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Physical activity, sedentary time and adiposity during the first two decades of life

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High amounts of time spent sedentary and low levels of physical activity have been implicated in the process of excessive adiposity gains in youth. The aim of this review is to discuss the role of physical activity, sedentary time and behaviour (i.e. television (TV)-viewing) in relation to adiposity during the first two decades of life with a specific focus on whether the association between sedentary time, and behaviour and adiposity is independent of physical activity. We identified nine cohort studies (three prospective) whether sedentary time was associated with adiposity independent of physical activity. Eight of these studies suggested that sedentary time was unrelated to adiposity when physical activity was taken into account. Results from studies (*n* 8) examining the independent association between TV-viewing and adiposity independent of physical activity were mixed. Those that observed a positive association between TV-viewing and adiposity independent of physical activity discussed that the association may be due to residual confounding. A few additional studies have also challenged the general notion that low levels of physical activity leads to fatness and suggested that higher baseline fatness may be predictive of a decline in physical activity. It appears unlikely that higher levels of sedentary time are associated with or predictive of, higher levels of adiposity when physical activity is controlled for in youth. Specific sedentary behaviours such as TV-viewing may be associated with adiposity independent of physical activity but the results may be explained by residual confounding.

Adolescents: Children: Obesity: Physical activity: Sedentary behaviour

Global data suggest that overweight and obesity affects almost every nation and every age group in the world with an almost doubling of obesity rates during the last 20 years[1]. The obesity epidemic also affects infants, children and adolescents. Despite some recent reports suggesting a levelling off of the prevalence of overweight and obesity in young people[2,3], childhood obesity rates have reached alarming proportions even in developing countries[4]. Obesity is multifactorial including genetic, pre- and post-natal factors, physiological, cultural, environmental, lifestyle and socio-economic factors, possibly acting differentially on the development of unhealthy weight gain and obesity throughout the life course. The main contributor to the recent obesity epidemic is most likely an imbalance between energy intake and energy expenditure. Physical activity is the most variable component of total energy expenditure and recent reports suggest that approximately 30–40 % of young people are physically active according to public health recommendations when assessed by self-report[5,6]. However, studies using direct measures of physical activity by accelerometry are extremely divergent with prevalence values for sufficiently active young people varying between 1 and 100 % depending on the definition of moderate- and vigorous-intensity physical activity[5]. While it is likely that physical activity levels

Abbreviations: MVPA, moderate-to-vigorous physical activity; TV, television; VPA, vigorous physical activity.
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have declined (and sedentary time increased) over time in young people, trend data on sufficiently active young people are scarce[5,6]. Furthermore, ecological observations can only be used to generate hypotheses about associations between physical activity, sedentary time and adiposity.

This review aims to discuss the role of physical activity and sedentary behaviours in relation to adiposity during the first two decades of life. The review is restricted to observational studies in which physical activity and sedentary time have been measured objectively or studies that have measured physical activity objectively and television (TV)-viewing by self-report. First, we will discuss whether physical activity may mediate or moderate associations between birth weight and early life growth and later levels of adiposity and related health outcomes; we will thereafter summarise the literature if physical activity predicts gain in adiposity in young people; the independent associations between objectively measured sedentary time, physical activity and adiposity; whether sedentary behaviour (usually assessed by time spent viewing TV) is associated with adiposity independent of objectively measured physical activity and finally; whether the association between physical activity and excessive gains in adiposity may be bi-directional or reverse.

Does physical activity mediate or moderate the association between early life factors and later adiposity?

According to the developmental origins of adult disease hypothesis, exposures to unfavourable environmental conditions during development *in utero* or during the early post-natal period programme physiological and metabolic changes that increase the risk of developing diseases later in life[7]. There is now a large body of evidence from cohort studies suggesting that low birth weight, or thinness, at birth is associated with increased risk of hypertension, diabetes, CVD and all-cause mortality in adulthood[8–11]. Furthermore, low birth weight appears to be associated with higher percentage body fat[12] and central adiposity in childhood[13], which is coherent with studies in adults showing a higher metabolic risk associated with low birth weight. Similarly, high birth weight appears to increase the risk of obesity and some cancers[14,15]. However, the associations are complex such as a positive association between birth weight and body weight (or BMI) may reflect an association between both greater fat mass and fat-free mass. Some data using more detailed measures of body composition indicate that birth weight may be more strongly associated with fat-free mass than fat mass[16].

Rapid weight gain in infancy and in early childhood has also been consistently associated with increased risk of overweight and obesity later in childhood. A recent meta-analysis suggested that each +1 unit increase in weight SD scores between birth and 1 year conferred a twofold risk of childhood obesity and a 23 % increased risk of adult obesity independent of sex, age and birth weight[17]. Interestingly, rapid weight gain between ages 3 and 6 years appears also independently associated with increased fat mass and central adiposity in late adolescence and young adulthood[18] suggesting that both infancy and childhood rapid weight gain is an independent risk factor for later obesity. The question then arises whether physical activity can act as a potential mediator or moderator of the association between early growth and later body composition?

It has been hypothesised that physical activity may be on the causal pathway between early life factors and later obesity[19]. It has also been hypothesised that higher levels of physical activity may be beneficial in attenuating the associations between low birth weight and adult metabolic risk including adiposity[20]. Using data from the European Youth Heart Study, Ridgway *et al.*[21] observed that higher birth weight was independently associated with higher fat mass index (kg/m^2) and greater waist circumference in 9- and 15-year-old children, whereas low birth weight was associated with insulin resistance. However, the latter association was only observed following additional adjustment for current abdominal adiposity (i.e. waist circumference). Interestingly, there was no evidence that objectively measured physical activity or aerobic fitness markedly attenuated or modified the associations between birth weight and later adiposity or insulin resistance[21]. In contrast, others have suggested that physical activity modified the association between birth weight and insulin resistance in young people[22]. Apparently, this modifying effect was observed following adjustment for current BMI. Interpreting associations or effect modifications for the association between birth weight and health outcomes later in life which are significant only after adjustment for current levels of body size (e.g. BMI) may suggest that the association is due to change in size (e.g. weight centile crossing) between the time points rather than early programming[23]. Taken together, future studies are needed to examine the potential mediating or modifying effects of physical activity on the relationship between birth weight, infant and childhood rapid weight gain and later adiposity and impaired metabolic health.

Does physical activity predict gain in adiposity?

The development of small, light-weight movement sensors aimed at measuring heart rate, body acceleration or a combination of both during the last 10–20 years have markedly enhanced our understanding about habitual physical activity and its association with health outcomes in young people[24]. Data from studies using objective measures of physical activity have provided compelling evidence of a strong inverse cross-sectional association between physical activity and body weight, fat mass and obesity in children and young people[25,26]. However, observational studies in young people examining the prospective association between objectively measured physical activity or physical activity energy expenditure and gain in adiposity are ambiguous[27,28]. Wilks *et al.*[27] summarised results from ten prospective observational studies and four trials in which physical activity or physical activity energy expenditure were measured at baseline in children and adolescents by accelerometry and doubly labelled water, respectively, and change in percentage body fat was the extracted outcome. Six (60 %) of the observational studies reported no association between baseline physical activity and change in body fat, one study reported a weak positive association and three studies a weak negative association. Negative associations were more frequently observed in those studies that analysed the association between the change in exposure and outcome. Intervention studies showed generally no effect on body fat and the authors concluded that despite the consistently established health effects of physical activity in young people, it may not be a key determinant of excessive gain in adiposity. This was contrasted by the results from one of the largest prospective studies so far using data from the Avon Longitudinal Study of Parents and Children (ALSPAC). This study followed 4150 children for 2 years between ages 12 and 14 years. Using a multilevel modelling approach an increase of 15 min moderate-to-vigorous physical activity (MVPA) per day at age 12 years was associated with approximately 1 kg (10–12 %) lower total fat mass at age 14 years[28]. Given the fairly low levels of time spent in MVPA in these young people (median 20 min/d), a substantial increase in MVPA of about 75 % is needed for lowering fat mass by about 1 kg over 2 years. The inverse association between baseline time in MVPA and gain in adiposity, suggesting that higher levels of MVPA are associated with lower gains in adiposity, was also observed in two recent studies[29,30] that simultaneously adjusted their analyses for time spent sedentary. Fisher *et al.*[29] examined the prospective associations between MVPA and total physical activity with adiposity in 8–10-year-old UK children during a 1-year period and concluded that baseline MVPA was significantly associated with BMI and fat mass index at follow-up independent of sedentary time. No data were reported on whether sedentary time was associated with adiposity independent of MVPA in that study. Similarly, Mitchell *et al.* [30] used quantile regression analysis to examine the longitudinal associations between time in MVPA and BMI across percentiles of BMI. They observed that MVPA was inversely and independently associated with BMI and that the magnitude of association was greater at higher BMI percentiles. Data from the same cohort also concluded that sedentary time was associated with BMI independent of time spent in MVPA[31] (see later).

Sedentary time, physical activity and adiposity: independent associations?

More recently, sedentary behaviour and sedentary time has emerged as a risk factor for overweight, obesity and other health outcomes. However, relatively few studies have examined the associations between sedentary time and sedentary behaviour (i.e. TV-viewing) with markers of adiposity with mutual adjustment for objectively measured physical activity. Adjusting sedentary time for total physical activity time is statistically impossible as these two variables are by definition perfectly inversely correlated. Therefore, most of the studies have adjusted their analyses for sub-components of physical activity such as time spent in MVPA or vigorous physical activity (VPA). Although these sub-components are inversely associated with sedentary time their correlation with sedentary time is usually weaker than between sedentary time and light-intensity physical activity and rarely introduces issues of multicollinearity.

Table 1 summarises observational studies that have examined the independent associations between sedentary time, physical activity and obesity indicators in children and adolescents aged 3–18 years. All studies reviewed have adjusted the association between sedentary time and obesity for time spent in moderate- and vigorous-intensity physical activity; most of the studies also examined the association between MVPA and obesity indicators following adjustment for sedentary time.

Six[32–37] cross-sectional studies were identified including between 398 and 20 871 participants. All studies assessed physical activity by accelerometry and outcome measures were BMI, BMI *z*-score, waist circumference and body composition (e.g. fat mass index and trunk fat mass index) measured by either bioimpedance or dual-energyX-ray absorptiometry. All studies consistently showed significant inverse associations between objectively measured time spent in MVPA with various measures of adiposity independent of time spent sedentary. Keeping in mind that different studies used different accelerometer intensity thresholds for defining MVPA, the magnitude of associations appeared stronger for more vigorous-intensity physical activity compared with moderate levels of activity. For example, Collings *et al.*[33] showed that VPA was strongly inversely associated with all adiposity outcomes independent of age, sex, birth weight, maternal education, maternal BMI, smoking during pregnancy, sleep duration and sedentary time in 4-year-old UK children. Furthermore, the association between MVPA and adiposity was explained by the vigorous intensity component of MVPA rather than moderate intensity activity. In a large UK study in 12-year-old children (the Avon Longitudinal Study of Parents and Children, *n* 5434) it was shown that for each 15 min MVPA the odds of obesity (defined as the top 10 % of fat mass) was 46 % lower, independent of sedentary time and confounders[34]. Consistently, most of the studies reported a positive association between sedentary time and adiposity outcomes. However, these associations were completely attenuated following adjustment for time spent in moderate- or vigorous-intensity physical activity, suggesting that sedentary time is unrelated to adiposity when physical activity is taken into account in cross-sectional analyses.

Two[38,39] prospective cohort studies confirmed the results from the cross-sectional studies summarised earlier. Basterfield *et al.*[38] followed 403 UK children aged 7 years at baseline for 2 years and concluded that a decline in MVPA was associated with a greater increase

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Table 1. Summary of observational studies examining the associations between objectively measured sedentary time, physical activity and obesity indicators in healthy children and youth. All studies have adjusted time spent sedentary for time spent in moderate- and vigorous-intensity physical activity

Reference	Study population	Study design/data analysis	Exposure assessment	Outcome	Summary of results	Confounding
Cross-sectional studies						
Steele *et al.*[32]	UK boys and girls, 9–10 years (*n* 1862) **s**port, PA and eating behaviour: environmental determinants in young people (SPEEDY study)	Linear regression analysis	Total PA, time in LPA, MPA, VPA, MVPA, SED by accelerometry and screen-time by self-report	WC, BMI and FMI by bioimpedance	SED unrelated to obesity following adjustment for MVPA Screen-time unrelated to obesity Total PA, MPA, VPA and MVPA significantly and inversely associated with all outcomes independent of SED; magnitude of association greatest for VPA	Age, sex, SES, birth weight, maternal BMI and sleep duration
Mitchell *et al.*[34]	UK boys and girls, 12 years (*n* 5434) Avon Longitudinal Study of Parents and Children	Logistic regression	Time in SED and MVPA by accelerometry	Odds of obesity (top 10 % of FM adjusted for age, height and height^2) assessed by DXA	SED unrelated to obesity following adjustment for MVPA Each 15 min/d spent in MVPA significantly decreased the OR for obesity (0·54)	Maternal obesity, birth weight, gestation, maternal smoking, maternal education, social class, sleep pattern, TV-viewing, pubertal status
Ekelund *et al.*[35]	Boys and girls from Australia, Brazil, Europe and USA, 4–18 years (*n* 20,871) International Children's Accelerometer Database	Linear regression analysis and meta-analysis	Total PA, Time in MVPA and SED by accelerometry	WC	No association between SED and WC independent of MVPA MVPA associated with WC independent of SED; Mean differences in WC between the bottom and top tertiles of MVPA were 5·6 cm (95 % CI, 4·8–6·4 cm) for high sedentary time and 3·6 cm (95 % CI, 2·8–4·3 cm) for low sedentary time	Sex, age and monitor wear time
Collings *et al.*[33]	UK boys and girls, 4 years (*n* 398) Southampton Women's Survey	Repeated measures linear regression	Time in LPA, MPA, VPA, MVPA, SED by accelerometry	Body composition (FFM, body fat (%), FMI) and trunk FMI by DXA	SED unrelated to adiposity VPA strongly and inversely associated with all adiposity outcomes independent of SED and confounders	Age, sex, birth weight, maternal education and maternal BMI, smoking during pregnancy and sleep duration
Byun *et al.*[36]	US boys and girls, 3–5 years (*n* 263+165) CHAMPS and EDPAPC	Mixed linear regression	Time spent in SED and MVPA by accelerometry	BMI *z*-score	No association between SED and BMI after adjustment for MVPA No results reported for the association between MVPA and BMI	Age, gender, race, parental education and preschools
Chaput *et al.*[37]	Canadian boys and girls, 8–10 years (*N* 550) QUebec Adiposity and Lifestyle InvesTigation in Youth (QUALITY)	Multilevel linear regression analysis	Total PA, Time in MVPA and SED by accelerometry	Body fat (%) by DXA and waist : height ratio	SED unrelated to adiposity outcomes independent of MVPA MVPA inversely associated with adiposity outcomes independent of SED and covariates	Age, sex, sleep duration, energy intake, sexual maturation, parental SES and parental BMI

Prospective studies						
Basterfield *et al.*[38]	UK boys and girls, age 7 years at baseline (*n* 403)	Prospective cohort study (2006/07 to 2008/09)	Change (follow-up minus baseline) in total PA, time in SED and MVPA	Change (follow-up minus baseline) FMI by bioimpedance and change in BMI	Increased SED not associated with increase in FMI and BMI following adjustment for MVPA	Baseline measure of exposure (FMI and BMI), sex and SES
	Gateshead Millennium Study	Linear regression analysis; change *v.* change in exposure and outcome			Decline in MVPA associated with greater increase in FMI and BMI in boys but not girls	
Kwon *et al.*[39]	US boys and girls, age 8 years at baseline (*n* 554)	Prospective cohort study (2000–2009), multilevel modelling	Time in SED and MVPA, and frequency of breaks in SED by accelerometry	FM by DXA	SED not associated with FM	Age, height and physical maturity
	Iowa Bone Developmental Study				MVPA significantly and inversely associated with FM	
Mitchell *et al.*[31]	US boys and girls, age 9 years at baseline (*n* 789)	Prospective cohort study (2000–2006), longitudinal quantile regression	Time in SED and MVPA by accelerometry	BMI	SED associated with greater increase in BMI at the 90th, 75th and 50th percentiles independent of MVPA	gender, race, maternal education, hours of sleep and healthy eating index, MVPA
	National Institute of Child Health and Human Development Study of Early Child Care and Youth Development					

DXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; FM, fat mass; FMI, fat mass index; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; MVPA, moderate and vigorous intensity physical activity; PA, physical activity; SES, socio-economic status; SED, sedentary; TV, television; VPA, vigorous intensity physical activity; WC, waist circumference; SPEEDY, Sport, Physical activity and Eating Behaviour: Environmental Determinants in Young People; CHAMPS, The Children's Activity and Movement in Preschool Study; EDPAPC, the Environmental Determinants of Physical Activity in Preschool Children.

in adiposity whereas an increase in sedentary time was unrelated to an increase in adiposity. The associations were markedly stronger in boys compared with girls. This study examined change in the exposure (e.g. MVPA) with change in the outcome (e.g. fat mass index) which could be regarded as a cross-sectional analysis despite the prospective study design. Kwon *et al.*[39] examined the associations between MVPA, sedentary and body fat mass measured by dual-energy X-ray absorptiometry in up to 554 US children over a 9-year period using a multilevel modelling approach. In these analyses, MVPA was strongly inversely associated with fat mass independent of sedentary time whereas sedentary time was not associated with fat mass in mutually adjusted models.

Conversely, a recent study in US children (*n* 789) aged 9 years at baseline followed for 6 years used quantile regression analysis to examine whether the association between sedentary time and BMI differed by BMI percentile[31]. The results showed that baseline sedentary time was associated with greater increase in BMI at the 90th, 75th and 50th percentiles with greater magnitude of associations for higher BMI percentiles. These results were independent of time spent in MVPA and suggest that sedentary time may be differently associated with BMI across BMI percentiles. As previously mentioned, Mitchell *et al.*, using the same dataset and the same analytical approach, showed that baseline time spent in MVPA was negatively associated with gain in BMI between ages 9 and 15 years independent of sedentary time and that the associations were greater in magnitude at the upper tail of the BMI distribution[30]. The results from these two studies in combination therefore suggest that both sedentary time and MVPA is prospectively associated with BMI when mutually adjusted.

The available data are limited to a few developed countries (i.e. UK and USA) and additional data from developing countries would be useful to further understand the importance of various intensities of physical activity in prevention of unhealthy body fat in young people globally. Despite this, the evidence from cross-sectional analyses is consistent in that time spent in MVPA is associated with adiposity independent of sedentary time. Although there is conflicting evidence from prospective studies whether time in MVPA is a predictor of gain in adiposity[27–30], with a few exceptions[31] it appears that time spent sedentary is unrelated to gain in adiposity when time spent in MVPA is taken into account[38,39]. Taken together, the evidence that higher levels of physical activity prevent unhealthy weight gain in young people is conflicting and therefore well-conducted large-scale cohort studies including repeated measures of precisely measured physical activity, adiposity and potentially confounding factors are warranted to fully understand the amount and intensity of physical activity needed to prevent excessive levels of body fat in young people. Meanwhile, it appears that the magnitude of association between physical activity and adiposity is greater for more vigorous intensity activity. This may then suggest that more vigorous intensity activity should be promoted in relation to adiposity in young people.

Television-viewing, physical activity and adiposity: independent associations?

The apparent lack of evidence for an association between objectively measured sedentary time and adiposity indicators following adjustment for time spent in MVPA then raises the question whether specific sedentary behaviours rather than the total time spent sedentary are related to body fat in young people? In large-scale cohort studies, self-reported time spent watching TV is usually used as a proxy marker of sedentary behaviour. Recent reviews[40–42] have concluded that TV-viewing is significantly associated with obesity and body fat, although one of these reported that this association was not likely to be clinically relevant[40]. However, few of the studies included in these reviews adjusted their analyses for objectively measured physical activity.

Table 2 summarises studies that have examined associations between TV-viewing with adiposity in young people and statistically adjusted their analyses for objectively measured physical activity. Six cross-sectional studies[43–48] were identified including 96–2200 children and adolescents aged between 3 and 18 years. All studies were of European or North American origin and only one study specifically focused on ethnic minority children[51]. Janz *et al.*[43] examined the independent associations between physical activity and parentally reported TV-viewing in 4–6-year-old US children in relation to adiposity indicators derived from dual-energy X-ray absorptiometry measurements. TV-viewing was associated with body fat percentages in boys and with body fat percentages and fat mass in girls after adjustment for VPA. However, VPA was significantly and inversely associated with all adiposity variables and explained a larger proportion of the variation in these outcomes. Mendoza *et al.*[48] did not observe any associations for TV-viewing after adjustment for MVPA in Latino preschool children whereas MVPA was inversely associated with BMI *z*-score. Colley *et al.*[46] analysed data from the Canadian health Measures Survey (*n* 878) and reported that MVPA was significantly associated with BMI and waist circumference after adjustment for self-reported screen time (TV-viewing, video game plus computer use), whereas no association was observed between screen time and adiposity variables. In another relatively large-scale study in Swedish children and adolescents (*n* 1073) it was observed that those with the lowest levels of VPA had significantly higher odds of being overweight or overfat compared with those with the highest levels of VPA independent of TV-viewing and other confounders. Again, there was no independent association between TV-viewing and adiposity[45]. In contrast, a large-scale (*n* 2200) European study (Healthy Lifestyle in Europe by Nutrition) comprising adolescents aged between 12·5 and 17·5 years suggested that watching TV for >2 h/d in girls and >4 h/d in boys was associated with significantly higher odds of being categorised as overweight independent of objectively measured time in MVPA; no association for time in MVPA and the risk of being overweight or overfat was reported[47]. Similar results were reported in Canadian 8–10-year-old children (*n* 536). In that study, self-reported screen time (TV-viewing, video game and computer use) was positively associated with waist circumference independent of measured time in MVPA, whereas accelerometry sedentary time was unrelated with waist circumference. The authors concluded that the type of sedentary behaviour may be more important than the overall time spent sedentary in relation to metabolic risk factors[37]. Finally, data from the European Youth Heart Study (*n* 1485) also suggested that TV-viewing time was positively associated with total adiposity measured as the sum of four skinfolds independent of accelerometry measured total physical activity and other confounding factors[44].

Two longitudinal studies examining the prospective association between TV-viewing and adiposity variables independent of physical activity were identified. Both studies examined these associations in US children and data were collected in the late 1980s or early 1990s. Proctor *et al.*[49] followed 106 children from the Framingham Children's Study for 7 years and calculated body fat from skinfold measurements. They did not observe any significant *P* for trend in adjusted models for the association between TV-viewing and body fat when total movement was taken into account. However, there was significant differences when comparing extreme groups of TV-viewing (<1·75 h/d *v.* >3 h/d) for both BMI and sum of skinfolds with the high viewing group gaining more body fat. Jago *et al.*[50], followed 149 children aged 3–4 years at baseline for 3 years. TV-viewing time was assessed by direct observation simultaneously with minute-by-minute heart rate recording for assessing time spent in MVPA. The results suggested that TV time was positively associated and MVPA negatively associated with BMI.

In summary, whether the association between TV-viewing and adiposity variables is independent of objectively measured physical activity remains inconclusive. Studies suggesting that the association between TV-viewing time and adiposity is not entirely attenuated following adjustment for time spent in MVPA indicate that the positive association between TV-viewing and body fat or development of obesity may be mediated or confounded by other behaviours, such as unconscious snacking while watching TV. A few studies have examined a potential mediating effect of dietary intake or snacking while watching TV on the association between TV-viewing and adiposity variables. Ekelund *et al.* [44] observed an association between TV-viewing and adiposity in European young people independent of total physical activity. However, this association was attenuated when controlling for self-reported frequency of snacking suggesting that other behaviours associated with TV-viewing, and not sedentariness *per se*, may explain the association between TV-viewing and adiposity.

Physical activity, sedentary time and obesity: a reverse causality argument?

There is a general notion that higher levels of physical activity may prevent unhealthy gain in body weight

Table 2. Summary of observational studies examining the associations between self-reported television (TV)-viewing, physical activity and obesity indicators in healthy children and youth. All studies have adjusted TV-viewing time for time spent in physical activity

Reference	Study population	Study design/data analysis	Exposure assessment	Outcome	Summary of results	Confounding
Cross-sectional studies						
Janz *et al.*[43]	US boys and girls, (4–6 years, *n* 467) Iowa Bone Developmental Study	Forward stepwise multiple linear regression	Time in VPA by accelerometry Parentally reported TV-viewing (h/d)	Body fat (%), FM and trunk FM by DXA	TV-viewing associated with body fat (%) in boys and with body fat (%), FM and trunk FM in girls after adjusting for VPA VPA associated with all adiposity outcomes in both sexes and explained a greater proportion of the variance compared with TV-viewing	Age and height
Ekelund *et al.*[44]	European children and adolescents, (9–10 years and 15–16 years, *n* 1485), European Youth Heart Study	Generalised Linear Models	Total PA (cpm) by accelerometry	Sum of four skinfolds	TV-viewing positively and significantly associated with adiposity Total PA not associated with adiposity	Sex, age group, study location, birth weight, sexual maturity, smoking status and parental SES
Ortega *et al.*[45]	Swedish children and adolescents (9·5 years and 15·6 years; *n* 557 + 517)	Binary logistic regression analyses	Time in MPA, VPA and MVPA by accelerometry; TV-viewing by self-report	Overweight (BMI) according to IOTF Overfat > sex- and age-specific 85 % percentile according to body fat from skinfolds Central obesity > sex- and age-specific 85 % percentile from WC	TV-viewing not associated with overweight after adjustment for VPA Low level (first tertile) of VPA, had significantly higher odds of being overweight compared with highest tertile of VPA after adjustment for TV and other confounders	Sex, age, sexual maturation, birth weight, parental BMI and maternal education
Colley *et al.*[46]	Canadian children (10–11 years, *n* 878) Canadian Health Measures Survey	Multivariate regression analysis	SED and MVPA by accelerometry Parentally reported screen time	BMI and WC	MVPA significantly associated with BMI and WC independent of screen time and confounders Screen time not associated with the outcomes independent of MVPA	Sex and age
Rey-Lopez *et al.*[47]	Boys and girls from ten European countries (12·5–17·5 years) *n* 2200) Healthy Lifestyle in Europe by Nutrition	Binary logistic regression analyses	Time in MPA and VPA by accelerometry; Dichotomisation of meeting PA recommendations (≥60 min of MVPA) Eating while watching TV Having TV in bedroom	Overweight (BMI) according to IOTF Overfat > sex- and age-specific 85 % percentile according to body fat from skinfolds Central obesity > sex- and age-specific 85 % percentile from WC	TV in the bedroom (OR: 1·33, 95 % CI, 1·01–1·74) and >4 h/d TV during weekdays (OR: 1·30, 95 % CI, 1·02–1·67) (in boys) and eating everyday with TV (OR: 1·18, 95 % CI, 1·07–1·30) and >2 h/d TV during weekend days (OR: 1·68, 95 % CI, 1·25–2·26) (in girls) were significantly associated with total obesity Associations between MPA and VPA with obesity not reported	Schools, VPA, MVPA, maternal education and age

Table 2. (*Cont.*)

Reference	Study population	Study design/data analysis	Exposure assessment	Outcome	Summary of results	Confounding
Mendoza *et al.*[48]	US Latino pre-schoolers (3–5 years, *n* 96)	Linear regression	Time in MVPA by accelerometry Parentally reported TV-viewing (TV diaries)	BMI *z*-score	No association between TV-viewing and BMI *z*-score MVPA significantly inversely associated with BMI *z*-score	Age, sex, parental education and BMI, neighbourhood safety and parent and child acculturation
Prospective studies						
Proctor *et al.*[43]	US boys and girls (4 years at baseline; *n* 106) Framingham Children's Study	Longitudinal study, annual measurements for 7 years of follow-up Mixed regression models	Total movement (counts per hour) by accelerometry TV-viewing during school-days and weekend days	BMI, triceps and sum of five skinfolds	No significant p for trend in adjusted models for an association between TV-viewing and body fat Significant differences between extreme groups (<1·75 h/d *v.* >3 h/d) for all outcomes with the high TV-viewing group gaining more body fat (30 mm in sum of skinfolds at age 11 years)	Sex, age, baseline anthropometry, parental education, parental BMI, energy intake
Jago *et al.*[50]	US boys and girls, (3–4 years at baseline; *n* 149) Studies of Child Activity and Nutrition – Texas	Longitudinal study, annual measurements for 3 years of follow-up (1986–1989) Repeated measures regression analysis with stepwise backward elimination	PA by minute-by-minute HR recording (time in MVPA >140 bpm) TV-viewing assessed by direct observation	BMI	TV-viewing positively associated with BMI over time and PA negatively associated with BMI	Sex, diet, ethnicity, BMI at baseline

DXA, dual-energy X-ray absorptiometry; FM, fat mass; HR, Heart rate; MPA, moderate-intensity physical activity; MVPA, moderate and vigorous intensity physical activity; PA, physical activity; SES, socio-economic status; SED, sedentary; VPA, vigorous intensity physical activity; WC, waist circumference; IOTF, International Obesity Task Force.

and adiposity, as supported by the energy balance theory. However, recently this assumption has been challenged and some have suggested that physical activity at baseline is unrelated to weight gain at follow-up, but that the converse was true, since greater adiposity levels at baseline was significantly related to lower levels of physical activity or an increased risk of becoming sedentary at follow-up, suggesting reverse causality[35,51,52].

Kwon *et al.*[51] examined the associations between objectively measured time in MVPA by accelerometry, with gain in fat mass in 326 US children, in which objectively measured physical activity and fat mass was available at three time points. Time spent in MVPA did not predict fat mass at follow-up. In contrast, baseline fat mass significantly predicted decreased time in MVPA at follow-up, suggesting that adiposity level may be a determinant of lower levels of physical activity. A similar study in UK children examined the prospective associations between physical activity assessed by accelerometry and body fat percentages assessed by dual-energy X-ray absorptiometry[52]. In total, 202 children aged 7 years at baseline were followed annually for 3 years until age 10 years. The authors modelled the associations between baseline physical activity and change in body fat by multiple linear regression adjusting for the earlier measure of the outcome (i.e. baseline body fat when physical activity was modelled as the exposure and vice versa). Over a 3-year period between 7 and 10 years baseline body fat was predictive of a decline in physical activity, whereas baseline activity did not predict subsequent changes in body fat. The authors concluded that physical inactivity may be the result of fatness rather than its cause. While these two studies may be somewhat limited by sample size, data from the International Children's Accelerometer Database[35] examining the prospective association between accelerometer measured sedentary time and waist circumference in 6413 youths partly confirmed these previous findings. In this study, neither time spent sedentary nor in MVPA predicted waist circumference at follow-up after adjustment for baseline waist circumference and additional confounders. In contrast, baseline abdominal adiposity significantly predicted higher levels of sedentary time 2 years later. However, the magnitude of association was small and may not be clinically relevant.

These results should be interpreted taking measurement precision of exposure and outcome variables into account. It is difficult to determine the direction of association in any observational study when the exposure and the outcome are measured with different degrees of precision. There is a marked difference in measurement precision between the measure of adiposity and that of physical activity or sedentary behaviour. When the more imprecise variable (physical activity) is used as the outcome, the magnitude of effect is estimated accurately, but with error. When the more imprecise variable is used as the exposure, the measure of effect is attenuated. Even when physical activity and sedentary time are measured objectively, the precision is lower compared with most measures of adiposity. This is because physical activity and sedentary time are usually only measured for a limited number of days and therefore only represent a snap-shot of the true activity levels of an individual. Thus, it is not surprising that baseline body weight or adiposity predicts follow-up physical activity or sedentary time, whereas because of measurement error, the reverse may not be detectable.

Selecting an appropriate marker of adiposity as the outcome variable is equally important when examining cross-sectional and temporal associations between physical activity, sedentary time and adiposity in young people. For example, the use of BMI as a surrogate for adiposity as the outcome variable is problematic in the paediatric population because the relative contribution of fat-free mass and fat mass to body weight vary by age, sex and pubertal status and increases in BMI during growth are largely due to increases in fat-free mass rather than fat mass[53,54]. Therefore, the use of fat mass index and fat-free mass index appears more appropriate as the outcome variable when identifying excess adiposity in young people[55]. Finally, sedentary time, physical activity and body composition are all influenced by maturation and it appears appropriate to adjust analyses for maturation when examining associations between these variables.

Taken together, data from the reviewed studies suggest that the nature of the complex relationships between physical activity, sedentary time and gain in excessive adiposity may be either reverse or bidirectional. It may be that the direction of association between physical activity and sedentary time with change in adiposity differs by age, by the baseline prevalence of obesity in the population, and by whether the population examined is in energy balance or in a positive energy balance during the follow-up period. Furthermore, the association is complicated by the impact of energy intake on energy balance, an exposure even more difficult to measure accurately than physical activity in observational cohort studies.

Summary and future directions

The importance of sufficient amounts of physical activity for health and wellbeing in young people is undisputable. In this review, we have summarised parts of the current knowledge on the complex associations between physical activity, sedentary time and behaviour with adiposity in young people. While the data appear consistent in that sedentary time is unrelated to adiposity when time spent in physical activity, especially higher intensities of activity, is controlled for additional research is needed examining the mediating effect of other health behaviours associated with TV-viewing. Furthermore, it is unclear whether physical activity may mediate or modify the associations between early life factors such as birth weight and early rapid weight gain and adiposity. Future longitudinal studies including multiple, repeated, precise measures of the exposure and outcome variables starting from early age (before the amount of fat accumulated may hinder physical activity) are needed to address the issue of bidirectional or reverse causality. Furthermore, well-conducted cohort studies examining

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these associations while simultaneously controlling for the confounding effect of dietary intake and change in sexual maturity during adolescence are warranted.

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