Although this does incorporate exercise and sport, it may also extend to include incidental exercise such as walking for transport.

Psychosocial outcomes

In the last ten years, multiple meta-analyses have found that physical activity has moderate-to-strong anti-depressive effects in populations with clinical depression disorders [96,97] There have also been two meta-analyses investigating the effect of physical activity in people with clinically diagnosed anxiety [98,99], but the findings are less consistent, ranging from negligible to medium effects.

Beyond clinical settings, in the same period, there have been at least two meta-analyses conducted on the effects of physical activity in reducing depression and anxiety symptoms in the general population [99]. These analyses conclude that there is evidence that physical activity reduces depression (with a medium effect) and anxiety (with a small effect) in the general population. However, these findings only appear to extend to reports on physical activity dosage interventions that may, or may not, involve participation in sports or prescriptive exercise regimes.

Whilst these findings support other large population-based correlational studies that show that people who are more physically active have lower onset ratios for clinical depression and clinical anxiety symptoms, they fall short of linking any potential of reversed causality. A recent meta-meta-analysis conducted by Rebar and colleagues [100] cited the potential that when people feel depressed or anxious, they characteristically struggle with the necessary motivation to be physically active. It is therefore prudent that future research investigates the reciprocity and inter-related relationship of psychological health and participation in sports and exercise.

The World Health Organization's (2005) definition of health also incorporates social health and wellbeing in its constitution, but this is not empirically addressed in any existing guidelines. The literature informing the world physical activity guidelines does suggest that creating social networks that encourage participation in physical activity is a necessary supportive strategy for physical activity promotion [101]. However, the literature fails to investigate sufficiently whether a reversal link of causality exists. In other words, increased participation in physical activity improves the likelihood of increased social connectivity and, hence, increased social health.

There are four modes of physical activity relevant to social health: 1) team sport; 2) individual sport; 3) organised but non-competitive physical activity and 4) non-organised physical activity [102]. Sport is an apparent form of physical activity with arguably the greatest potential effect on social health, given that participation is predominately in a social context. As such, it is commonly inferred that sport participation may be associated with greater social health benefits than other forms of physical activity [103]. In 2011, Australian researchers determined that there were many different social health benefits reported, with the most common being improved social interaction and integration, resulting from regular participation in sports [102]. The authors also determined that sport for youth may be associated with improved social health benefits above and beyond improvements attributed to participation in other forms of physical activity [104].

Eime and colleagues later conducted a systematic review that reported qualitatively on the few studies investigating the social health benefits of sport participation for adults [103]. The studies included reported a general consensus that there are many benefits associated with participation in sports for adults, including greater overall wellbeing, reduced distress and stress and greater vitality and social functioning. Furthermore, there is coherent support for the notion that club and team-based sport participation than participation in other individual forms of physical activity is associated with better social health outcomes. It is generally concluded that it is the social nature of this participation that facilitates the relationship between participation and improved health.

Recognising that research to date is predominantly based on cross-sectional studies, participation in sport can be advocated with caution as a form of physical activity that can produce social health benefits. It is also recommended that the causal link between participation in sport and psychosocial health be further investigated.

The psychosocial negatives associated with higher levels of physical activity, exercise and sport participation are limited in the literature, with the notable exception of alcohol consumption. Alcohol consumption linked to short-term harm most frequently occurs in licensed venues (such as clubs and bars) [105] that often have sporting club associations or actively support the activities of sporting teams. At both the elite and the amateur level, athletes have reported consuming alcohol at higher levels than those in people not involved in physical activity and sports [106,107]. Studies of collegial athletes in the United States found significantly higher levels of binge drinking behaviour (more than 20% higher) among collegial athletes than among those not involved in college sports, regardless of sex [108]. Similarly, studies in New Zealand report rates of binge drinking among elite and non-elite sportspeople, which are more than 20% higher than that of non-sportspeople [107], and non-elite sportspeople in Australia have reported higher rates of risky drinking (35%) than the general population (26%) [106]. The alarming high alcohol consumption compared with the wider population associated with participation in sport is of serious concern. In 2007, the World Health Organization identified alcohol consumption as a primary cause of psychosocial harm in many communities to both the consumer and those in their vicinity of those who drink to excess [109].

Summary: psychosocial benefits and negatives of participation in sport and exercise

While recognising limitations with the current literature, which typically evaluates effects of physical activity, it appears that participation in physical activity, exercise and sport has an overwhelmingly beneficial psychosocial effect. The major concern identified in the literature is behaviour associated with alcohol consumption, which has a long-established relationship with sport. Further work is needed to determine other potential negatives associated with exercise and sport participation.

Concluding remarks

In the current literature, the remaining evidence suggests that the benefits of participation in exercise and sport do outweigh the negatives, from a biological, a psychological and a social perspective. Moderate amounts of exercise and sport participation provide the most optimal balance, and while this intensity is specific to the individual's exercise capacity, an international recommendation of 150 min of aerobic exercise and two resistance exercises session each week is generally applicable to balance positive and negative effects, allaying some of the potential harms associated with low or high participation. Our findings add weight to current campaigns for individuals to be more active, whether they choose activities such as walking or running, resistance exercise or participation in multidirectional sport. While beyond the scope of this review, there are other forms of exercise and sport that should also be considered, such as cycling and aquatic-based exercise. Health professionals are advised to take an active role in encouraging both patients and the general population to engage in exercise and physical activity. Notably, they should consider the potential positive and negative effects of the different types of exercise and sport, as well as established guidelines for recommended amounts of physical activity, in shared decision-making.

Practice Points

- Impact forces appear to be required to maximise benefits to bone mineral density but need to be (a) of great enough magnitude and (b) limited duration.
- There does not appear to be an association between participation in sport and exercise and the onset of idiopathic osteoarthritis.
- Traumatic knee or hip injuries do initiate an osteoarthritic process, which highlights the need for appropriately implemented injury prevention programs in sport, particularly in adolescent years.
- Ratings of perceived exertion must be hard', rather than somewhat hard' to achieve optimal improvements in muscular strength.
- Resistance exercise is safe for people with high blood pressure and has been found to low blood pressure, even in people with hypertension.
- Club and team-based sports are associated with greater social wellbeing than other forms of physical activity
- Moderate levels of physical activity achieve the widest range of biological benefits compared with high and low levels.

Future Research Agenda

- Future studies should seek to fill gaps in the evidence on benefits and harms in exercise by investigating sex-specific differences and specific groups of interest (e.g. individuals with osteoarthritis). For example, the majority of research on resistance training for bone mineral density has been conducted in pre- and post-menopausal women despite osteopenia and osteoporosis also occurring in older men.
- Studies evaluating concurrent effects of exercise and sport on multiple body systems will further our knowledge of specific interactions.
- More research is needed into the psychological and social benefits and negatives associated with exercise and sport participation, the temporal relationship between participation and psychosocial health and how these may interact with biological effects.

Conflicts of interest

The authors declare no conflicts of interest.

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