

Physical activity: Health impact, prevalence, correlates and interventions

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Objective: To provide a broad overview of the state of physical activity (PA) research in the form of (1) definitions of PA, (2) health benefits, (3) prevalence, (4) correlates and (5) interventions.

Design: A high-level overview of published reviews of the literature.

Results: Regular PA is an effective primary and secondary preventative strategy against at least 25 chronic medical conditions with risk reduction typically in the 20–30% range. While approximately 75% of adults meet recommended PA guidelines, the prevalence is slightly lower for women compared to men, and considerably lower for youth, older adults and those in higher income countries. Motivation, self-efficacy and self-regulation remain consistent correlates of PA. Interventions show PA changes in the small effect size range for adults and youth but the heterogeneity is considerable across studies. Only a few (aggregate of behavioural regulation strategies, supervision, high frequency of contact) reliable moderators of intervention success were identified across study quality, sample characteristics, theory/behaviour change techniques and delivery modes/settings.

Conclusion: PA research should continue to examine the mechanisms causing health outcomes, the dose that can lead to clinically relevant changes in health status, the scope and validity of PA surveillance and innovative behaviour change techniques, while improving the reach and duration of PA interventions.

Keywords: exercise; health; intervention

Introduction

This paper is a high-level review of the current state of international research on physical activity (PA). The paper is divided into five sections that correspond with the scope of PA research: (1) definitions of PA, (2) health impact of PA participation, (3) PA prevalence and surveillance, (4) PA correlates and determinants and (5) interventions to change PA. The main purpose of this paper is to provide a broad overview of the contemporary evidence in each of these five domains and conclude by highlighting important future directions for the advancement of PA research.

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Definitions of physical activity

In its simplest sense, PA refers to any bodily movement that results in an increase in energy expenditure. PA is often characterised using the FITT principles where *F* = frequency, *I* = intensity, *T* = time and *T* = type. The frequency refers to how often a person is active. The intensity refers to how vigorous the PA is; PA research often focuses on moderate to vigorous PA wherein a person's energy expenditure level is at least three times greater than while at rest. The time refers to the total duration of PA, and could reflect the time spent in a bout of PA (e.g. a 30 -min walk) or the accumulated time spent in PA over the course of a day or a week (e.g. five 30-min walks performed over a week = 150 min). The type of PA can be based on whether it is aerobic or anaerobic in nature (e.g. walking or weight training), or the domain in which it occurs (e.g. occupational, transportation, leisure time).

Although PA is on a continuum, ranging from extremely sedentary and inactive (e.g. bed ridden) to incredibly active (e.g. elite triathletes), research studies often classify participants based on whether or not they meet recommendations, such as the global recommendations on PA (World Health Organization, 2010) or country specific recommendations, which for the most part are consistent with the global ones. The PA recommendations provided by the World Health Organization (2010) for school-aged children and adolescents (aged 5–17), adults (aged 18–64) and older adults are presented in Table 1 along with Canadian recommendations (Canadian Society for Exercise Physiology, 2016) for preschool children (aged 0–4). The PA recommendations are based upon the relationship between PA and health, which will be discussed in the next section.

Health impact of physical activity

The following sections highlight the recent evidence relating to premature mortality and chronic medical conditions that have a large impact on the health and well-being of society. We also discuss briefly the literature demonstrating the benefits of PA participation (e.g. clinical exercise rehabilitation) in the secondary prevention of chronic disease and other PA benefits.

Premature mortality

Early pioneering epidemiological research demonstrated a clear dose-response relationship between PA and the risk for all-cause mortality. For instance, the Harvard Alumni study revealed a graded relationship between PA and all-cause mortality with the least active individuals having the greatest risk (Supplemental Figure 1; Paffenbarger, Hyde, Wing, & Hsieh, 1986). Importantly, the largest risk reductions were seen when moving from the least active group to the next more active group. That is, large risk reductions were seen with relatively small differences/changes in PA behaviour.

These early findings have now been consistently supported in numerous epidemiological studies and systematic and meta-analytic reviews (Hupin et al., 2015; Warburton, Charlesworth, Ivey, Nettlefold, & Bredin, 2010) such that we can confidently state that routine PA participation markedly decreases the risk for premature all-cause mortality. For instance, in a systematic review of the literature, Warburton

Table 1. Recommendations on physical activity for health.

Age group	Physical activity recommendations ^a	Criteria typically used to define meeting physical activity recommendations for surveillance
Children of the early years aged 0–4	(1) Infants (aged less than 1 year) should be physically active several times daily – particularly through interactive floor-based play (2) Toddlers (aged 1–2 years) and preschoolers (aged 3–4 years) should accumulate at least 180 min of physical activity at any intensity spread throughout the day, including: (a) A variety of activities in different environments (b) Activities that develop movement skills (c) Progression towards at least 60 min of energetic play by 5 years of age (3) More daily physical activity provides greater benefits	For 1–4 year olds, ≥180 min of physical activity at any intensity on all 7 days of the week
School-aged children and adolescents aged 5–17	(1) Accumulate at least 60 min of moderate to vigorous intensity physical activity daily (2) Amounts of physical activity greater than 60 min provide additional health benefits (3) Most of the daily physical activity should be aerobic. Vigorous intensity activities should be incorporated, including those that strengthen muscle and bone, at least 3 times per week	≥60 min of moderate to vigorous intensity physical activity on all 7 days of the week

(Continued)

Table 1. (Continued).

Age group	Physical activity recommendations ^a	Criteria typically used to define meeting physical activity recommendations for surveillance
Adults aged 18–64	(1) At least 150 min of moderate intensity aerobic physical activity or 75 min of vigorous intensity aerobic physical activity throughout the week or an equivalent combination of moderate and vigorous intensity activity (2) Aerobic activity should be performed in bouts of at least 10 min (3) For additional health benefits, adults should increase their moderate intensity aerobic physical activity to 300 min per week, or engage in 150 min of vigorous intensity aerobic physical activity per week or an equivalent combination of moderate and vigorous intensity activity (4) Muscle-strengthening activities should be done involving major muscle groups on 2 or more days a week	≥150 min/week of moderate aerobic activity, or ≥75 min/week of vigorous activity or an equivalent combination of moderate and vigorous activity accumulated in bouts of ≥10 min
Adults aged 65 or older	(1) At least 150 min of moderate intensity aerobic physical activity throughout the week or at least 75 min of vigorous intensity aerobic physical activity throughout the week or an equivalent combination of moderate and vigorous intensity activity (2) Aerobic activity should be performed in bouts of at least 10 min	≥150 min/week of moderate aerobic activity, or ≥75 min/week of vigorous activity or an equivalent combination of moderate and vigorous activity accumulated in bouts of ≥10 min

(Continued)

Table 1. (Continued).

Age group	Physical activity recommendations ^a	Criteria typically used to define meeting physical activity recommendations for surveillance
	(3) For additional health benefits, older adults should increase their moderate intensity aerobic physical activity to 300 min per week, or engage in 150 min of vigorous intensity aerobic physical activity per week or an equivalent combination of moderate and vigorous intensity activity	
	(4) Older adults, with poor mobility, should perform physical activity to enhance balance and prevent falls on 3 or more days per week	
	(5) Muscle-strengthening activities, involving major muscle groups, should be done on 2 or more days a week	
	(6) When older adults cannot do the recommended amounts of physical activity due to health conditions, they should be as physically active as their abilities and conditions allow	

^aFor school-aged children and youth, adults and older adults these are the global recommendations produced by the World Health Organization. For children of the early years, these are the Canadian recommendations as this age group is not included within the global recommendations.

et al. (2010) found overwhelming epidemiological evidence that routine PA was associated with a lower risk for all-cause mortality. There was a 31% lower risk for all-cause mortality in the most active individuals in comparison to the least active (Supplemental Figure 2). Similar to several other reviews, a clear dose-response relationship was observed with relatively small changes in PA/fitness leading to significant reductions in the risk for all-cause mortality.

Similar to the earliest studies on PA and all-cause mortality, consistent evidence now demonstrates that the greatest relative risk reductions are seen when comparing the least active group to the next more active group. Several epidemiological studies (Kushi et al., 1997; Lee & Skerrett, 2001; Lee, Rexrode, Cook, Manson, & Buring, 2001; Leon, Connett, Jacobs, & Rauramaa, 1987; Myers et al., 2004, 2002; Paffenbarger et al., 1993; Villeneuve, Morrison, Craig, & Schaubel, 1998; Wisloff et al., 2006), randomised controlled trials (Foulds, Bredin, Charlesworth, Ivey, & Warburton, 2014) and

recent systematic reviews/meta-analyses of the literature (Arem et al., 2015; Lee et al., 2014; Löllgen, Böckenhoff, & Knapp, 2009; Paterson & Warburton, 2010; Warburton et al., 2010; Wen et al., 2011) have revealed marked risk reductions with relatively small volumes of PA. For instance, Wen et al. (2011) revealed recently that 90 min/week (or 15 min per day) of moderate intensity PA significantly reduced the risk for deaths related to all-causes, all cancers, cardiovascular disease and diabetes. This volume of activity was associated with a 14% risk reduction for all-cause mortality, and every additional 15 min of daily PA (to a maximum of 100 min per day) resulted in a further 4 and 1% reduction, respectively, in the risk for all-cause and all-cancer-related mortality (Wen et al., 2011).

Arem et al. (2015) also revealed that any level of PA participation (e.g. 6 to <450 MET-min/wk; Figure 1) was associated with a significantly lower risk of mortality (20%). The optimal health benefit (39%) was observed at approximately 3–5 times the international 150-min MVPA recommendation; however, the greatest relative gain in health benefit was seen when comparing inactive individuals to those that participated in low volumes of activity. Engaging in $\leq 50\%$ of the recommended 150 MVPA (i.e. 6–225 MET-min/wk of leisure time MVPA (roughly 75 min of brisk walking per week)) resulted in approximately two years of life gained (Moore et al., 2012). More recently, Hupin et al. (2015) in a systematic review revealed that a low volume of MVPA (1–499 MET-min/wk or 15 min/day) led to a 22% reduction in all-cause mortality risk in older (<60 yr) adults. Additional risk reductions were observed in those engaging in 150 min/wk MVPA (28%) and individuals who participated in more than 1000 MET-min/wk

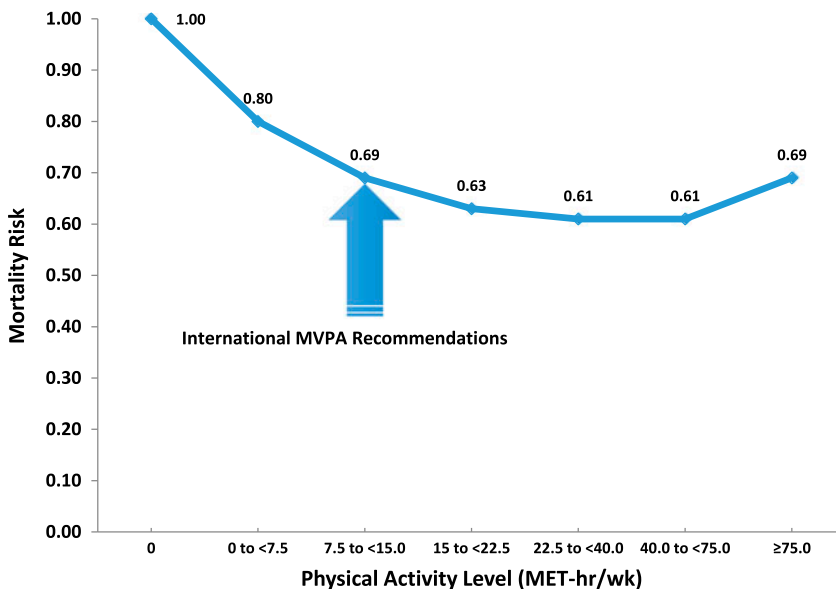


Figure 1. Dose-response relationship between physical activity and mortality risk considering minimum international physical activity recommendations.

Notes: Figure adapted from Arem et al. (2015). The relative risk for mortality was compared across physical activity levels related to the minimum recommended level of 7.5 MET-hr/wk.

(35%). However, the greatest relative changes were observed with the lowest doses of activity (Hupin et al., 2015).

Collectively, this research demonstrates the capacity of routine PA to reduce the risk for premature all-cause mortality, and the potential for even small volumes of PA participation to lead to clinically relevant health benefits. Importantly, when examining this literature, we see that the 150 MVPA recommendation leads to risk reductions for premature mortality that are closer to the optimal than the minimal (Warburton & Bredin, 2016).

Primary prevention of chronic disease

Regular PA participation has been associated with the primary prevention of more than 25 chronic medical conditions (Warburton & Bredin, 2016; Warburton, Nicol, & Bredin, 2006a, 2006b; Warburton, Taunton, Bredin, & Isserow, 2016; Warburton et al., 2010). For instance, systematic reviews of the literature (Warburton, Katzmarzyk, Rhodes, & Shephard, 2007; Warburton et al., 2010) have revealed mean risk reductions of 20–30% for multiple chronic medical conditions in persons that were regularly active. Table 2 illustrates the relative risk reductions observed in physically active/fit individuals for several chronic medical conditions that have a large impact upon society (such as cardiovascular disease, stroke, hypertension, colon and breast cancer and Type 2 diabetes). The strength of the epidemiological evidence is overwhelming, supporting the health benefits of routine PA. The strength of the relationship is even greater (approximately 40–60%) when objective measures of aerobic fitness were related to morbidity.

Similar to the research on PA and all-cause mortality, the current evidence indicates that relatively small volumes of PA are associated with marked risk reductions for chronic disease. For instance, Sattelmair et al. (2011) in a recent meta-analysis demonstrated that individuals that were physically active at half of the current recommendations demonstrated a 14% lower risk of coronary heart disease (RR = .86; 95% CI, .76–.97). The authors stated ‘...the biggest bang for the buck for coronary heart disease risk reduction occurs at the lower end of the activity spectrum: very modest, achievable levels of PA’ (Sattelmair et al., 2011).

Considerable research has examined the potential for routine PA to reduce the risk for diseases of the cardiovascular system (such as heart disease, stroke, hypertension), cancer (particularly colon and breast cancer) and type 2 diabetes. However, important emerging evidence has demonstrated the remarkable health benefits for cognition and well-being in persons that are regularly active. For instance, Rebar et al. (2015) in a recent meta-meta-analysis of 92 studies showed that PA reduced depression by a standardised mean difference of $-.50$ and anxiety by $-.38$. Reiner, Niermann, Jekauc, and Woll (2013) in a systematic review of the literature recently revealed that the few existing longitudinal studies observed a negative relationship between PA and the incidence of Alzheimer’s disease and dementia in healthy men and women (Reiner et al., 2013). Similarly, Paterson and Warburton (2010), in their systematic review of the literature, reported that regular PA was associated with improved cognition and a reduced risk of developing dementia in healthy older adults. A recent systematic review (Cox et al., 2016) also found preliminary evidence supporting a positive effect of routine PA participation on indices of cognitive function in young to middle-aged adults.

Table 2. Relative risk reduction observed when comparing active/fit vs. inactive/unfit.

Premature all-cause mortality

- 31% risk reduction
- 45% risk reduction when aerobic fitness is assessed

Cardiovascular disease

- 33% risk reduction
- 50% or greater risk reduction when aerobic fitness is assessed

Stroke

- 31% risk reduction
- 60% or greater risk reduction when aerobic fitness is assessed

Hypertension

- 32% risk reduction
- 50% or greater risk reduction when aerobic fitness is assessed

Colon cancer

- 30% risk reduction

Breast cancer

- 20% risk reduction

Type 2 diabetes

- 40% risk reduction
- 50% or greater risk reduction when aerobic fitness is assessed

Osteoporosis

- Bone adaptations to exercise are load dependent and site specific
- Routine physical activity is associated with improved bone health

Note: Created from data provided by Warburton et al. (2010).

Windle, Hughes, Linck, Russell, and Woods (2010) recently conducted a systematic and meta-analytic review of literature relating older adults (≥ 65 yr) living in a variety of settings (e.g. at home, in the community, in supported housing or in residential care homes). The authors revealed that exercise and PA interventions can lead to significant improvements in mental well-being (via SF-36 and self-esteem) in people aged 65 and older (Windle et al., 2010). Another recent systematic review examined the relationship between physical fitness and activity and brain white matter in older adults (Sexton et al., 2016). These authors reported promising (but cautious) findings related to a positive relationship between physical fitness and activity levels and white matter structure in the ageing brain. However, this area remains a topic of debate and discussion. For example, another recent systematic review (Young, Angevaren, Rusted, & Tabet, 2015) of randomised controlled trials found limited evidence to support cognitive improvements after aerobic interventions in healthy adults (without cognitive impairment). Research in this field is often confounded/limited by small sample sizes, different cognitive and/or mental well-being indicators, differences in the baseline cognitive status of the participants and differences in research quality and design. Moreover, relatively

limited mechanistic research has been conducted in the field in comparison to other chronic medical conditions. Further research is clearly warranted.

From a primary prevention perspective, it is also important to emphasise the risks of physical inactivity in comparison to other traditional risk factors for chronic disease. For instance, of the modifiable risk factors for heart disease physical inactivity has the highest prevalence in Canadian society (Supplemental Figure 3) (Warburton & Bredin, 2016). The pioneering work of Blair et al. (1996) demonstrated that the relative risk for cardiovascular disease-related mortality associated with PA inactivity was similar to that observed for other risk factors (such as hypertension, hypercholesterolemia and obesity) approaching the risks seen with moderate cigarette smoking. This important early research set the framework for future research demonstrating the importance of promoting routine PA participation for all. More recent research (Brown, Pavey, & Bauman, 2015) has revealed that the population risk of heart disease attributable to inactivity is greater than other risk factors such as obesity (high body mass index), smoking and high blood pressure. Based on these findings, Brown et al. (2015) made the important statement that ‘Programmes for the promotion and maintenance of PA deserve to be a much higher public health priority...than they are now, across the adult lifespan’.

Secondary prevention of chronic disease

It is important to highlight that exercise rehabilitation (and/or routine PA participation) can provide marked health benefits for numerous chronic conditions (e.g. Type 1 diabetes and various psychological conditions) that are not the result of physical inactivity. This further emphasises the importance of promoting the health benefits of PA/exercise participation within contemporary society in individuals living with chronic medical conditions. Exercise is considered an essential ‘medicine’ for the secondary prevention of varied chronic medical conditions with leading agencies throughout the world such as the Canadian Association of Cardiovascular Prevention and Rehabilitation, the American Association of Cardiovascular and Pulmonary Rehabilitation and European Association for Cardiovascular Prevention and Rehabilitation creating formal position statements/recommendations (Balady et al., 2007; Hamm et al., 2011; Mezzani et al., 2013; Stone, McCartney, Millar, Tremblay, & Warburton, 2007). Importantly, this research demonstrates that remarkably small volumes of activity (or exercise) can lead to clinically relevant risk reductions in persons living with chronic medical conditions. This highlights the importance of individualised exercise prescriptions and the need to avoid generic PA recommendations in the treatment of those living with chronic medical conditions.

Musculoskeletal fitness

The majority of the evidence related to health-related physical fitness and PA has focused on aerobic activities/exercises. However, many activities of daily living necessitate significant musculoskeletal fitness without requiring a significant aerobic output (Warburton, Gledhill, & Quinney, 2001a, 2001b) and clinically relevant health benefits can occur without marked changes in aerobic fitness (Warburton, 2015). There is now clear evidence that musculoskeletal fitness is associated with various indicators of health status (in particular functional status) (Katzmarzyk & Craig, 2002; Katzmarzyk, Craig,

& Gauvin, 2007; Mason, Brien, Craig, Gauvin, & Katzmarzyk, 2007; Payne, Gledhill, Katzmarzyk, Jamnik, & Ferguson, 2000; Warburton, 2015; Warburton & Bredin, 2016; Warburton et al., 2001a, 2001b, 2006a).

For instance, two systematic reviews of the literature showed that musculoskeletal fitness was positively correlated with glucose homeostasis, functional status, bone health, mobility, psychological well-being and overall quality of life, and negatively associated with fall risk, morbidity and premature mortality (Warburton et al., 2001a, 2001b). Also, improvements in musculoskeletal fitness via exercise training improved markers of health status, particularly in individuals with a low musculoskeletal fitness and functional reserve (Warburton et al., 2006a, 2010). Other research has shown that musculoskeletal fitness is a significant predictor of weight gain over a 20-year period (Mason et al., 2007), quality of life (Payne et al., 2000), mobility (Lauretani et al., 2003), various chronic medical conditions (e.g. type 2 diabetes, stroke, arthritis, coronary heart disease and pulmonary disorders) (Rantanen et al., 1998) and premature mortality (Katzmarzyk & Craig, 2002). Maintaining or increasing musculoskeletal fitness is very important for functional independence across the lifespan particularly for the frail elderly and many living with chronic medical conditions (Warburton et al., 2001a, 2001b, 2006a).

The ability for routine PA to simultaneously reduce the risk for varied chronic conditions and premature mortality is remarkable. The precise mechanisms by which routine PA positively affects multiple conditions remain difficult to independently discern (Warburton et al., 2006a). However, it would appear that routine PA participation leads to various physiological and psychological adaptations that work in a coordinated and additive fashion to improve health status and reduce the risk for multiple chronic conditions and premature mortality (Warburton et al., 2006a). Routine PA participation has been shown to: (1) improve health-related physical fitness, (2) increase exercise tolerance and functional status, (3) improve body composition (e.g. protect against obesity, reduce abdominal obesity and/or improve weight control); (4) enhance lipid lipoprotein profiles (e.g. reduced triglycerides, higher HDL cholesterol, lower LDL to HDL ratios, (5) improve glucose homeostasis and insulin sensitivity, (6) reduce blood pressure, (7) improve autonomic tone, (8) decrease blood coagulation, (9) improve coronary blood flow, (10) augment cardiac function, (11) enhance endothelial function, (12) reduce systemic inflammation and (13) improve psychological well-being (e.g. reduced stress, anxiety and depression). These adaptations may explain (at least in part) the ability for routine PA to be an effective primary and secondary preventative strategy for at least 25 chronic medical conditions and premature mortality (Warburton et al., 2006a).

Prevalence of physical activity

Physical activity recommendations

This section of the review discusses the PA levels of the population and reflect adherence to the PA recommendations shown in Table 1. Note that for surveillance purposes the criteria used to define adherence to the PA recommendations is usually slightly different than the recommendations themselves. For instance, for 18 to 64-year olds the aerobic activity components, but not the muscle-strengthen components, of the recommendations are used to determine whether or not somebody is sufficiently active.

Prevalence of not meeting physical activity guidelines based on self-reported physical activity measures

The vast majority of PA prevalence data is based on surveys that employed self-reported PA questionnaires such as the Global PA Questionnaire or International PA Questionnaire (Hallal, Martins, & Ramírez, 2014; Hallal et al., 2012). Approximately 90% of countries have conducted at least one survey that provides estimates on the prevalence of the population meeting PA recommendations (Hallal et al., 2014). However, in most countries the data is sparse and sporadic and less than a third have a continuous PA surveillance system (Hallal et al., 2014).

The World Health Organization has assembled and harmonised the self-reported PA prevalence data that has been collected in different countries, and these data are freely accessible online in their Global Health Observatory (World Health Organization, 2016). To be included in the observatory, a country's PA prevalence data needed to: (1) be based upon a random sample of the general population for adults, or for adolescents a random sample of the school population, (2) present sex- and age-specific prevalence estimates based on adherence to the global recommendation on PA or a very similar recommendation and, for adults, (3) be based upon a questionnaire that captured PA across work/household, transportation and leisure time. Before being included in the global observatory statistical adjustments were made to harmonise and standardise the country specific prevalence estimates to the year 2010. The adjustments accounted for differences in survey year, questionnaires used to assess PA and recommendations used to define insufficient PA.

Results from the global observatory suggest that in the year 2010 23% of adults aged 18+ across the globe were insufficiently active as they did not accumulate enough PA to meet the global PA recommendations. More women (27%) than men (20%) are insufficiently active. Older adults were more likely to be insufficiently active than were younger adults: 19% of the youngest age group did not meet PA recommendations while 55% of the oldest age group did not meet PA recommendations. Among school-aged adolescents aged 11–17, 81% did not accumulate at least 60 min of moderate to vigorous intensity PA on a daily basis. Girls were more likely to be insufficiently active than were boys, with 84 and 78% not meeting PA recommendations, respectively. Note that volume of physical activity needed to meet the adolescent physical activity guidelines is far greater than the volume of physical activity needed to meet the adult physical activity guidelines which, to a large extent explains the higher prevalence of insufficient activity in adolescents. Also note that the prevalence estimates for adolescents are based on those who attend school and not the general population as in most countries the survey data were collected from self-reported questionnaires collected within schools. This also explains why there is an absence of global data on PA in children aged 11 and younger (i.e. children of this age cannot complete their own questionnaire).

In addition to demonstrating sex and age differences in PA, data from the global observatory highlight that there are differences across countries based on income and geographic location. Based on World Bank income categories, there was a clear income gradient in adults such that the prevalence not meeting PA recommendations was lowest in the lowest income countries and highest in the highest income countries (Table 3). Conversely, in adolescents there was not a clear income gradient (Table 3). In terms of location, the prevalence of adults who were insufficiently active was

Table 3. Prevalence of adults and adolescents who were insufficiently active in 2010 according to World Bank income categories.

World bank income category	Adults (aged 18+)	Adolescents (aged 11–17)
Low-income	16.6	84.5
Low-middle-income	16.8	77.9
Upper middle-income	24.4	84.4
High-income	32.7	79.9

lowest in South-East Asia and highest in the Americas and Eastern Mediterranean (Table 4). The prevalence of adolescents who were insufficiently active was at least 8 percentage points lower in South-East Asia than it was in all other regions of the world (Table 4). Although there are important geographic, sex and age variations, insufficient PA is highly prevalent in all regions of the world, in males and females and adults and adolescents. PA, or a lack thereof, is truly a global public health issue.

Readers interested in country specific prevalence estimates from the global observatory are referred to the online supplemental file (Supplemental Table 1). The data presented in the supplemental file demonstrate that adult PA prevalence data are available in 75% of countries, or 146 out of 194 WHO member states, and in these countries the estimated prevalence of insufficient activity in 2010 ranged from a low of 3.3% in Nepal to a high of 65.5% in the Cook Islands. Adolescent PA data is available in 62% of countries, or 120 out of 194 WHO member states, and in these countries the estimated prevalence of insufficient PA ranged from a low of 70.5% in India to a high of 94.8% in the Republic of Korea.

Prevalence of not meeting PA recommendations based on objective measures

Self-reported PA measures are subject to recall and social desirability biases and they relate poorly to objective measures obtained by pedometer and accelerometer (Adamo, Prince, Tricco, Connor-Gorber, & Tremblay, 2009; Prince et al., 2008). This has led many PA researchers to question that utility of self-reported PA measures, and for recommendations to use objective measures in all types of PA research, including descriptive studies that aim to assess the prevalence of the population who adhere to PA recommendations.

Table 4. Prevalence of adults and adolescents who were insufficiently active in 2010 according to region of the world.

Region	Adults (aged 18+)	Adolescents (aged 11–17)
Africa	20.9	85.2
Americas	32.4	81.2
South-East Asia	14.7	73.4
Europe	24.5	83.2
Eastern Mediterranean	31.1	87.5
Western Pacific	25.2	85.0

While objective measurement techniques are now commonly used in studies looking at the correlates and health outcomes of PA, they are rarely used in surveillance studies since it is expensive and not pragmatic to collect PA using a pedometer, accelerometer or other objective technique in a thousands of participants sampled from the general population (or school population) across an entire country. Therefore, nationally representative objectively measured PA data are only available in a few countries, and in most of these few instances a systematic and continuous surveillance system is not in place and only selected age groups have been examined. For these reasons, global estimates of PA based on objective measures are not available at present, and this is likely to be the case for the foreseeable future.

Canada is one of the few countries that has a systemic surveillance system for assessing PA using objective measures. Findings from Canada are highlighted in this review as an example; comparable data from other countries, although not discussed, would be just as insightful. Canada's objective PA surveillance system is collected as part of the Canadian Health Measures Survey. This is a repeated nationally representative cross-sectional survey of 3–79-year olds, with repeated ~2-year-long data collection cycles that date back to 2009. Actical accelerometers are used to measure PA over a week long measurement period.

Accelerometer-derived PA findings from the 2013 cycle of the Canadian Health Measures Survey (Colley et al., 2013; Statistics Canada, 2015) can be used to examine and compare PA levels across a wider age range than what is done with the global observatory. When examining the age trends it is important to consider both age-related changes in PA levels and differences in the PA recommendations for different age groups. Within the 2013 Canadian Health Measures Survey only 20% of 3–4-year-old Canadians did not meet PA recommendations and this prevalence jumped to 87% for 5–11-year olds. This dramatic difference reflects not only an age-related decrease in PA, but also a difference in the PA recommendations, which from age 4 to 5 change from 180 min of activity of any intensity to 60 min of moderate to vigorous activity. The change in the prevalence of insufficient activity from 87% within school-aged children aged 5–11 to 95% within adolescents aged 12–17 reflects only reflects the age-related decrease in PA. Conversely, the sudden drop in the prevalence of insufficient activity from 95% within 12–17-year olds to 68% within 18–39-year olds reflects a change in the PA recommendations between ages 17 and 18, and adherence to these very different recommendations (i.e. the MVPA recommendations for adults are far less stringent than for adolescents). Within adults, where the recommendations are consistent at all ages, the expected age-gradient is present with an increase the prevalence who are insufficiently active increasing from 68% within 18–39-year olds to 82% within 40–59-year olds to 88% within 60–79-year olds.

The objectively measured PA prevalence estimates presented in Figure 2 were based on data collected at approximately the same time frame as the 2010 self-reported estimates for PA for Canada that are available in the global repository. According to the repository, 26% of adult Canadians do not meet PA recommendations and are insufficiently active (World Health Organization, 2016). In contrast, the accelerometer-derived PA measures suggest that 86% of adult Canadians are insufficiently active (Statistics Canada, 2015). Thus, there is a more than threefold increase when comparing the prevalence estimates derived from questionnaires and accelerometers! Although not as dramatic as in adults, the adolescent data also illustrate how prevalence estimates were

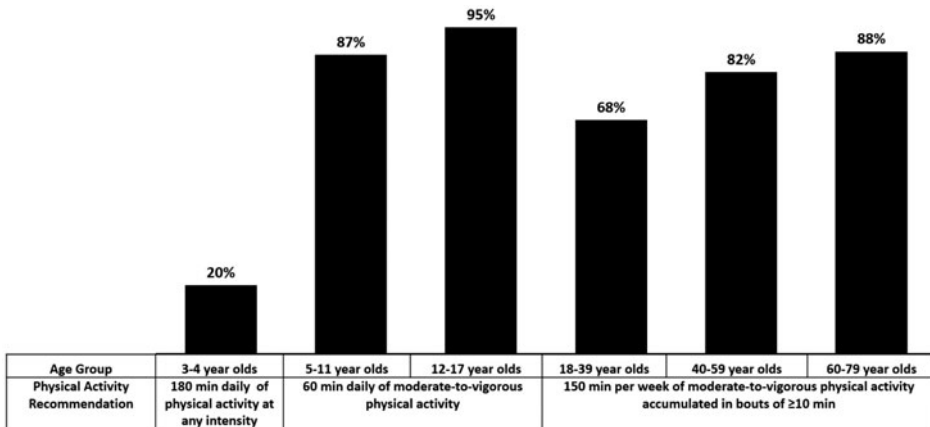


Figure 2. Prevalence of Canadians not meeting physical activity recommendations according to age group. Data are based on accelerometer measures of physical activity obtained in the 2013 Canadian Health Measures Survey.

different depending on the measurement technique, with a 14% point difference between the questionnaire and objective measures (i.e. 77 vs. 91% insufficiently active) (Statistics Canada, 2015; World Health Organization, 2016).

A variety of factors could account for the differences in prevalence estimates based on self-reported and objective measures. As mentioned previously, self-reported measures are subject to recall and social desirability biases that likely lead to an over-estimation of PA (Adamo et al., 2009; Prince et al., 2008). Conversely, pedometers and accelerometers do not fully capture the intensity of activities that are not step based, such as bicycling, and likely underestimate activity levels. Self-reported and objective tools also measure different constructs of PA that while related are not interchangeable (Troiano, McClain, Brychta, & Chen, 2014). Self-reported measures estimate the amount of time spent participating in bouts of PA behaviours, and many of these bouts include a combination of movement intensities and are not limited to continuous moderate to vigorous PA. Accelerometers, on the other hand, measure the time spent at different intensities and capture intermittent activity and not just bouts of activity. To better illustrate these differences, consider the following example of a 60-min basketball game. If recalled correctly, the game would be recorded as 60 min of moderate to vigorous activity on a questionnaire. However, the accelerometer would record far less moderate to vigorous activity as it would record light intensity activity and sedentary behaviour during stoppages in play, the halftime break and while the player is sitting on the bench. The 3-min walk the basketball player makes from the parking lot to the basketball court before the game, and then again after the game, would not be captured by the questionnaire but it would be recorded as moderate intensity activity by the accelerometer. Because of these differences, it is challenging to compare self-reported and objective measures of PA. Furthermore, because the PA recommendations were derived primarily from studies that used self-reported PA measures (World Health Organization, 2010), an argument could be made that objective measures should not be used when determining whether a research participant adheres to PA recommendations.

Correlates and determinants of physical activity

Background

Based on the general low worldwide prevalence of PA that met recommended levels, effective interventions are needed. For effective interventions, research is needed to better understand the reasons, causes and determinants of PA behaviours. Much of the research to date has been descriptive cross-sectional ‘correlates’ research identifying factors associated with being active, but of limited use in identifying causal inferences or even the direction of the association (Bauman, Sallis, Dzewaltowski, & Owen, 2002). More recently, ‘determinants’ research has been proposed, requiring better research methods and measurement, and using longitudinal designs; these provide stronger causal relationships with PA, as they assess the temporal relationship between exposure to the proposed factors and subsequent changes in PA. This section reviews research on correlates and determinants of physical activity.

Previous research on the correlates and determinants of physical activity

The 2012 Lancet PA series updated correlates and determinants research on PA, and used a systematic approach to identify individual, social and environmental correlates. Very few reports emanated from low- and middle-income countries (LMICs), with the exception of Brazil and China (Bauman et al., 2012). This review included new integrative approaches to determinants that encompassed human and evolutionary biology, as well as identifying genetic determinants of PA. Finally, a life-course perspective was proposed, whereby correlates and determinants could be characterised within age groups. These varied by country, as degree of industrialisation and urbanisation result in different patterns of, and changes to, the reasons for engaging or not engaging in occupational, transport and leisure time PA.

Among children, consistent correlates included self-efficacy for activity, previous PA and for adolescents, high levels of perceived behavioural control and social supports to be active. Possible correlates included ethnicity (Caucasian children in North America and Europe were often more active than minority or migrant children), parental activity modelling and parental support for their children participating in activity and sport. Among adults, consistent correlates included good health status, self-efficacy, expected benefits of being active, previous history of being active as an adult, males, younger ages, higher education and social support for activity. Less consistency was noted between PA and marital status, obesity, perceived barriers to activity and personality factors. Among the few longitudinal studies, self-efficacy and intention to be active were determinants of initiating PA, and health status was a consistent determinant of maintaining PA (Bauman et al., 2012).

Environmental correlates were reviewed separately. Among adults, correlates included land use mix and accessibility to recreational facilities; the latter was consistently seen as a determinant as well. Among children, the environmental evidence was mixed, but somewhat consistent correlates included walkability, land use mix, low traffic and access to recreational and park facilities. Although much has been written on the built environment and public transport systems and their relationship to PA, limited longitudinal or intervention evidence exists; there is a need to extend beyond the

plethora of correlational studies in the built environment field (Bauman, 2005; Bauman et al., 2012).

This review was updated in the 2016 Lancet PA series from a global perspective. Most correlates and determinants studies were from high-income or upper middle-income countries, and 94% still used a cross-sectional design (Sallis et al., 2016). Correlates in middle-income countries included lower physical activity among urbanised and more affluent groups, which is the opposite socio-economic distribution to that seen in high-income countries (Sallis et al., 2016).

Recent research on the correlates and determinants of physical activity

The current updated review of research on correlates and determinants studies over the period 2013–2016; studies were examined using the Scopus database, with the search terms comprising (Title = PA OR exercise OR walking) AND (Title = correlate* or determinant*). If constrained to only 'PA (title)', 301 papers were located. This was an annual rate of 75 correlates papers per year, an increase from the 56/year in the 2008–2012 quinquennium and 29/year in the 2003–2007 period. While this does not adjust for the unknown denominator of increases in total publications in all areas, it does confirm an absolute annual increase in publications on the correlates of PA.

In order to summarise this field, the 33 review papers 2013–2016 were considered. Some reviews examined the correlates of PA for people with chronic conditions. From 19 primary studies of multiple sclerosis, Learmonth and Motl (2016) concluded that absence of facilities, mixed health professional advice on activity and low perceived control were associated with low activity levels. A concurrent review (Streber, Peters, & Pfeifer, 2016) identified that multiple sclerosis patients had reduced PA if they had substantial disability, walking limitations and low self-efficacy or a low capacity for self-regulation. PA levels have been studied in people with a variety of mental health problems. Those with alcohol disorders ($n = 5$ papers) showed mixed correlates for inactivity, and no conclusion could be drawn (Vancampfort et al., 2015). People with depression (59 studies) showed lower PA if the depression was more severe, or if they reported lower self-efficacy (Vancampfort et al., 2015). People with binge eating disorders ($n = 9$ studies) showed no consistent correlates of PA (Vancampfort et al., 2014). Those with schizophrenia ($n = 25$ studies) were generally less active if they had more symptomatic disease, cardio-metabolic complications, lower self-efficacy or social isolation (Vancampfort et al., 2012). Finally, those with bipolar disorders ($n = 11$ papers) reported lower PA if they had lower self-efficacy or co-morbidity (Vancampfort et al., 2013).

Other chronic conditions have been systematically explored in relation to activity patterns. Those with rheumatoid arthritis were more active if they were motivated, had higher self-efficacy or if they had a previous history of regular PA (Larkin & Kennedy, 2014); by contrast, these patients were less active if they had more severe arthritis or greater fatigue. People from 29 studies with knee or hip osteoarthritis showed less activity with increasing age, or worsened symptomatic disease, and those with increased body mass index or lower socio-economic status (Stubbs, Hurley, & Smith, 2015). Among cancer survivors, previous exercise history was a correlate, but other personal and psychological factors were inconsistently associated ($n = 18$ studies, (Kampshoff et al., 2014)). People in the community with dementia were less active if they had

reduced social functioning, reduced gait speed, impairments to global motor function, polypharmacy or a history of recent falls ($n = 12$ studies, (Stubbs et al., 2014)). Similar findings for reduced activity were noted among people with diabetes and people with chronic lung disease (Heiss & Petosa, 2014); (Gimeno-Santos et al., 2014). Almost all studies of the correlates of activity among people with chronic disease were limited by most summarised primary studies using a cross sectional design.

Broader population groups were the subject of some systematic reviews of PA correlates. A systematic review of built environment correlates in China (42 studies) showed associations between activity and the built infrastructure, aesthetic factors, park infrastructure and distance to facilities (Day, 2016). Studies of PA among the indigenous Canadian Inuit populations ($n = 45$ studies) showed low access to transport or facilities, low self-efficacy and socio-cultural fragmentation was consistently associated with physical inactivity (Akande, Hendriks, Ruiter, & Kremers, 2015).

Several narrative and systematic reviews of PA correlates and determinants among children and adolescents were published 2013–2016. These included narrative reviews of the settings and conditions in which children can be more active (Loprinzi, Cardinal, Loprinzi, & Lee, 2012). Tonge, Jones, and Okely (2016) examined the correlates of activity among children in early childhood, and observed negative associations for children who were older, female, lacked outdoor facilities and had less well-developed gross motor skills; no associations were seen for educator or organisational characteristics. Studies of children in sub-Saharan Africa ($n = 71$ studies) indicated that lower PA was reported if the children were from more affluent families, were urban residents or were female (Muthuri et al., 2014). Children with physical disabilities were less active if the disability was more severe, if they reported low access to programs, or parental motivation was low for their child to be active (Li et al., 2016). A few studies commented on the methodological limitations in the field, including selection biases in the children studied in correlates research (Lim & Biddle, 2012). Recent reviews of longitudinal papers were sparse. Kelly and Pomp (2013) updated a review on the genetics of PA, but reached similar conclusions on the heritability of PA to the previous review (Bauman et al., 2012). However, one study followed 27,332 twins from ages 7 to age 18 years, using the Netherlands Twin Register (Huppertz, 2016). During the transition from childhood through adolescence, the proportion of variance in physical activity that was explained by genetic factors ('heritability') increased, but the influence of their shared environment on physical activity substantially decreased. These determinants point to the potential use of family-based environmental interventions being most likely to succeed among children, rather than later adolescents.

Interventions to change physical activity

Based on the overwhelming evidence for the health benefits of regular PA, the low prevalence of population participation and the target correlates of behaviour outlined in the current review, there is a need to implement effective interventions. The purpose of this section is to provide a high-level overview of the state of PA interventions. To accomplish this task, we conducted a review of narrative reviews and meta-analyses of PA interventions (see supplemental Figure 4 for review procedures). Effect sizes among the available meta-analyses were averaged to create a high level summary of the point estimates and 95% confidence intervals. For the narrative reviews and moderators of

intervention success, scoring was based on Sallis, Prochaska, and Taylor's (2000) rubric for determining an association. A theme was considered to have a positive association (+) if greater than 59% of studies supported an increase in PA; a negative association (−) if greater than 59% of studies supported a decrease in PA; inconclusive (?) if 34–59% of studies found any association and no association (0) if less than 34% of studies showed any association.

Review characteristics

This high-level review identified 27 meta-analyses and 39 narrative reviews of adult PA interventions and three meta-analyses and 17 narrative reviews for youth PA interventions (see supplemental Tables 2 and 3 for the reviews and supplemental Appendix A for the full reference list). Reviews ranged from three (Engbers, van Poppel, Paw, & van Mechelen, 2005) to 206 (Conn, Hafdahl, & Mehr, 2011) studies within a review. Among adults, specific review topics included broad adult demographics and intervention types (17%), as well as focused participant samples such as type 2 diabetes (2%), cancer survivors (3%), cardiac patients (3%), older adults (3%), college students (2%), chronically ill patients (2%), low socioeconomic status populations (3%), pregnant or post-natal women (3%), obese individuals (3%) and specific ethnic groups (6%). Other reviews were focused on specific theories applied to intervention (9%) or behaviour change techniques such as goal setting and implementation intentions (3%), environmental change (5%), incentives (2%) and peer support (2%). Finally, the remaining reviews were focused on specific modes of intervention delivery such as telephone (6%), Internet (12%), e-/m-health (8%), mass media (3%) and print (2%) and settings such as the workplace (3%).

Among youth, specific review topics included general youth interventions (30%), and participant samples such as girls only (20%), teenagers (5%) or specific ethnic groups (5%). Other reviews were focused on specific behaviour change techniques such as affect (5%) or changes to the built environment (5%). The remaining reviews were focused on specific modes of intervention delivery such as technology (5%) and settings such as schools (25%), childcare centres (5%) and the family home (10%).

Overall effectiveness of current physical activity interventions

Tables 5 and 6 highlight the overall review results for PA interventions among adults and youth, respectively. Among adults, the average of the 27 effect size estimates was $d = .27$ ($SD = .13$) placing it within the small effect size range (Cohen, 1992). Furthermore, the average 95% confidence interval estimates were between .17 ($SD = .12$) and .37 ($SD = 0.15$) showing that intervention effectiveness is most often in the small range. The results were very similar for youth PA ($d = .30$; $SD = .05$), although the limited number of effect sizes ($k = 3$) suggests less confidence in this averaged estimate at present. Perhaps not surprising given this heterogeneity in the findings, narrative reviews most often reported intervention effectiveness as inconclusive (62% for adult interventions; 70% for youth interventions).

Table 5. High-level summary of physical activity intervention reviews among adults 18+ years.

Effect size <i>d</i>	Number of meta-analyses 27	Mean (SD) .27 (0.13)	95% CI Mean (SD) low .17 (0.12)	95% CI Mean (SD) High .37 (0.15)
Overall narrative Review Interpretation			Number of Reviews 39	Result 17% Effective 62% Inconclusive 21% Ineffective
Moderators			Number of reviews	Association
<i>Overall</i>				
Study quality			16	0
Publication bias			10	0
PA measurement (direct vs self-report)			4	0
Intervention duration			12	?
<i>Sample characteristics</i>				
Age			11	0
Sex			9	0
Health status			6	0
Clinical population vs. non			5	0
Weight classification			4	0
Baseline PA status			4	?
<i>Use of theory</i>				
Theory vs. no stated theory			17	0
Comparisons across theories			6	0
<i>Use of behaviour change techniques</i>				
Self-monitoring (general)			15	? (+)
Health information consequences			11	? (+)
Consequences (general)			7	0
Goal setting (general)			16	0
Feedback (general)			10	0
Modelling			8	0
Restructuring the physical environment			7	? (+)
Problem solving/coping planning			13	0
Behavioural contract			3	0
Rewards			4	? (+)
Motivational interviewing			5	0
Stimulus control (prompts/cues)			7	0
Relapse prevention			8	? (+)
Action planning			5	0
Graded tasks			5	0
Information on when and where to perform			4	0
Instruction on performance			7	? (+)
Prompt (generalisation)			3	0
Behavioural practice			6	? (+)

(Continued)

Table 5. (Continued).

Moderators	Number of reviews	Association
Social comparison	9	? (+)
Social support	7	? (+)
Self-talk	5	0
Stress-management	5	0
Time-management	5	0
Prompt intention formation	4	? (+)
Aggregate of behavioural strategies	5	+
Aggregate of cognitive strategies	4	? (-)
Total # of change techniques	6	0
<i>Intervention delivery</i>		
Supervision	6	+
Frequency of contact	9	+
Trained professional	6	0
Tailoring	6	? (+)
Multiple behaviour change	6	? (-)
Reach	3	-
<i>Medium of delivery</i>		
Mass media	6	0
Print	8	0
Physician	6	0
Telephone	11	0
Face-to-face	12	? (+)
Point of decision	5	+
Internet	11	0
Multi-mode	4	0
<i>Intervention setting</i>		
Worksite	4	0
Group	7	0
Community	8	0
Home-based	5	0

Notes: At least three studies were required for a theme and an estimate of strength behaviour. + = positive association (>59% of studies), - = negative association (>59% of studies), ? = indeterminate (34–59% of studies showing an association) and 0 = no association (<34% of studies showing any association). Parentheses beside the ? designation indicate where the minority of studies were also located if relevant.

Furthermore, few reviews attempted to quantify what the magnitude of intervention changes may actually mean in terms of PA and health outcomes. One could expect that the absolute value in PA change is in part influenced by baseline PA of the sample. This was partially supported by two reviews that attempted to convey effect sizes into minutes of PA. Conn et al. (2011) for example, suggested that an effect size $d = .19$ equates to approximately 14.7 min per week change in PA in apparently healthy populations but Chase (2015) suggested that an effect size of $d = .18$ corresponded with 73 min per week of PA in older adults. Thus, the meaningfulness of this small effect size needs to be interpreted with a clear understanding of the distribution of baseline PA within the sample. Both these meta-analyses also showed that control groups had no increase in PA ($d < .02$), highlighting that changes in PA occur from intervention.

Table 6. High-level summary of physical activity intervention reviews among young people under 18 years.

Effect size <i>d</i>	Number of meta-analyses 3	Mean (SD) .30 (.05)	95% CI Mean low (SD) .12 (.01)	95% CI Mean High (SD) .49 (.13)
Overall narrative Review interpretation			Number of reviews 17	Result 12% Effective 70% Inconclusive 18% Ineffective
Moderators			Number of reviews	Association
<i>Overall</i>				
Study quality			6	0
Intervention duration			5	0
<i>Sample characteristics</i>				
Age			4	0
Sex			4	0
Socio-economic status			3	?
<i>Use of Theory</i>				
Theory vs. no stated theory			4	0
<i>Use of behaviour change techniques</i>				
Health information consequences			9	? (–)
Multi-component			8	? (+)
Restructuring the physical environment			8	? (–)
Social support (general)			3	+
<i>Intervention delivery</i>				
Multiple behaviour change			4	–
<i>Intervention setting</i>				
Primary care			3	? (–)
School			11	? (+)
Community			5	0
Home-based			9	? (–)

Note: At least three studies were required for a theme and an estimate of relationship. + = positive association (>59% of studies), - = negative association (>59% of studies), ? = indeterminate (34–59% of studies showing an association) and 0 = no association (<34% of studies showing any association). Parentheses beside the ? designation indicate where the minority of studies were also located if relevant.

Unfortunately, no clear estimates of PA intensity were present in these calculations, given the heterogeneity in methods of assessment, so this is also a limitation to our current understanding of the effectiveness of PA interventions and health outcomes. Taken together, contemporary interventions do show PA changes in the small effect size range but the heterogeneity is considerable and the value of PA change is not well understood. This heterogeneity in PA interventions suggests the presence of moderators. The remaining sections overview whether certain study, participant, intervention, delivery and setting characteristics moderate intervention success.

Study and participant characteristics

Several adult ($n = 16$) and youth ($n = 6$) intervention reviews contained sufficient information to explore whether study quality, scored with a range of instruments for risk of bias assessment, affected the heterogeneity of the PA change findings. In both populations, study quality was not associated with the heterogeneity of findings among the majority of reviews (adults = 81% of reviews; youth = 100% of reviews). This null finding was also present in the adult reviews in more specific study quality details such as the use of direct vs. self-reported PA measurement (4/4 reviews) and publication bias (7/10 reviews). The potential exception was the duration of the intervention. While intervention length did not affect the results of youth interventions (5/5 reviews), the results were mixed in the adult literature with some reviews reporting larger PA changes in shorter durations (2/12 reviews), many showing null findings regardless of duration (7/12 reviews) and some PA changes more likely in higher duration trials (3/12 reviews). Overall, study quality factors do not explain the heterogeneity of intervention success.

Our analysis of sample characteristics also showed generally null findings as moderators of intervention effectiveness across reviews. For example, age (100% of reviews) and sex (adults = 78% of reviews; youth = 75% of reviews) did not account for differences in PA change across interventions. In the adult review literature, this null effect also extended to health status (5/6 reviews) and clinical conditions (5/5 reviews) as well as weight status (4/4 reviews). There were insufficient reviews that examined ethnicity and socioeconomic status to appraise whether these characteristics moderate adult intervention effectiveness and the results were mixed among a small number of youth-based reviews. Interestingly, baseline PA status had mixed evidence in a small number of adult reviews that was dispersed equally among negative, null and positive associations with PA change. This has not been examined sufficiently among youth populations at present. Clearly, ethnicity, socio-economic status and baseline PA profile need more examination, but the results are fairly robust that age and sex are not linked to intervention effectiveness and health/clinical conditions among adults seem equally unrelated.

Explicit use of theory and behaviour change content

Seventeen reviews of adult interventions and four reviews of interventions among young people explored whether the use of theory compared to no reported theory moderated PA change. Among the adult literature, the theories applied most for this evaluation were Bandura's (1998) social cognitive theory (88% of reviews) and Prochaska and DiClemente's (1982) Transtheoretical Model (82% of reviews), followed by Ajzen's (1991) theory of planned behaviour (29% of reviews). No difference in the application of theory on PA outcomes was reported in 76% of reviews, while 18% of the reviews drew the conclusion that the presence of a stated theory was associated with more successful interventions. Among young people, the theoretical applications all involved variants of social cognitive theory and 75% of reviews concluded no difference between use of a reported theory or no such reporting. One review showed that interventions not reporting a theory resulted in greater PA than those based on an explicit theory. Overall, the evidence suggests that explicit use of theory does not moderate the effectiveness of interventions among youth or adults, yet the use of theory thus far is limited to the social cognitive tradition.

Among adults, six reviews also explored whether certain theoretical approaches were superior to others. Similar to the tests of theory vs. no stated theory, these comparisons were generally limited to the transtheoretical model (100%), social cognitive theory (100%) and theory of planned behaviour (67%), but more recent comparisons also included protection motivation theory (Rogers, 1983) (50%) and self-determination theory (Deci & Ryan, 1985) (50%). Four of these six reviews found no evidence that any particular theory could explain the differences in intervention effectiveness compared to any other theory, while two studies highlighted that social cognitive theory resulted in greater PA change than the transtheoretical model. Overall, the results support relatively negligible differences in effectiveness among theories.

While theories may help represent the mechanisms for behaviour change, these are thought to still require behaviour change techniques or strategies in order to impart change (Michie et al., 2013). To this end, 16 adult reviews and nine youth reviews engaged in behaviour change content coding to examine whether certain behaviour change techniques were associated with intervention effectiveness. Among the youth reviews, the coding of intervention strategies varied by each study but most often was divided by health education, environmental change, social support and multi-component designations. Of these, social support (2/3 reviews) and the multi-component approach (3/8 reviews) had the most support as a behaviour change strategy, while environmental change (3/8 reviews) and health education had evidence for their ineffectiveness (4/9 reviews).

Eight of the adult reviews used the CALO-RE (Michie et al., 2011) taxonomy or a variant while the remaining reviews used study created coding schemes to separate behaviour change strategies. This allowed us to code and report on 25 possible behaviour change strategies as well as three forms of aggregates: total number of behaviour change techniques, aggregate of behavioural techniques and aggregate of cognitive techniques. Overall, no specific technique emerged as conclusively linked to intervention success. Nevertheless, self-monitoring (5/15 reviews), information about health consequences (4/11 reviews), restructuring the physical environment (2/7 reviews), rewards (1/3 reviews), relapse prevention (3/8 reviews), instruction on performance (3/7 reviews), behavioural practice (3/7 reviews), social comparison (3/8 reviews), social support (3/7 reviews) and prompting intention formation (2/4 reviews) had some evidence as moderators of positive PA change. Further, the aggregate of behavioural strategies did emerge as a moderator of PA change in four of the five reviews to use this form of coding. This moderating effect was also found in two of two reviews that examined co-occurrence clusters of selected behavioural techniques (Greaves et al., 2011; Michie, Abraham, Whittington, McAteer, & Gupta, 2009). Taken together, both the adult and youth intervention literatures do not have clear indicators of any single behaviour change technique/strategy that can account for the heterogeneity among interventions. There is better evidence that a multi-strategy approach results in better PA outcomes than singular change approaches. For adults, this appears to be a cluster of behavioural techniques (e.g. goal setting, feedback on performance, self-monitoring), while a socio-ecological focus (education, social support, environmental restructuring) is presently the most successful approach for youth.

Intervention modes of delivery and setting characteristics

Twelve reviews among adults and four reviews among youth coded for selected intervention delivery aspects as a moderator of success. Among adults, supervised (4/6 reviews) and higher frequency of intervention contact exposure (6/9 reviews) were both associated with greater intervention success. By contrast, three of three reviews on the topic highlighted the limited reach of interventions and 50% of reviews (3/6) showed that targeting multiple health behaviours resulted in less intervention success than interventions targeting PA exclusively. This finding was also supported in all four of the reviews for youth interventions.

While the reviews on youth interventions did not focus on modes of delivery consistently enough to estimate whether they moderate intervention success, the adult literature showed that point of decision prompts effectively increased PA in the majority of reviews (3/5 reviews). Most delivery modes, such as telephone, Internet, print and physician recommendation were equivocal in terms of intervention effectiveness with the majority (60%+) of reviews showing no moderation. By contrast, face-to-face had some support (5 of 12 reviews) as engendering PA change more than other modes of intervention.

Finally, eight reviews in the adult literature and 11 reviews in the youth literature examined settings as potential moderators of intervention effectiveness. Among the youth literature, there were no settings that showed conclusive evidence as a superior avenue for PA change success. Schools did show positive findings over other settings in four of 11 reviews; by contrast, primary care (2 mixed, 1 less effective) and family home (3 null, 3 mixed, 3 less effective) settings had a minority of reviews that concluded these were inferior settings for intervention success over other locales. The general mixed or null findings were similar in the adult intervention literature. Worksite (3/4 reviews), group (5/7 reviews), community (5/8 reviews) and home-based (3/5 reviews) settings generally showed no effect on intervention success compared with other settings.

Conclusions

The purpose of this paper was to provide a broad overview of the state of PA research in the form of (1) definitions of physical activity, (2) health impact of PA participation, (3) PA prevalence and surveillance, (4) PA correlates and (5) contemporary PA interventions. The focus of this overview relied on reviews of the literature in these content areas as well as key studies that have advanced PA research.

Our overview of the health benefits of PA showed clear evidence that virtually everyone can benefit from being more physically active (Warburton & Bredin, 2016). Regular PA is an effective primary and secondary preventative strategy against at least 25 chronic medical conditions (Warburton et al., 2006a, 2006b, 2007, 2010). Further, small changes in PA (e.g. less than half of the current 150-min MVPA recommendation) can lead to marked and clinically relevant changes in health status (particularly in inactive and/or clinical populations).

In a critical analysis of the literature, several key future directions for research into PA and health emerge. For example, further research is required to determine the change in PA associated with minimally clinically relevant changes in health status/risk

for diverse chronic conditions and premature mortality. Continued research in this area will help to develop more accurate PA recommendations and prescriptions for diverse populations. Indeed, further research that examines the utility of generic PA guidelines vs. the need for an individualised holistic approach to lifestyle behaviour modification will be helpful.

Further research is also required to determine if there are elevated risks for chronic conditions (such as atrial fibrillation) and sudden death in individuals that engage in extreme volumes of PA/exercise with little time for recovery. Finally, continued basic research that examines and narrows our understanding of the mechanisms of PA on health outcomes will be most helpful.

Given this compelling evidence for the health benefits of PA, surveillance of PA is a priority in order to understand whether there is a need for promotion efforts and potentially underserved populations who are at risk due to low PA participation. Our review showed that the vast majority of PA prevalence data is based on self-reported data, yet information is available for 90% of countries, suggesting we have an impressive reach in beginning to understand PA participation across the globe. At present, approximately one in four adults were not active enough to meet the global PA recommendations. Still, men were more active than women and older adults were far less active than adults, suggesting that targeted promotion programs should consider these vulnerable populations. Most distressing, 81% of school-aged adolescents aged 11–17, did not accumulate at least 60 min of moderate to vigorous intensity PA on a daily basis and girls were more likely to be insufficiently active than were boys. This suggests that adolescents are missing out on several health benefits, and also that the preventive aspects of PA across the life span may be problematic in the future – although the different PA guidelines between adults and youth make this difference less clear.

Additional research is also needed in the youngest age groups of the population. While there is a global repository of descriptive PA data for adults and adolescents, this is not the case for school aged children (5–11-year olds) and children of the early years (0–4-year olds). PA has health benefits for people of all ages, and at the global level there is much to learn about the PA levels of children.

Given the health benefits of PA and its generally low prevalence of participation, the next section of our paper was a broad overview of the correlates and determinants literature, aimed primarily to inform interventions. The field of PA correlates research continues to increase, but still focuses predominantly on studies using cross-sectional designs (Bauman et al., 2012; Trost, Owen, Bauman, Sallis, & Brown, 2002). These studies of statistical association provide limited understanding of the actual determinants or causes of behaviour, and better methods and longitudinal designs are repeatedly sought to inform programme theory or development.

The field has focused on using the socio-ecologic model, a broad model that encompasses multiple levels of influence on behaviour from policy and the built environment to individual decision-making, and these multiple levels of influence are now widely recognised. Many correlates remain as fixed socio-demographic factors, such as age, gender and socioeconomic factors, but these are mostly well established. Among intrapersonal factors, motivation, self-efficacy (and occasionally self-regulation) remain consistent correlates of PA behaviour. Progress has been made with more research from low-middle-income countries (Sallis et al., 2016), and more research is reported on

macro-level components of the socio-ecologic model, including global, societal-level and policy influences (Bauman et al., 2012).

Our high-level review of PA interventions yielded a summary of the state of behaviour change and highlighted several areas for future research. Overall, contemporary interventions do show PA changes in the small effect size range for adults and youth but the heterogeneity is considerable across studies and the absolute magnitude of PA change is not well understood. This heterogeneity explains why the majority of narrative reviews conclude by indicating that the effectiveness of interventions is 'inconclusive'. While standardised effect size estimates do show we can shift PA 1/3 of a standard deviation, this is still not well-understood in terms of absolute volume of physical activity change. Given that we have recommended metrics for PA (World Health Organization, 2012) as well as units that are fairly well established and easy to understand (e.g. METs, min MVPA) we suggest that future research reporting should implement these to improve our understanding of PA interventions.

Clearly, the heterogeneity in PA interventions suggests the possible presence of moderators. Our review of the potential moderators of PA proved extremely interesting by showing how few reliable moderators emerge when trying to understand intervention success or failure. In terms of general study characteristics, it was interesting to note that study quality does not affect the overall results of the findings. Thus, while improving our certainty that the intervention does influence behaviour change is essential to the scientific process, it has not contributed to explanations for the success of interventions thus far. Similar to the general null findings of study characteristics, sample characteristics of age, sex, clinical status and health status had a negligible effect on intervention outcomes. These null findings have also been identified in the correlates literature, where sample characteristics do not moderate the relationship between individual and inter-personal factors and PA (Rhodes & Blanchard, 2007; Rhodes, Blanchard, & Blacklock, 2008). On the positive side, this supports the robustness of our interventions across many different sub-populations. Still, PA research has engaged in a lot of sub-population research under the auspices of 'uniqueness' of PA-related determinants and intervention. Our findings would suggest there is limited evidence to support this rationale. Future research should be designed to examine whether sub-population uniqueness in PA is effective so we do not continue to proliferate research around factors that do not affect intervention success.

Our findings on the utility of theory and behaviour change techniques were also interesting. Massive effort and attention in health psychology has been spent on the importance of theory and yet these results suggested that theory-based interventions were no more effective than interventions without a stated theory; further, theories had little difference in their effectiveness when compared among each other. The finding has several possible explanations. For example, the fidelity of theory implementation is likely more important than merely stating the use of a theory and this varies in interventions (Prestwich et al., 2014). Also, interventions that state no theory may use many of the same change techniques and target similar mechanisms to interventions that state theory. Finally, our study of theory has been heavily based in the social-cognitive tradition, with theories that typically contain similar constructs with different names (Bandura, 1998; Fishbein et al., 2001). Thus, differences may be just an exercise in semantics. Still, future research should be designed to examine whether theory in PA is

effective with as much clarity around the similarities and differences in the constructs applied as possible.

Similarly, our content analysis of behaviour change strategies /techniques yielded equally ambiguous and often null findings when explaining intervention success. The creation of a taxonomy (Michie et al., 2011, 2013) has been a massive advancement in cataloguing and defining intervention techniques. This approach has had only a single application among youth (Hynynen et al., 2016), but several reviews are now present to gauge the efficacy of various techniques among adults. Our review found that no specific technique was a reliable marker of PA change. Instead, clusters of certain behavioural (more than cognitive) techniques were moderators of intervention success for adults while a multi-component (education, social support, environmental change) approach was most successful for youth. The review also highlighted that our knowledge of PA change techniques has tended to focus on social-cognitive and cognitive-behavioural approaches. For example, almost no interventions have focused on habit, learned associations or identity development so future research should explore these and other techniques in the taxonomy where we have very limited information on their utility.

The findings from our review of implementation characteristics complement our null results identified in theory and behaviour change techniques. Overall, most modes and settings for implementing the intervention were no more effective than others. Instead, we found the most support for supervision and high intensity contact time, which suggests that minimal contact ‘do it yourself’ approaches to PA change were less effective. Unfortunately, this has cost and other human and structural resource implications. Future research should continue to focus on cost effective ways to implement interventions while maintaining as much supervision and contact as possible.

Our review also highlighted some areas that should become a primary focus of PA intervention research. For example, sustained PA is the sought after goal for lifelong health and current trials capture short-term successes more than long-term intervention. Years of study are needed, which requires partnerships, massive effort and time. To really make a difference (or learn whether we can make a difference) the research structure of interventions will likely need to change to a style similar to longitudinal cohort trials (Guangwei Li et al., 2008). Another area that has seen low attention is the inclusion of sub-samples with low socioeconomic characteristics and diverse ethnicity. Indeed, the low reach of PA interventions was a consistent theme in our review (Antikainen & Ellis, 2011) and this extended to distance-based modes such as web-based interventions (Kohl, Crutzen, & de Vries, 2013). Thus, our main knowledge of PA intervention likely comes from motivated volunteers who have made the decision to change their lives and actively seek consultation. While all population groups are important, this is a very small proportion of people (Cavill & Bauman, 2004). The challenge for future research will be to reach beyond this small group of more easily accessible people in order to explore whether we can make PA changes to less motivated, more diverse and vulnerable populations.

In summary, there is clear evidence that almost everyone can benefit from being physically active. Regular PA is an effective primary and secondary preventative strategy against at least 25 chronic medical conditions with risk reduction typically in the 20–30% range. While approximately 75% of adults meet recommended PA guidelines, the prevalence is slightly lower for women compared to men, and considerably lower

for older adults and higher income countries. Further, over 75% of youth worldwide are not meeting PA recommendations. The field of PA correlates and determinants research continues to increase, but still focuses predominantly on studies using cross-sectional designs. Individual-level correlates of motivation, self-efficacy and self-regulation remain consistent correlates of PA. Contemporary interventions show PA changes in the small effect size range for adults and youth ($<1/3$ of SD) but the heterogeneity is considerable across studies. Despite this heterogeneity, only a few (i.e. total # of behavioural strategies, supervision and high frequency of contact) reliable moderators of intervention success were identified across study quality, sample characteristics, theory and behaviour change techniques and delivery modes and settings. Future research in PA should continue to examine the mechanisms causing health outcomes, the dose that can lead to clinically relevant health status, the scope and validity of PA surveillance, longitudinal studies on the predictors of PA change and innovative and novel behaviour change techniques, while improving the reach and duration of PA interventions.

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All Authors report no conflict of interest for the paper.

Supplemental data

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